The EAAP series is published under the direction of Siem Korver and Jean Boyazoglu

ORGANIZING COMMITTEE

Ir. A.A. Jongebreur (chairman), DLO Institute of Agricultural Engeneering, Wageningen
Ing. W. Rossing (secretary), DLO Institute of Agricultural Engineering, Wageningen
Ir. A.H. Ipema (finance), DLO Institute of Agricultural Engineering, Wageningen
P.N. Blauw, Gascoigne-Melotte Holding B.V., Emmeloord
P. Blokland, Board for Agriculture, Section Dairing Farming, The Hague
Dr. ir. E.E. Bolhuis, Royal Netherlands Dairy Federation, Rijswijk
Dr. ir. J. Dommerholt, Royal Dutch Cattle Syndicate, Arnhem
Ir. A. Hagting, BCZ Friesland, Leeuwarden
Dr. ir. H. Korevaar, The Agricultural Research Department (DLO) of the Ministry of Agriculture, Nature Management and Fisheries, Wageningen
Dr. ir. A. Kuipers, Research Station for Cattle, Sheep and Horse Husbandry, Lelystad
Drs. H. Schelhaas, Commodity Dairy Produce Board, Rijswijk
J. v.d. Walle, Manus-Holland B.V., Zutphen
Dr. ir. J.G. de Wilt, Department for Animal Husbandry and Dairying (VZ) of the Ministry of Agriculture, Nature Management and Fisheries, The Hague
Mrs. Dr. ir. A.J. v.d. Zijpp, DLO Research Institute for Animal Production 'Schoonoord', Zeist

Sponsors
The Symposium is sponsored by:
ALFA-LAVAL AGRI INTERNATIONAL, Tumba, Sweden
BCZ Friesland, Leeuwarden, The Netherlands
GASCOIGNE-MELOTTE B.V., Emmeloord, the Netherlands
ING Lease, Amsterdam, the Netherlands
MANUS-HOLLAND B.V., Zutphen, the Netherlands
Ministry of Agriculture, Nature Management and Fisheries, the Hague, the Netherlands
NEDAP-POIESZ B.V., Hengelo (Gld), the Netherlands
Royal Dutch Cattle Syndicate (NRS), Arnhem, The Netherlands
TEXAS INSTRUMENTS REGISTRATION AND IDENTIFICATION SYSTEM (TIRIS), Almelo, the Netherlands

Prospects for automatic milking

Proceedings of the International Symposium
on Prospects for Automatic Milking
Wageningen, Netherlands, 23 - 25 November 1992
(EAAP Publication No. 65, 1992)

A.H. Ipema, A.C. Lippus, J.H.M. Metz & W. Rossing (Editors)

Pudoc Scientific Publishers
Wageningen 1992

CIP-data Koninklijke Bibliotheek, Den Haag

ISBN 90-220-1076-7
NUGI 835

ISSN 0071-2477

Printed in the Netherlands.

Contents

Preface 1

Introduction 3

1. Techniques of the milking process

The automation of milking as a key issue in future oriented dairy farming 7
H. Schön, R. Artmann & H. Worstorff
Status, results and further development of anautomatic milking system 23
R. Artmann
Mains Project - Automatic Milking 33
Ph. Marchal, G. Rault, Ch. Collewet & L. Wallian
Design features of the Silsoe automatic milking system 40
M.J. Street, R.C. Hall, D.S. Spencer, A.L. Wilkin, T.T. Mottram & C.J. Allen
Evolution of Düvelsdorf milking robot 49
M. Dück
Robotic milking system (RMS): design and performance 55
R. van der Linde & J. Lubberink
Automatic milking: reality 63
J. Bottema
Field trials of the Silsoe automatic milking system 72
C.J. Allen, T.T. Mottram, A.R. Frost, M.J. Street, R.C. Hall & D.S. Spencer
Observations of automatic teat cup attachment in an automatic milking system 80
P.H. Hogewerf, P.J.M. Huijsmans, A.H. Ipema, T. Janssen & W. Rossing

2. Milk quality

Physiological response of dairy cows to milking 93
M.J. Paape, A.V. Capuco, A. Lefcourt, C. Burvenich & R.H. Miller
A non-invasive method for measuring the compressive load on teats and the congestion of the teat ends during milking 106
O. Rønningen
The influence of switch level in automatic cluster removers on milking performance and udder health 113
M.D. Rasmussen
Measuring quarter milk electrical conductivity, milk yield and milk temperature for detection of mastitis 119
K. Maatje, P.H. Hogewerf, W. Rossing & R.T. van Zonneveld
Composite milk electrical resistance as a means for monitoring mastitis 126
E. Shoshani & A. Berman

Measuring milk conductivity and temperature during milking 134
J. Vegricht, P. Ambroz & A. Machalek
Investigations on the suitability of different milk parameters for the early detection of mastitis, and implications for automated monitoring 141
D. Schlünsen & R. Bauer
Experiments to influence the content of somatic cells in bulk milk by separating the milk from quarters with high electrical conductivity in fore-milk 149
M. Graupner, G. Wehowsky, F. Tröger & K. Barth
Automatic milking: milk quality 157
D. Westhoff & C.J. Liu
Teat cleaning and stimulation 164
E. Schuiling
Effects of milking intervals on the demand for cleaning the milking system in robotized stations 169
D. Ordolff & D. Bölling
Cleaning frequency of automatic milking equipment 175
J.G.P. Verheij
Composition of milk in relation to its processing in dairy industry 179
P. Zoon
Near-infrared spectroscopy for evaluating milk quality 185
R.N. Tsenkova, K.I. Yordanov & Y. Shinde
Fresh raw milk composition analysis by NIR spectroscopy 193
Z. Schmilovitch, E. Maltz & M. Austerweil

3. Milking frequency

The effects of frequent milking on udder physiology and health 201
J.E. Hillerton & A. Winter
Role of milking in the maintenance of lactation in dairy animals 213
Y. Shinde
Milk production, and some related nutritional and reproductive variables, of dairy cows under two different milking regimes in early lactation 219
U. Bar-Peled, A.R. Lehrer, Y. Folman, I. Bruckental, J. Kali, H. Gacitua, E. Maltz, H. Tagari & B. Robinzon
Milking primiparous cows three times every two days in early lactation: milk secretion and nutritional status 227
B. Rémond, M. Petit & A. Ollier
The effect of feeding during milking on milk production and milk flow 233
K. Svennersten & B. Samuelsson
Effects of frequent milking on heart rate and other physiological variables in dairy cows 237
C. Royle, P.C. Garnsworthy, A.J. McArthur & T.B. Mepham
Production, duration of machine-milking and teat quality of dairy cows milked 2, 3 or 4 times daily with variable intervals 244
A.H. Ipema & E. Benders

Experiences with continuous robot milking with regard to milk yield, milk composition and behaviour of cows 253
J.H. Kremer & D. Ordolff
The effect of increased milking frequency and automated milking systems on the behaviour of the dairy cow 261
A. Winter, R.M. Teverson & J.E. Hillerton
The use of a selection unit for automatic milking: consequences for cow behaviour and welfare 270
C.C. Ketelaar-de Lauwere
Behaviour of cows before, during and after milking with an automatic milking system 278
J. Metz-Stefanowska, P.J.M. Huijsmans, P.H. Hogewerf, A.H. Ipema & A. Keen
Feeding strategies and automatic milking 289
H. Pirkelmann

4. Herd management

Scope of management and management decisions 299
A.A. Dijkhuizen, R.B.M. Huirne & J.B. Hardaker
The design of the management system for the Silsoe automatic milking system 309
D.S. Spencer & M.J. Street
Control and management in the automatic milking system dairy farm 315
S. Devir
Expert system for cow transfer between feeding groups: potential applications for automatic self feeding and milking 322
E. Maltz, P. Grinspan, Y. Edan, A. Antler, O. Kroll & S. L. Spahr
Dairy herd lactation expert system, a program to analyze and evaluate lactation curves 331
R.H. Fourdraine, M.A. Tomaszewski & T.J. Cannon
A method for continuous automatic monitoring of accuracy of milk recording equipment 338
G. Wendl, X. Zenger & H. Auernhammer
The performance of an automated dairy management data-gathering system 346
S. Carmi
Influence of threshold values and duration of increased activity on the prediction of oestrus by pedometers 353
R.J. Pulvermacher & K. Maatje
Signal processing of activity data for oestrus detection in dairy cattle 360
W.J. Eradus, W. Rossing, P.H. Hogewerf & E. Benders
Detecting mastitis with a neural network using electrical conductivity data 370
M. Nielen, M.H. Spigt & K. Maatje
An integrated approach to support treatment and replacement decisions in dairy cows with special attention to mastitis 377
E.H.P. Houben, R.B.M. Huirne & A.A. Dijkhuizen

Development of a knowledge-based system describing the relations between mastitis and milking machines 385
H. Hogeveen, J. van Vliet, E.N. Noordhuizen-Stassen & A. Brand

5. General assessments

Automatic milking and animal breeding 395
H.O. Gravert

Ethology and technology: the role of ethology in automation of animal production processes 401
J.F. Hurnik

The perception by stockpersons of the effect on their esteem, self-concept and satisfaction of the incorporation of automatic milking into their herds 409
M.F. Seabrook

Human aspects in automatic milking 414
P. Lundqvist

Short and long term economic aspects of automatic milking systems 421
S.B. Harsh, R.B.M. Huirne, A.A. Dijkhuizen & R.W. Gardner

Analysis of capital investment in robotic milking systems for U.S. dairy farms 432
D.V. Armstrong, L.S. Daugherty, D.M. Galton & W.A. Knoblauch

Automatic milking in Italy: implementation on the dairy farm and economic aspects 440
F. Sangiorgi & G. Provolo

Conditions for implementation of automatic milking on dairy farms 449
A. Kuipers & A.T.J. Van Scheppingen

6. Poster presentations

Voluntary entrance into the milking parlour 459
J.L. Albright, A.R. Cennamo & E.W. Wisniewski

Simulation as a tool for designing automatic milking systems 466
E. van Elderen

Assessment of the use of a decision support system to manage insemination through routine milk progesterone analysis 472
R.J. Esslemont & M.E. Williams

A computer program to analyze herd management using DHI testday information 478
R.H. Fourdraine, M.A. Tomaszewski & T.J. Cannon

Computer aided system for health and reproduction control in dairy cows 483
P.H. Hogewerf, K. Maatje & W. Rossing

Free fatty acids; influence of milking frequency 491
A.H. Ipema & E. Schuiling

Monitoring cow performance using lactation curves 497
L. Jones

A study of the energy consumption and power requirements of electrical equipment used on Turkish dairy farms 502
A. Kasap
Quality control of 'ex-farm' milk in The Netherlands 507
C. de Koning
Search for a criterion for oestrus detection based on telemetric measurement of body temperature 511
J. Metz-Stefanowska, A. Keen & W. Rossing
Automatic feeding station for forage 522
S. Mihina, K. Kovalcik, M. Kovalciková & S. Talich
A model for monitoring health and reproduction based on a combined processing of variables 527
R.M. de Mol, R.T. van Zonneveld,, B. Engel, A. Keen, W.J. Eradus, G.H. Kroeze, A.H. Ipema, K. Maatje & W. Rossing
Automated cow and machine performance monitoring in the Ruakura milk harvester 531
R.A. Sherlock & M.W. Woolford
Labour organization aspects of milking with an automatic milking system: structure of the problem 538
B. Sonck
Practical experiences with automated electronic animal identification using injected identification transponders 546
S.L. Spahr & R.S. Surber
Effects of local pre-stimulation versus post-stimulation on milk production and milk composition 552
K. Svennersten
Practical application of Milkodat palettes for early detection of mastitis and mastitis monitoring during lactation period 556
P. Tongel & S. Mihina
Modification of suction-pressure pulsation ratio 561
L. Tóth & J. Bak
The Hungarian milking robot 569
L. Tóth, J. Bak & T. Liptay
An alternate paradigm for fostering collaborative research and technology transfer 572
M.A. Varner & R.A. Cady

Preface

Specialists from more than a dozen countries attended the International Symposium on Prospects for Automatic Milking, held in Wageningen, The Netherlands in November 1992. This symposium followed three earlier meetings on the subject of Automation in Dairying, held in 1978, 1982 and 1987.

The symposium was the first to deal with automatic milking in broad multidisciplinary terms. Apart from the many engineering questions raised by automatic milking, substantial attention was paid to milk quality, milk production and the health of cows, behaviourial reactions and welfare of cows, computerized management programmes, the role of the stockman, integrating automatic milking systems into farms and the economic constraints of such developments.

Indeed, automatic milking is likely to cause substantial changes in dairy farming just as milking machines did when they were first introduced. The dairy farm will become less dependent on the input of physical labour and will need a higher input of advance technological knowledge. Higher investments will also be required. But there are advantages too: for example, flexibility in milking frequency combined with higher yield, and - at least under condition of good management - better prospects for the welfare of individual cows. It is a great challenge to continue and bring to completion the technological development associated with automatic milking systems, and to do this in close cooperation with various disciplines, whilst taking into account the farmer's needs, the animal's requirements and the need for economic benefits.

These proceedings include papers on all oral and poster presentations made at the symposium. A number of posters focus directly on the themes of the sessions, whilst other deal more broadly with the topic. Together, the oral and poster presentations give a good overview of the present state of knowledge.

Various persons contributed to the preparation of these proceedings. Members of the organizing committee as well as other anonymous referees helped to review the papers included here. The contributions of W. Rossing and A.H. Ipema in the development of the scientific programme, and A.C. Lippus, who took care for the final editing of the manuscripts, require particular acknowledgement.

J.H.M. Metz
Chairman of the Scientific Programme Committee

Introduction

During the third symposium on "Automation in Dairying" held in Wageningen in September 1987 the state of the art of automation on dairy farms was reviewed. It became clear that many new techniques and technologies were topics of research. Robot milking was one such topic. Research and development in commercial companies and research institutions have continued and progress has been achieved. Today we know that robot milking influences many aspects of dairy farming. Therefore, I want to stress that automatic milking is more than the robot that attaches the clusters.

Going back into the history of machine milking Dodd & Hall (1992) note that the modern milking machine was invented a century ago! It was pioneered in Scotland, refined in Australia and perfected in many countries, particularly in New Zealand, U.S.A., U.K. and Sweden. The story is remarkable. No other machine in livestock farming has such a close biological association! During the first half of this century, machine milking was largely ignored as a research topic and progress depended largely on the ideas of inventors and manufacturers.

In many institutions and company laboratories research is being done on a large variety of technical and biological themes related to the milking process. This contrast favourably to the first half of this century. The delegates to this symposium, who come from different disciplines, are proof of this. The automatic milking system is the last step towards the complete automation of the milking process. Yet we must remember that this system can greatly change the activities on the dairy farm.

The physiological and behaviourial aspects of automatic milking systems require the attention of the relevant scientists. These aspects are crucial if we are to improve the health, welfare and productive lives of the most important production factors in the dairy operation: the cows.

However, there has also been criticism. For example, De Hoogh (1991): "What on earth is agricultural research doing with respect to the milking robot? Is this an efficient location of those scarce production factors, science and technology?" These questions must be evaluated against the background of the scale of production and production surpluses. I have already said we must applaud the fact that scientific research is paying some attention to the automatic milking system. In my opinion this could lead to improvements in the social and working conditions on dairy farms. And, unlike biotechnological research in plant science and dairy science, automatic milking systems form a logical step forward.

The topic dealt with in the present symposium is "Prospects for Automatic Milking". The state of the art revealed in these proceedings supports the idea that modern dairy production and sustainability can be combined.

A.A. Jongebreur,
Chairman of the Organizing Committee

References

Dodd, F.H. & H.S. Hall, 1992. History and Development. In: A.J. Bramley, F.H. Dodd, G.A. Muin & J.A. Bramley (Eds.): Machine Milking and Lactation, Insight Books, Berkshire, England/Vermont, USA, p. 33.

Hoogh, J. de, 1991. Agricultural technology: for better or for worse? In: Agricultural Economics and Policy: International Challenges for the Nineties, LEI-DLO, Den Haag, The Netherlands, p. 205-214.

1. Techniques of the milking process

The automation of milking as a key issue in future oriented dairy farming

H. Schön*, R. Artmann** & H. Worstorff***

* *Technical University of Munich, Institute of Agricultural Engineering, Vöttinger Straße 36, D-8050 Freising-Weihenstephan, Germany*

** *FAL, Institute of Production Engineering, Braunschweig-Völkenrode, Germany*

*** *Technical University of Munich, Institute of Physiology, Freising-Weihenstephan, Germany*

Summary

Technical innovation in agricultural engineering and animal husbandry, based on electronics has led to further improvements in dairy farming. Computer-based production includes computerized animal feeding, monitoring of yield, health and milking. Further improvements have to be achieved in the milking process. Machine milking should match mechanics with very sensitive physiological reactions in order to achieve complete, gentle and fast milk removal. However, even partially automated systems have so far lacked essential factors related to stimulation, main milking phase, over-milking and udder evacuation. The last step towards complete computerized dairying is the automation of milking. Automated cluster attachment has not yet been perfected, but technical solutions have been proposed. When these problems are overcome new forms of dairy farming can be established. Computer-based dairying will allow simple, more natural forms of dairy husbandry, improve labour productivity and reduce the workload on family farms. It may also accelerate the adjustment of farm sizes all over Europe but will not necessarily lead to larger-scale industrialized dairy production.
Keywords: computer-based dairying, milking robot, stimulation, main milking phase, udder evacuation, economics of automation.

Introduction

Technical innovation is a decisive factor in the continuing progress of agricultural productivity (Figure 1). To date three major phases can be recognized in this process (Schön, 1991):

1. The objective of the first phase was to provide a sufficient food supply to the population. The prime task of agricultural engineering was to maximize plant and animal yields. The tie stall system was preferred in dairy farming, which allowed intensive, individual feeding and control.
2. Mechanization of agricultural production to offset the migration of labour to other, better paying industries, was the primary goal of the second phase. Initially this included the attempt to further mechanize the tie stall system, but soon it became clear that sufficient labour productivity could only be achieved in free stall barns with milking parlours.
3. We are now in the third phase, of employing artificial intelligence in agricultural production. This provides the opportunity to further reduce production cost, but also to better satisfy ecological and environmental requirements.

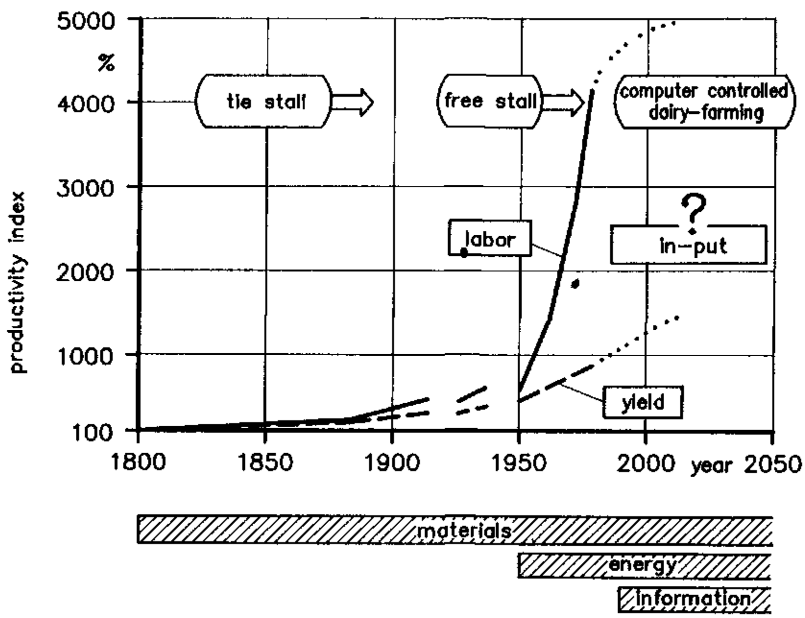


Figure 1. Yield and labour productivity in German agriculture since 1800 (source: Statistical Yearbooks).

These three phases clearly show that two new conceptual approaches have now entered the future development of dairy operations (Schön & Boxberger, 1991):

1. The transition from the tie stall to the free stall system achieved significant gains in labour productivity but also introduced additional obstacles to the individual feeding and control of the animals. Computer-based systems of animal identification, feed rationing and herd supervision allow a more natural, species oriented form of animal husbandry with a superior utilization of the genetic production potential.
2. In the past the dairy farmer was compelled to a continuous labour schedule without any interruption, which eventually could cause severe vocational stress. This constraint also led to a production rhythm, determined by considerations of human labour, rather than by the physiological requirements of the animals. A "process control" by the animal, coupled with an "observation function" of the dairy farmer becomes increasingly possible in fully automated, computer controlled dairy farming.

Computer-based systems in dairy farming

The main sectors for computer-based control in dairy farming have been classified as (Figure 2):

- animal feeding;
- monitoring of animal performance and health;
- milking.

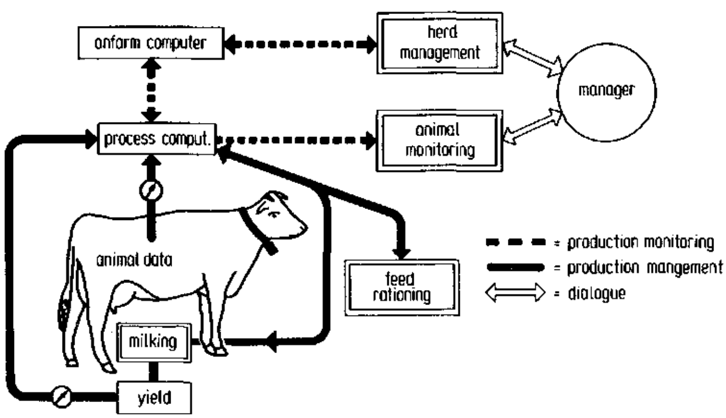


Figure 2. Computer based system for production management and monitoring in dairy farming.

Animal identification

A prerequisite for automated animal identification is the development of cheap identification hardware and software, which can be integrated into the computer control system for free stall barns. The first symposium on "Automation in Dairy Farming" held in 1976 in Wageningen established a number of essential results (Anonymous, 1976) in this area. Miniaturized responders are currently being tested. They are implanted in the animal's ear region (Figure 3) and transmit a code, which is received by an antenna for identification in the control computer. They last the entire lifespan, from calf to carcass (Pirkelmann et al., 1992).

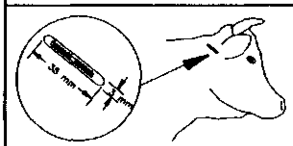
	Identification DM/unit	Receiver DM/unit
	90 – 120	1000 – 1500
	60 – 80	1000 – 1500
	10 – 20 (5)	stationary 1000 – 1500 monitor 2000 – 3000

Figure 3. Identification systems.

Computer controlled feed rationing for dairy cows

Two computer-based methods of automated feed rationing are currently in use:

- individual concentrate rationing and milk yield measurement by control computer, complied with free roughage consumption (Artmann, 1988; Pirkelmann & Wendl, 1989);
- individual concentrate and roughage rationing based on milk yield measurements (Anonymous, 1983).

Computer-based monitoring of animal performance

The monitoring of animal performance is a significant component of computer-based dairy farming. It uses specific sensors to collect and store physiological data indicating health and productivity status. The second symposium on "Automation in Dairying" provided important contributions to this (Anonymous, 1983).

The automatic recording of body temperature from continuous measurements of milk temperature or the recording of milk quality from measurements of its electrical conductivity are important criteria for evaluating the general health of dairy cows (Schlünsen et al., 1987).

Metabolic disorders are indicated by an immediate reduction of roughage intake followed by a significant and measurable loss of body weight. The electrical conductivity of the milk changes after a certain time-log in this case.

The milk temperature and the activity record are positive factors for oestrus detection, coupled with milk conductivity as a rejection factor. An oestrus evaluation system based on these measurements was developed by Maatje et al. (1983) and is now used in dairy farming.

Current state of art of milking technology

The mechanization of the milking process is a key issue in dairy production. In addition to labour conditions and milk quality, it significantly affects animal yield and health. Thus, development work has to match mechanics with complex, very sensitive physiological reactions. Intelligent, computer-based control might help to reduce shortcomings. On the other hand, over 50 years of more or less intensive development have not yet led to really adequate man-operated procedures.

Partial automation of milking

In the 1960s, the need to minimize labour input and workload made high throughput rates a priority. In the meantime, however, we face increasing demands based on ethology, environmental compatibility, product quality and economics which often counteract traditional means of rationalization by omitting work elements.

Udder Stimulation. The access of the milking machine is limited to the small quantity of cisternal milk, and continuous supply from the alveolar region can only be gained by cooperation of the cow. Physiologists agree that hormonal reactions of milk ejection and the rate of udder pressure increase require about 1 min pre-stimulation at two milkings per day (Bruckmaier et al., 1992). Thus, both for an optimal milk release with a bimodality rate of no more than 5% for the herd and to minimize time required for routine work an adequate general mechanization of milking is required.

The time-controlled positive pressure system was the first to stimulate via its moving liners, but the load it exerts on the teat is no longer compatible with today's conception of animal treatment. A flow-controlled technique appeared some years later but has to be considered as a stimulation aid because it does not allow proper pre-stimulation time (Figure 4; Göft & Dethlefsen, 1992). At present, the vibration system is the only cluster technology to match skilled manual udder preparation on a herd basis (Karch, 1990). For various reasons recent "stimo"-pulsators from different companies have not yet reached the necessary performance (Worstorff & Prediger, 1992).

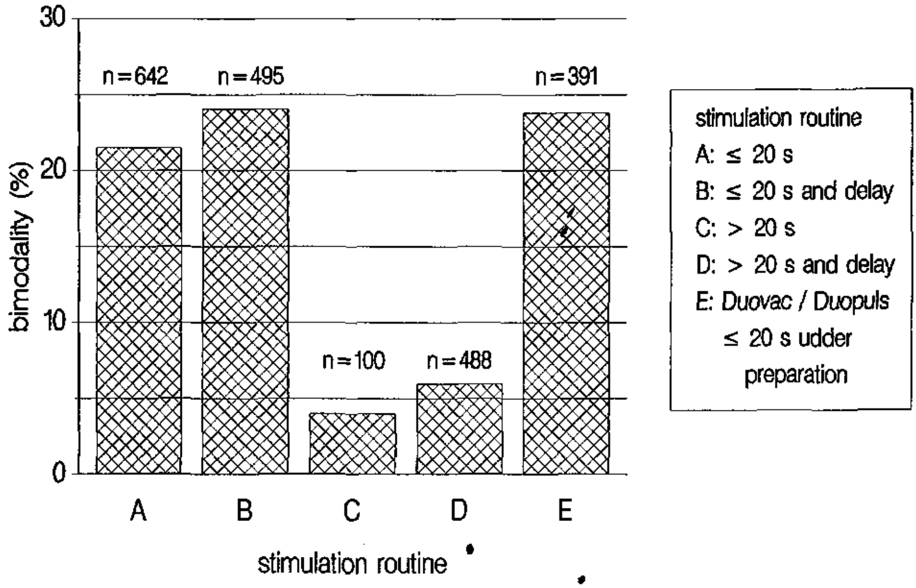


Figure 4. Bimodality and stimulation routine (n=2116).

Main milking phase. The main milking phase must start immediately after successful pre-stimulation and support the established milkability (including muscle tone relaxation) by a gentle machine action. More work is needed on type and stability of vacuum application and liners in order to counteract teat tissue reactions like swelling and hyperkeratosis as well as existing cell count problems.

Overmilking. On average, overmilking for 2 min with a variation of 0-10 min between cows seems to be quite common (Worstorff et al., 1992). Even flow-controlled machines tend to exceed the 200 g/min threshold by 1 min and more for the whole udder, which implies a higher deviation for individual quarters (indicator-induced overmilking). In order to limit milking time and related tissue load, flow-controlled pulsators should switch to steady release at 400 g/min if followed by machine stripping. Indicators should generally not create vacuum losses.

Udder evacuation and automatic cluster removal. At two milkings/day, about 400 g of available milk (0-2 kg) will stay in the udder if not gained by machine stripping, and this will affect lactation yield and probably udder health (Ebendorff et al., 1989). Automatic stripping devices have been developed and can likewise improve cluster position. Thus, teat cup removal should primarily be installed in addition to automatic stripping.

Flow controlled main milking phase

In milking machine research complete, gentle and fast milk removal must also be the target of flow controlled approaches. Present designs, however, shorten the release phase at higher flow rates and act contrary to information from milk flow profiles within pulsation cycles (Schmidt, 1986). Generally, milking parameter control has to be improved if the main milk flow is to be followed closely by vacuum application. Nevertheless, even recent efforts to improve milkability by flow control seem to offer limited return relative to basic solutions such as vibration stimulation and automatic stripping.

Relation to breeding objectives

Research and development of milking technology should always be related to genetic progress. At present, flow rates and flow distribution -as defined by milk flow profiles- need discussion: If a rate of 3 - 4.5 kg/min (Grindal & Hillerton, 1991) could be sustained for a few minutes, high yields could be milked fast and with reduced teat stress by relatively simple handy machines. Extreme peak rates, on the other hand, tend to increase mastitis prevalence, have only limited influence on milking time and demand cluster designs beyond reasonable requirements.

Automation of milking

The last step towards the full computer-based control of dairy farming, namely the automatic cluster attachment to the udder has not been completed yet, but technical solutions for all other equipment or process elements have been proposed (Figure 5). Recent developments in sensor and computer technology including robotics have removed at least the technical barriers for the completion of this final step (Rossing & Ipema, 1988).

The process element "cluster attachment" can be divided into two parts:

1. localizing the teats
2. cluster handling and positioning.

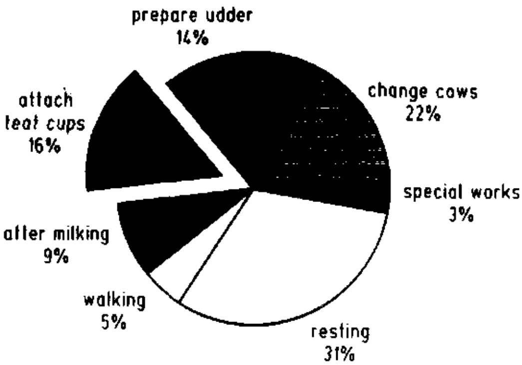


Figure 5. Time requirement for milking (4×4 auto tandem parlour).

Localizing the teats

A two-stage sensing process has been found feasible for localizing the teat positions (Artmann, 1990):

- the approximate position of the udder is determined in the first step (udder position);
- the precise position of each teat is determined in the second step (teat position).

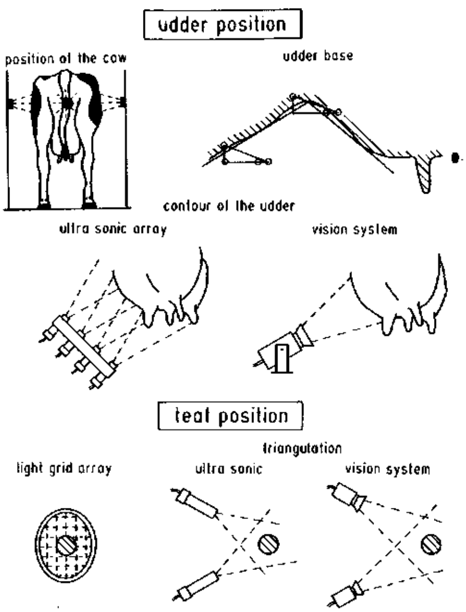


Figure 6. Sensoric for measuring the teat location.

The udder position can be derived from the position of the cow in the milking stand (Figure 6). Simple and cheap systems employing mechanical or electronic location sensors can be used with advantage. More precise results are obtained if the udder contours are measured directly with contact sensors or mapped from ultrasound and video co-ordinates determined by a microprocessor.

The following methods have been used to localize teats:

- optical sensors and emitters, which can signal the entry of a teat into their beams of alignment;
- ultrasound sensors, which allow the computer evaluation of teat positions from their reflection sectors;
- video cameras, which allow computer evaluation of the teat positions from image co-ordinates.

The last two methods employ triangulation procedures, which in the case of method 3 are still too slow to meet control timing requirements.

Cluster attachment

Cluster attachment can be achieved in different ways (Figure 7). If cluster and robotic elements are from separate units, then one robot can serve several milking stands. If both elements are combined in one unit, then each milking stand requires an independent system.

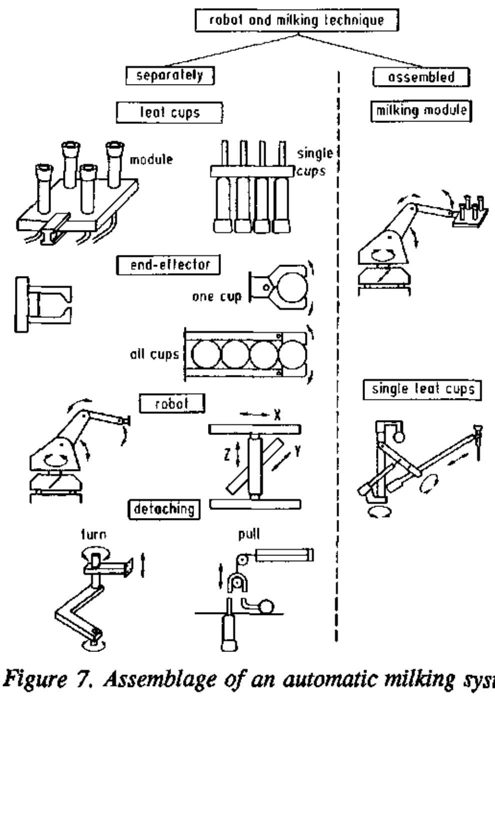


Figure 7. Assemblage of an automatic milking system.

Animal position

Most cows are milked from a side position in conventional milking stands. Adjacent stands are laid out for milking from the rear of the cow. For fully automated milking the equipment access could be provided from the floor of the stand. These different forms of milking stands are illustrated in Figure 8. Most parlour developments favour the tandem stands. For medium size herds they are combined with an automated concentrate dispenser, whose "self service" feature attracts the animals to enter the milking stand without further technical support.

Pilot scale experiments with automated milking

Some firms and a number of research stations are currently conducting pilot-scale experiments with automated milking under normal farming conditions. Interest is mainly focused on the animals' reactions to automatic cluster attachment. The experimental results show that animal movements need to be monitored with special sensors to trigger successful cluster attachment at a moment of statistically sound calmness. Further technical and ethological investigations are needed to bring the systems closer to practical application. The technical feasibility of automatic cluster attachment has been proved empirically (Schillingmann, 1992).

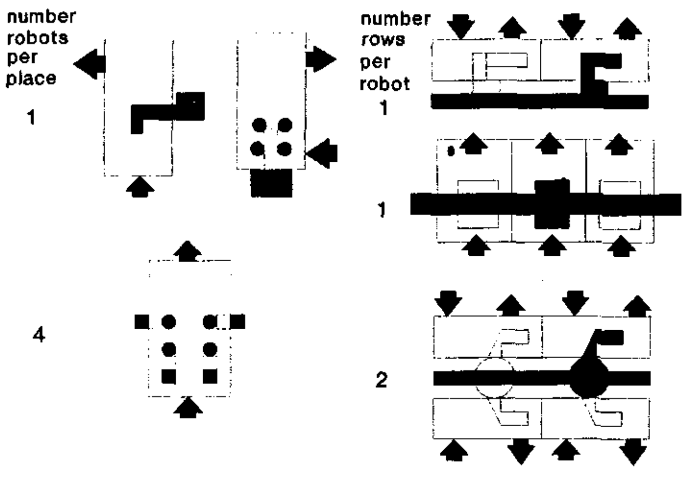


Figure 8. Arrangement of milking stands and robot.

Conclusions

Automation as an incentive for new forms of dairy farming

Computer-controlled systems with automated milking and concentrate dispensers for animal "self-service" have proven their technical feasibility (Rabold, 1986). They established a new concept with the following advantages for medium-size dairy operations:

1. Computer-based systems satisfy the desire of the dairy cows to move freely and to form a herd. At the same time they allow the close monitoring of animal performance and related individual feed rationing. This is a new concept, which was not available with the old tie-stall systems and their unnatural confinement.
2. Automated dairying improves labour conditions. Human observation and control are still needed, but the input is not tied to a rigid daily schedule irrespective of normal working periods. Labour loads, especially in family type dairy operations, can thus be significantly reduced.
3. The physiological requirements and biorhythm of the dairy cows determine the timing of feed consumption and milking, which improves animal comfort and performance. Dairy production is no longer dependent on human work patterns, which do not relate well to the animal needs.

The advantages listed above can be realized in the design of new dairying operations. The climate and space requirements of the animals can be accommodated to a significantly greater degree since human labour can be minimized. Experiments have shown that dairy cows prefer to rest on bedding even at low temperatures outdoors rather than on a bare and cold floor in a barn. Thus a very simple structure providing ample bedding and protection against wind, draughts and precipitation would suffice the animals. The building does not need to be insulated.

Future designs will feature spacious barns and yards rather than the traditional confined narrow housing. Computer-based control of the animals will form an integral part of this more natural concept of dairying.

Economic consequences

Milking robots will affect the economic conditions of dairying in two ways:

- The milk yield of a herd will rise by 10 to 20% due to the more natural milking frequency;
- Labour requirements can be significantly reduced by the automation of milking.

Figure 9 shows that labour requirements can be reduced by approximately two-thirds by the introduction of the milking robot. Additionally the remaining work will be easier and not bound to a rigid time schedule. These advantages, however, can only be gained with significant capital expenditures, as shown in Figure 9. According to

Doluschitz & Kugler, (1992) the capital requirement will rise from DEM 1600, DEM/cow to DEM 6000, DEM/cow in smaller operations and from DEM 1050, DEM/cow to DEM 2600, DEM/cow in a larger herd with 90 cows.

The difference in production cost between conventional and robotized dairying is the main criterion for their economic feasibility.

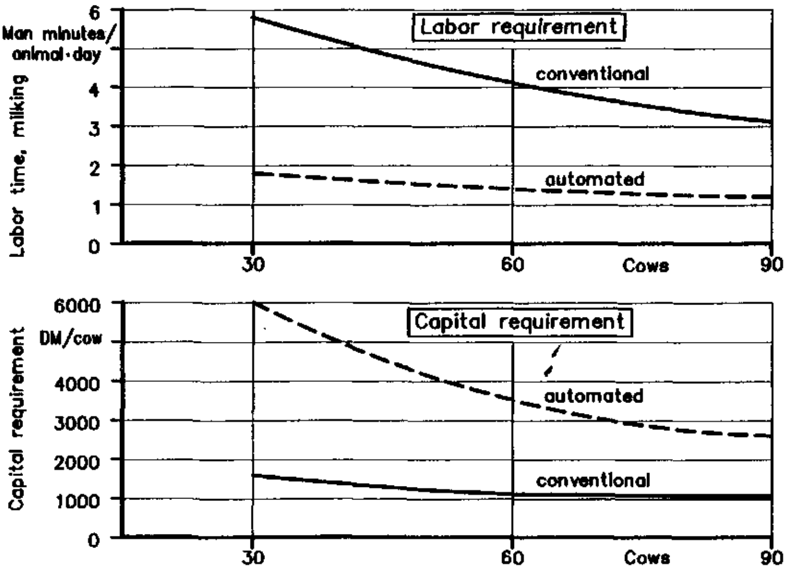


Figure 9. Labour and capital requirement for conventional and automated milking (source: Doluschitz et al., 1992).

The major cost factors are:

- herd size;
- milk yield increase and;
- labour wages.

Figure 10 shows the production cost per litre milk for conventional and automated systems. The model calculations indicate that a 30-cow dairy farm can profit from a milking robot only when wages of labourers are very high and the milk price can be raised by 0.11 DEM/l.

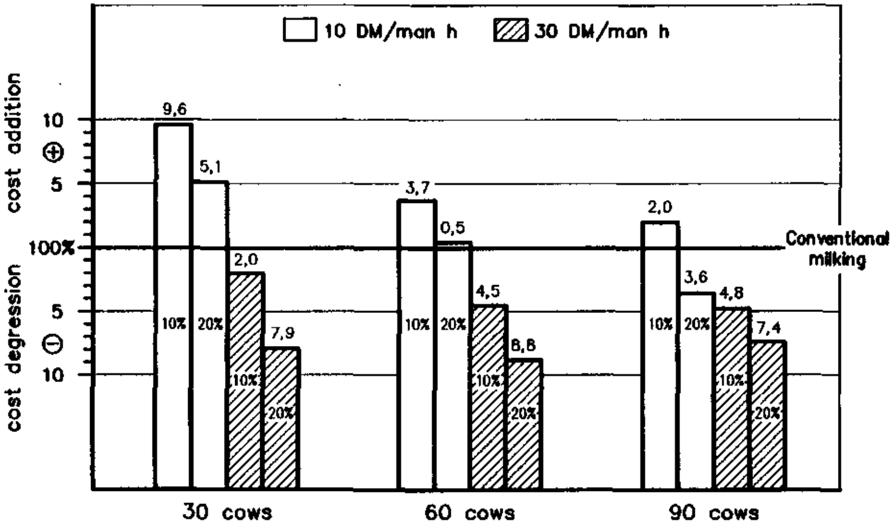


Figure 10. Total cost changes by automation of milking, expressed in litre milk (source: Doluschitz, 1992).

Significant cost advantages can be gained by a 60-cow operation. Then even when wages are low the production costs of conventional operations are not exceeded. These estimates show that herd size should be adjusted to 60 cows and above for the profitable utilization of a milking robot. Smaller operations can profit if labour costs are excessive. It appears that the technical progress of the milking robot can thus be fully exploited by family-run dairy farms.

Changes in farm structure

After the installation of a milking robot the production volume of family farms will increase due to the improved labour productivity. An estimate by Isermeyer shows that a dairy farm with a labour input of 1.5 man years for 60 cows can increase the herd size to 100 cows. This will require the acquisition of an additional milk quota (Figure 11). Under these conditions the larger herd will yield a significantly higher profit (income) even at quota prices of 0.20 DEM/l. This expansion would not be possible without the milking robot.

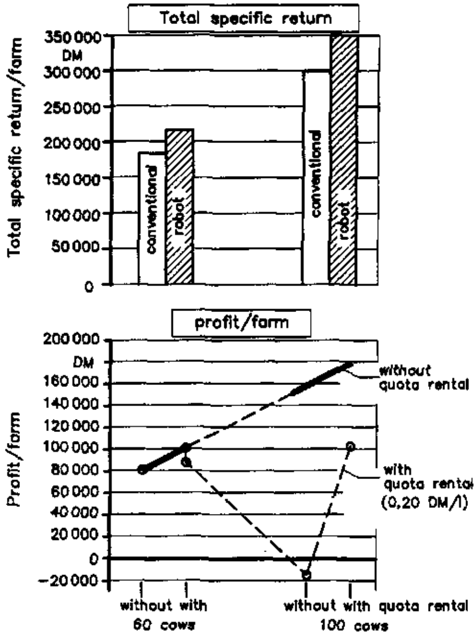


Figure 11. Economic feasibility of extending production in dairying (source: Isermeyer, 1990).

The options for operational expansion are limited in the EC (Figure 12), where the average herd size is 19 cows per farm. This means that 43% of all dairy cows are kept in herds of 30 cows or less. Only 10% of the cows are in herds of more than 100 cows. Farm sizes vary greatly among the EC states: in former West Germany 62% of the dairy cows are on small farms and only 1% on large farms, whereas in the United Kingdom approximately 50% of all cows are kept on large farms.

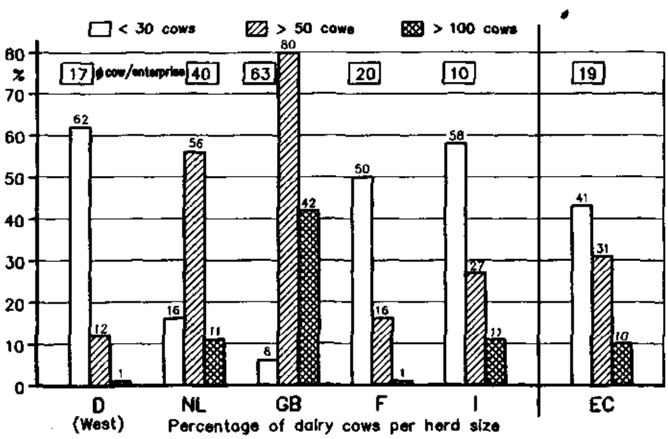


Figure 12. Dairy farm classification in the EC.

Resume

Computer-based production control and the milking robot will induce fundamental changes in dairy farming. Labour productivity and workload on family farms will be significantly improved. Computer-based controls will allow simple, more natural forms of dairy husbandry satisfying the new regulations for animal and environmental protection. Automation will accelerate adjustment of farm sizes all over Europe, but will not necessarily lead to large industrialized dairy production. Rather it can be expected that dairy farms will generally expand to a size that will sustain a secure and adequate income to the employed members of family-owned operations.

Acknowledgements

Decisive innovations are generally not the result of some anonymous technical progress, but largely depend on the creative mind of single, dedicated people. One individual deserves to be mentioned in this context, namely Dr. Rossing, who recognized the importance of electronic control in dairying in the 1960s. Since then he has persisted in the promotion of computer-based automation from individual feed rationing to robotized milking. The symposia of these topics which he has organized have been showcases of high calibre and have profoundly affected thinking about the technical evolution of dairying.

References

Anonymous, 1976. Symposium on Cow Identification Systems and their Applications. IMAG, Wageningen, The Netherlands.

Anonymous, 1983. Automation in Dairying. IMAG, Wageningen, The Netherlands.

Artmann, R., 1988. Konzepte, Einrichtungen und Ergebnisse aus rechnergestützter Gruppen- und Einzeltierfütterung. Landbauforschung Völkenrode, Germany. Sonderheft 93, p. 27-49.

Artmann, R., 1990. Konzepte und Entwicklungen zur Automatisierung des Melkens. In: Robotereinsatz in der Landwirtschaft am Beispiel des Melkens; Tagung Braunschweig-Völkenrode. VDI/MEG Kolloqim Landtechnik, Düsseldorf, Germany 9:45-69.

Bruckmaier, R., D. Schams & H. Mayer, 1992. Stimulation, Ocitocinfreisetzung, Intramammärdruck und Milchabgabe beim Rind in Abhängigkeit vom Laktationsstadium. In: Proceedings of the International Symposium Stimulation und Melken, Grimma, Germany, p. 24-31.

Doluschitz, R. & M. Kugler, 1992. Sind "Melkroboter" wirtschaftlich? Landwirtschaftlicher Wochenblatt Hannover, 14:26-27.

Ebendorff, W., J. Wallstabe, J. Ziesack, K. Hartmann & U. Möhrchen, 1989. Einfluß von Druckluftstimulation und automatischem Nachmelken auf die Leistung und Eutergesundheit von Kühen. Monatshefte fur Veterinarmedizin, 44:484-487.

Göft, H. & A. Dethlefsen, 1992. Analyse von Milchflußkurven aus bayerischen Praxisbetrieben unter besonderer Berücksichtigung von Vorstimulation und Milchflußanstieg. In: Proceedings of the International Symposium Stimulation und Melken, Grimma, Germany, p. 204-211.

Grindal, J. & J.E. Hillerton, 1991. Influence of milk flow rate on new mammary infection in dairy cows. Journal of Dairy Research 58:263-268.

Isermeyer, F., 1990. Wirtschaftliche und agrarstrukturelle Auswirkungen des Einsatzes von Melkrobotern. In: Robotereinsatz in der Landwirtschaft am Beispiel des Melkens; Tagung Braunschweig-Völkenrode. VDI/MEG Kolloquim Landtechnik, Düsseldorf, Germany 9:240-252.

Karch, G., 1990. Experimentelle Untersuchungen zur Vorstimulation von Kühen unter besonderer Berücksichtigung technischer Einflußgrößen der Vibrationspulsierung auf das Milchabgabeverhalten und arbeitswirtschaftliche Aspekte. Dissertation Technical University of Munich, Freising-Weihenstephan, Germany. MEG-Heft 181.

Maatje, K., W. Rossing, G.J. Garssen & H.G. Pluijgers, 1983. Automation of electrical conductivity measurements during milking. In: Proceedings of the Symposium Automation in Dairying. IMAG, Wageningen, The Netherlands, p. 89-100.

Pirkelmann, H. & G. Wendl, 1989. Elektronikeinsatz zur leistungsbezogenen Milchviehfütterung. Landtechnik 44(Sonderheft):383-387.

Pirkelmann, H., G. Wendl & C. Kern, 1992. Elektronische Tieridentifizierung als Voraussetzung für den Einsatz rechnergesteuerter Verfahren in der Tierhaltung. KTBL, Frankfurt, Germany. Arbeitspapier 170:9-19.

Rabold, K., 1986. Vollautomatisches Melken - Erste Ergebnisse aus Tierhaltungs- und physiologischen Untersuchungen. Landtechnik 41(5):224-226.

Rossing, W. & A.H. Ipema 1988. Stand der technischen Entwicklung zur Automatisierung des Milchentzuges. Landbauforschung Völkenrode, Germany. Sonderheft 93, p. 197-206.

Schillingmann, O., 1992. Untersuchungen zum Melken mit Robotern. Dissertation. Technical University of Braunschweig, Germany.

Schlünsen, D., H. Roth, H. Schön, W. Paul & H. Speckmann, 1987. Möglichkeiten einer rechnergestützten Gesundheits- und Brunstüberwachung in der Milchviehhaltung. Züchtungskunde 59(2):81-96.

Schmidt, W.L., 1986. Entwicklung einer Melk-Meßeinrichtung zur Erfassung von Milchabgabeprofilen innerhalb der Pulszyklen bei abgestuften Druckverhältnissen. Dissertation. Technical University of Munich, Freising-Weihenstephan. MEG Heft 124.

Schön, H. 1991. Neuorientierung der Landbewirtschaftung und ihre Konsequenzen für die Landtechnik. Landtechnik 46:8-13.

Schön, H. & J. Boxberger, 1991. Technische Ansätze zur Entwicklung naturnaher Haltungssysteme in der Milchviehhaltung. In: G. Brem (Ed.): Fortschritte in der Tierzüchtung. E. Ulmer, Stuttgart, Germany, p. 61-88.

Statistical Yearbook. Federal Ministry of Agriculture, Germany. several volumes.

Worstorff, H., H. Göft & E. Zierer, 1992. Milchflußkurven in der Leistungsprüfung. Proceedings of the Symposium of the International Commitee for Animal Recording (ICAR), Neustift, Austria, part 10:5.

Worstorff, H. & A. Prediger, 1992. Anforderungen an die Mechanisierung der Vorstimulation vor dem Hintergrund unserer Arbeiten zum Vibrationsverfahren. Proceedings of the International Symposium Stimulation und Melken. Grimma, Germany, p. 197-203.

Status, results and further development of an automatic milking system

R. Artmann

Federal Research Centre for Agriculture (FAL), Institute for Production Engineering, Bundesallee 50, D-3300 Braunschweig-Völkenrode, Germany

Summary

The automatic system consists of a robot, a milking-box and an upgraded personal computer as master computer. The robot has been constructed from components used for industrial robots and has three linear axles and one rotatory axle, all driven by asynchronous motors with integrated encoders in a four-quarter-positioning mode. The gripper, milking-box, sensor technology and electronics, including software, were developed in our institute. So far, the system has been tested in two trials with cows. At last, 94% of the teat cups were successfully attached. No difference in animal behaviour compared to manual milking could be observed. However, an unacceptable amount of time was spent on attaching teat cups. In order to reduce the time investment, a multiple cup gripper was tested and the sensor technique was improved.
Keywords: Automated milking, milking robot, teat localization, ultrasonic sensor, vision system.

Introduction

Because of milk quotas, the high degree of working stress and daily barn duties which are time-intensive and must be performed at specific times, dairy farmers need to use existing production reserves and to invest in automation. The development of automatic milking systems serves both objects. Such systems can improve profitability of milking production (Doluschitz & Kugler, 1992; Isermeyer, 1991; Langbehn & Wahlers, 1990; Parsons, 1988) and working expenditure as well as reducing or removing the time obligation.

Late in 1987, the Institute of Production Engineering decided to contribute to the development of automatic milking systems. Since no product suitable for this application could be bought at the time, it was decided to develop the system in-house; this has the advantage of giving great flexibility during application trials.

Project concept, stage of technical development, experience with the system to date and ongoing further development are presented in this paper.

Concept

For the concept of an automatic milking system (Artmann, 1991) it was assumed that cows are kept in cubicle houses. A clever arrangement of the different functional areas (lying, eating, watering, milking) will ensure that the cows visit an automatic milking-place several times a day.

To a large extent, this can be achieved by feeding concentrate. Practical experience with automatic concentrate feeders shows, however, that this measure is not sufficient to ensure that every lactating cow voluntarily visits the milking-place twice a day. So it is necessary to get the animals to move from the lying area along the milking-places or through them, respectively, to the fodder, if necessary to the drinking trough and from there back to the lying area, by a rearranging the functional areas. The use of water intake as a controlling instrument must be tested most exactly since a resulting depression of yield cannot be excluded.

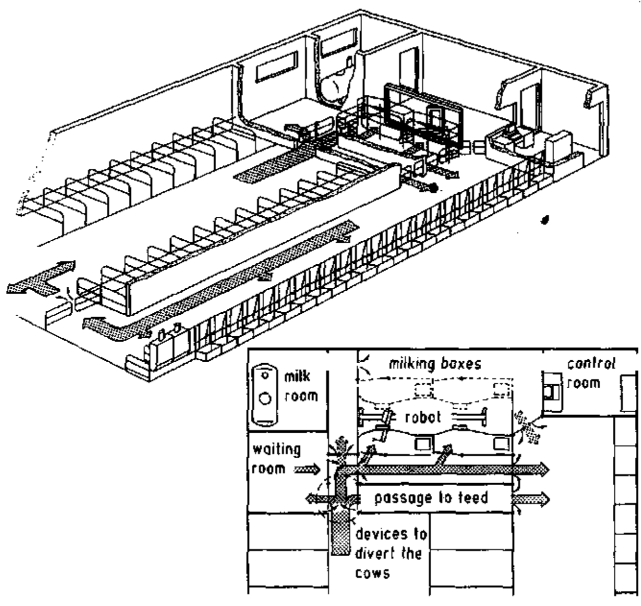


Figure 1. Computer controlled cubicle house for dairy cows.

Using the foregoing considerations the layout of a cubcle house was designed (Figure 1). On the way to their fodder, the cows pass through a computerized device which diverts them to the fodder, or to the milking-place, or to the collecting yard (problem cows). The animals return to the lying area after having eaten. The arrangement of the cubcle house interior as shown here also permits the integration of an automatic driving-aid, should this be necessary.

Stage of technical development

Figure 2 shows the present layout of the automatic milking system (Artmann & Schillingmann, 1989) in a loose housing system at our experimental station. Figure 3 shows top and side views of the technique used.

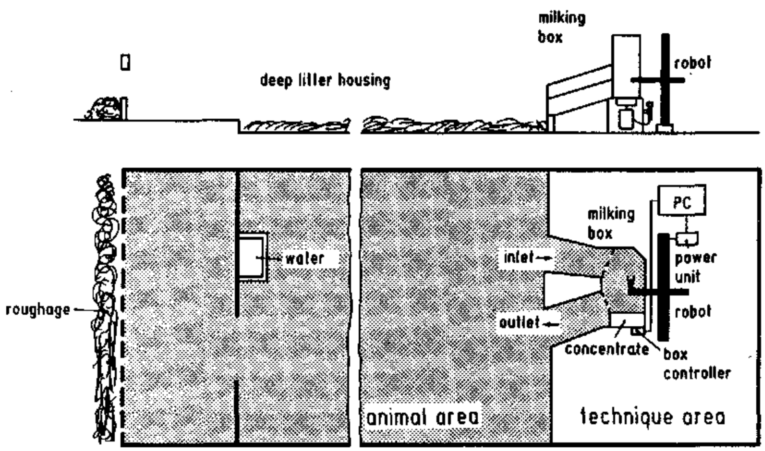


Figure 2. Location of milking robot in loose housing system.

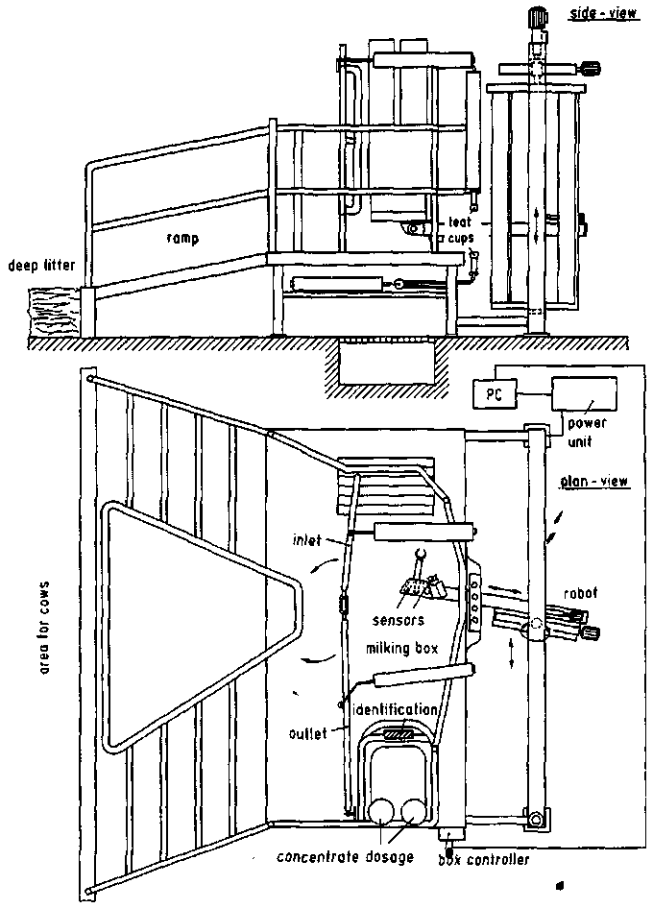


Figure 3. Design of the automatic milking system.

The robot to attach the teat cups was built from standard components (Figure 4). Three axles consist of extruded aluminium shapes whose carriages are moved by gear belts and asynchronously controlled induction motors. The driving mechanism allows a four-quadrant-operation in Cartesian space. An additional turning gear permits rotation on the z-axle.

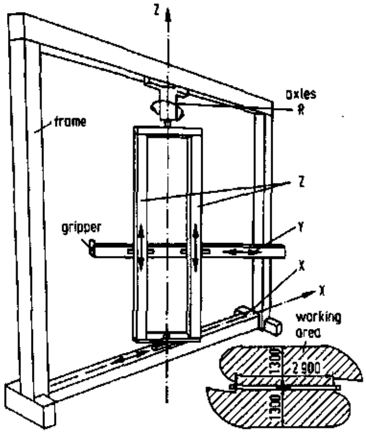


Figure 4. Schematized robot and working area.

The milking-box corresponds to a raised auto-tandembox with entry and exit doors on the sides. To it we added feeding equipment for two types of concentrate and the necessary milking technique, plus a job computer controlling all processes at the milking-box and communicating with the master computer. The box had to be raised because all the milking equipment had been installed underneath (Figure 5). First the tubes got entangled and jammed while the teat cups were being retracted, so the removal device was transfered to the top of the milking box.

The milking technique applied includes a sensor technique to record milk quantity, temperature, conductivity and vacuum level and to separate deviant milk. The vacuum sensors serve both as attaching control and as a signalling system if the teat cups fall off.

We are testing two alternative sensor technique systems to recognize the position of the teats (Artmann et al., 1991).

The ultrasonic system consists of up to 8 ultrasonic sensors. The procedure to recognize the position of the teats is as follows: One by one sensors the emit a sound impulse in the course of which all sensors act as receivers. Up to 3 echoes per sensor are measured and evaluated.

The second sensor technique is based on a vision system. It consists of CCD camera, laser diode with collimater, vision processing card and the PC already mentioned. First of all, a picture is taken under natural light conditions via the CCD camera, then the laser diode is switched on, so that a light line is projected on the udder at the height of the teats. Then a second picture with subsequent picture subtraction is taken. The binary picture is evaluated by the software and the position of the teats is calculated.

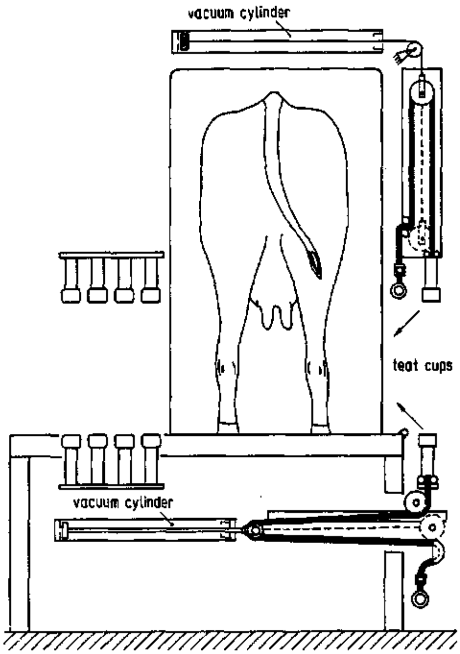


Figure 5. Attach/detach unit for teat cups.

Results with the system

Mechanically and electronically of the milking system works satisfactorily. With the robot a repetition accuracy of ±1 mm is achieved, which is sufficient for the purpose of this application. The stick-slipeffect of the linear sliding axles and the loose working in the reducing gears inserted between motor and gear belt drive, at low speed, are unsatisfactory. A solution without gears would improve accuracy. Sporadic problems occur with regard to the axle control. We assume they are due to time problems of the purchase axle control cards. So far we have not been able to localize the error, since it does not occur systematically and the software is stored on the card.

So far, only the ultrasonic sensor technique has been tested in animal experiments. We remain under the measurement accuracy of ±1 mm stated by the manufacturer. The range of the repetition accuracy is around 0.2 mm. It has become became apparent that the temperature sensor measuring air temperature, and thereby the velocity of sound, reacts too slowly. Hence, a reference distance (inclined plane to z-axle) is measured and used for calculating the velocity of sound.

In the experimental results presented, first the approximate position of the teats was registered and in a second step one teat was aimed at and followed with the help of sensors. For this procedure two sensors were used; Their sound lobes crossed over the opening of the teat cup to be attached, Figure 6.

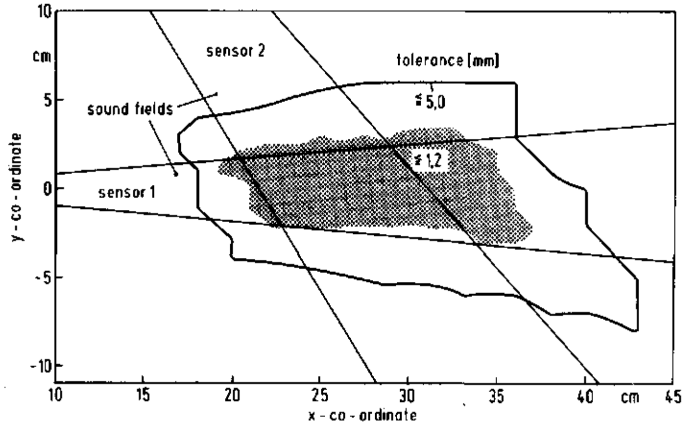


Figure 6. Accuracy of measured position obtained with two ultrasonic sensors (object: round iron ∅ 25 mm)

The robot is directed on the basis of the calculated deviations between teat and cup centre. At present, the sensors can redirect the robot up to the relative velocity of 181 mm/s. The most important results obtained in practical application are to do with success of attaching teat cups, animal behaviour, influence on quantity and changes in milk quality, respectively (Schillingmann, 1991 & 1992).

As shown in Figure 7, the success rate of attaching the teat cups could be raised from 70% at the end of the first experiment to 94%, the mean value of the second trail, thanks to an improved search program. It is completely unsatisfactory that on average, 7.2 minutes per cow are necessary for the attaching. The use of the one cup gripper is one of the main causes for this slowness. Four drives from the cup magazine to the udder and back are required, during which the position data of the teats are lost every time and consequently have to be redetermined.

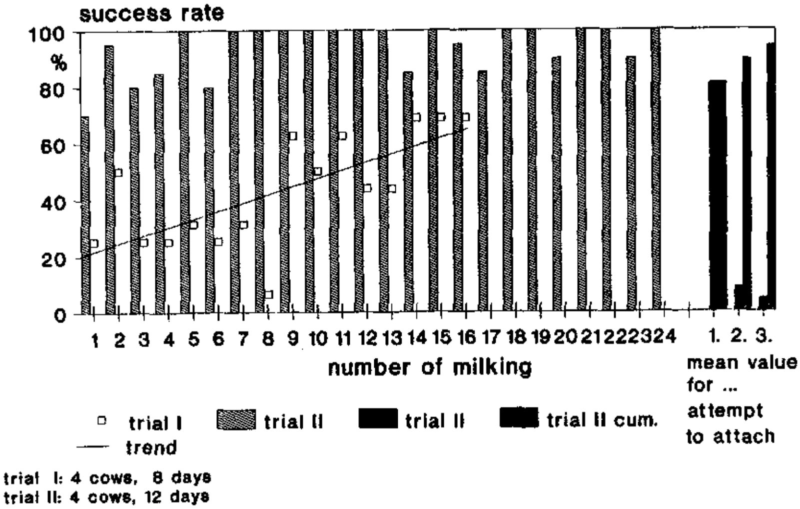


Figure 7. Success rate of attachment of the teat cups.

Figure 8 classifies the motion behaviour of the cows during attaching and milking, in lengthwise (x) and crosswise (y) direction to the longitudinal axis of the animal. Astonishingly, the cows are calmer during milking by the robot than during milking by hand. Subjectively assessed, no differences could be observed.

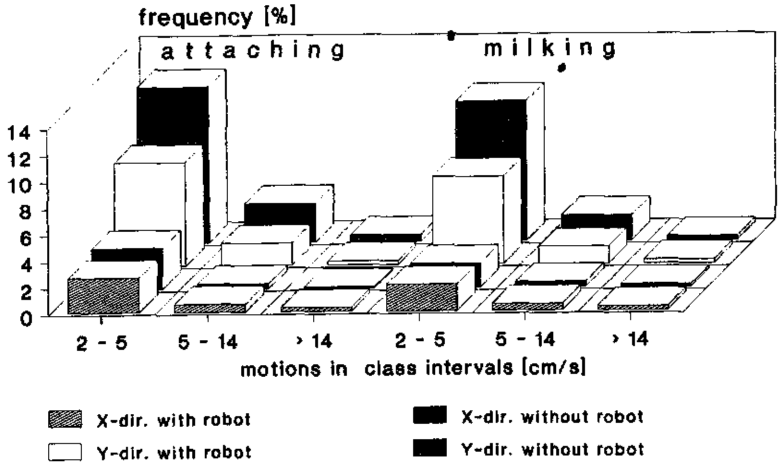


Figure 8. Behaviour of the cows during attaching and milking

Compared with milking without a robot, no changes in milk quantity and temperature and only minor changes in electrical conductivity could be observed.

Further developments

As mentioned earlier, the time required to attach the teat cups is completely unsatisfactory. A major reason for this is the considerable time required for the drives to get the cups.

Attaching a single gripper as fast as possible (teach-in) takes about 100 s, sensor-guided attaching takes 260 s and attaching to the real animal takes on average up to 7 minutes. Gripper variants able to take up all cups at once and to hand them over sequentially have been developed in our institute (Schillingmann & Artmann, 1991). At present, the technique presented in Figure 9 below is being tried out. The process of attaching is as follows. The teat cups hanging in the cup magazine are pulled in the gripper.

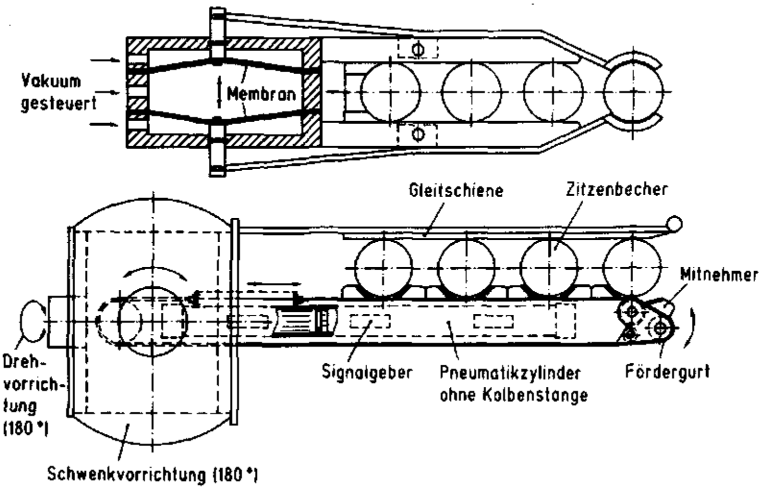


Figure 9. Grippers developed for all teat cups.

While driving down, the robot rotates the gripper 180 degrees and drives in a favourable position under the cow. In doing so first the position of the teats is determined and then all 4 cups are sequentially attached. The cup to be attached is released by the turning of the gripper head. While driving to the next teat the released cup is replaced by the next cup which is pushed by a pneumatic conveyor belt.

It is expected that under practical conditions attachment in under 60 s will be possible with this technology and the available sensor technology.

Further improvements will be possible faster and more reliably once the position on the teats can be determined. In future, our work will concentrate on the application of the vision system. We aim also to determine udder cleanliness and injuries.

Acknowledgement

The development of the automatic milking system described would not have been possible without financial assistance from the Deutsche Forschungsgemeinschaft. The author thanks the organization for its funding. He also expresses his thanks to his former colworker Dr.-Ing. Schillingmann and to the numerous students of the Technical University Braunschweig, who took an active part in developing the technique and obtaining the results.

References

Artmann, R., 1991. Konzepte und Entwicklungen zur Automatisierung des Melkens. In: Robotereinsatz in der Landwirtschaft am Beispiel des Melkens; Tagung Braunschweig-Völkenrode. VDI/MEG Kolloquim Landtechnik, Düsseldorf, Germany 9:45-69.

Artmann, R. & D. Schillingmann, 1989. Automation of milking by using robots and electronics. In: Proceedings of the second international conference AGROTIQUE, Bordeaux, France, p. 331-348.

Artmann, R., D. Schillingmann, G. Kröger & B. Bollmann, 1991. Lokalisierung der Zitzenpositionen mittels Ultraschall- und Bildverarbeitungssystem. In: Robotereinsatz in der Landwirtschaft am Beispiel des Melkens; Tagung Braunschweig-Völkenrode. VDI/MEG Kolloquim Landtechnik, Düsseldorf, Germany 9:127-152.

Doluschitz, R. & M. Kugler, 1992. Sind "Melkroboter" wirtschaftlich? Hannoversche Land- und Forstwirtschaftliche Zeitung 14:26-27.

Isermeyer, F., 1991. Wirtschaftliche und agrarstrukturelle Auswirkungen des Einsatzes von Melkrobotern. In: Robotereinsatz in der Landwirtschaft am Beispiel des Melkens; Tagung Braunschweig-Völkenrode. VDI/MEG Kolloquim Landtechnik, Düsseldorf, Germany 9:240-252.

Langbehn, C. & H.W. Wahlers, 1990. Chancen für den Melkroboter? Die Milchpraxis 28(2):92-95.

Parsons, D.J., 1988. An Initial Economic Assessment of Fully Automatic Milking of Dairy Cows. Journal of Agricultural Engineering and Research 40:199-214.

Schillingmann, D., 1991. Versuchsanlage zum automatischen Melken - Konzeption und Ergebnisse. In: Robotereinsatz in der Landwirtschaft am Beispiel des Melkens; Tagung Braunschweig-Völkenrode. VDI/MEG Kolloquim Landtechnik, Düsseldorf, Germany 9:70-91.

Schillingmann, D. & R. Artmann, 1991. Alternativen zur Handhabung der Melkbecher. In: Robotereinsatz in der Landwirtschaft am Beispiel des Melkens; Tagung Braunschweig-Völkenrode. VDI/MEG Kolloquim Landtechnik, Düsseldorf, Germany 9:111-126.

Schillingmann, D., 1992. Untersuchungen zum Melken mit Roboter. Dissertation Technical University Braunschweig, Germany (in press).

Mains Project - Automatic Milking

Ph. Marchal, G. Rault, Ch. Collewet & L. Wallian

CEMAGREF, French Institute of Agricultural and Environmental Engineering Research, Division Technology, 17 Avenue de Cucille, 35044 Rennes Cedex, France

Summary

To build the first generation of our milking robot we have chosen a technology capable of solving the principal obstacle: attaching the clusters with a high rate of success. Now we are developing a new system that takes complete charge of cow traffic, quality of milk and which is able to make a good selection of information. This project is called MAINS (Milking Automatically and Information Management with Neural System). It began in 1991 and is divided into four sub-projects:

- robotic and sensors;
- robotic, cow welfare and cow behaviour;
- milk management;
- herd management.

This research project is carried out together with the CIMIS industrial project which aims to commercialize a milking robot in farms in the near future.
Keywords: milking robot, teat sensing sensors.

Introduction

Introducing electronics and computers into dairy farms brings considerable relief to farmers. The only part of the milking process that has not yet been automated is attaching the teat cups. That is why the CEMAGREF is working on "the milking robot project". It has three phases:

1. robotization of the attachment of teat cups (Milking Robot I);
2. milking robot with cow traffic food management (Milking Robot II);
3. the AIMS concept includes technical management (keeping track of health, fecundity control, food management, milk quality control) and economic management.

The milking robot targets and results

The project called "Automatic applying of teat cups" has been presented during the last seminars (Marchal, 1990). Now we are designing a second project, Milking Robot II which includes cow traffic and milk and food management (Artmann, 1990). Parts of this project are done in the Eureka project CIMIS (CIMIS is a collaboration between CEMAGREF, IMAG-DLO, Manus-Holland, Sagem, Diablo Manus and Prolion).

Engineering concepts

In developing our projects, we have had to make fundamental choices. These are:

- the stall;
- the manipulator arms;
- teat detection;
- system architecture.

The last two key points will be discussed.

Teat sensing

Establishing teat position involves both a global sensor and a local sensor. The three-dimensional vision system is based on the triangulation principle with a CCD camera and a LASER plane (Figure 1).

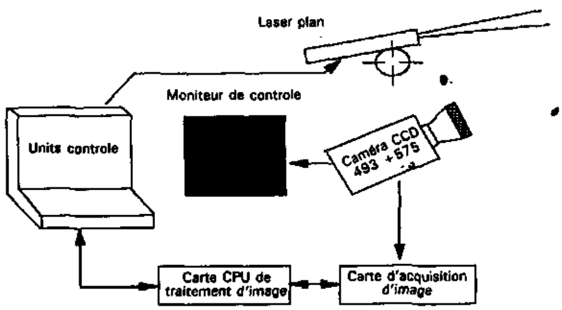


Figure 1. Global sensor (Vision System).

Two years ago, the system was detecting the co-ordinates for the front teat. The co-ordinates for the rear teats were computed from the co-ordinates for the front teats and from information on udder morphology. Now, we use two lasers to get the co-ordinates for the four teats in real-time without any correlation.

The local sensor is a network of infrared emitting devices and phototransistors around each teat cup (Figure 2). This sensor relieves the global sensor when the arm is underneath the teat and enables the alignment of the axis of the teat cup with that of the teat to ensure a successful fitting.

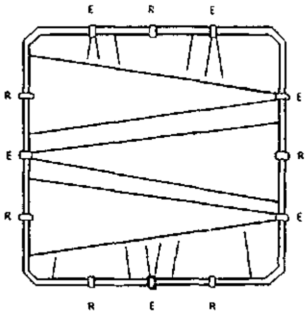


Figure 2. Local sensor in teat cup.

The system architecture

The system is made of several processing units linked by a field bus to a central supervision unit (Figure 3). The field bus we use is a serial bus optimized for high speed transfer of short control messages. It is based on RS485 electrical specification, uses a master/slave protocol, and the data are transferred at the rate of 37 kbytes. All the units are based on a micro-controller that executes communications software and I/O control procedures under the control of a multi-tasking operating system.

For example, the vision unit consists of three boards; the power supply, the CPU board and the real time image acquisition board. This unit manages the image acquisition, executes some basic image processing and drives the LASER mastered by the central unit.

The distributed control approach ensures that the central unit does not have to deal with any decision that can be made at the local level. Another important point is that this kind of architecture, reducing cabling, brings more reliability and makes maintenance easier.

The central unit has to manage several jobs (Figure 4). It must synchronize the different units, compute some calculations too complex to be computed by the units, record and look for information in a data base. It must also be able to react quickly to external events, for example, when the cow moves or kicks. All these specifications led us to work with a multi-tasking real-time operating system.

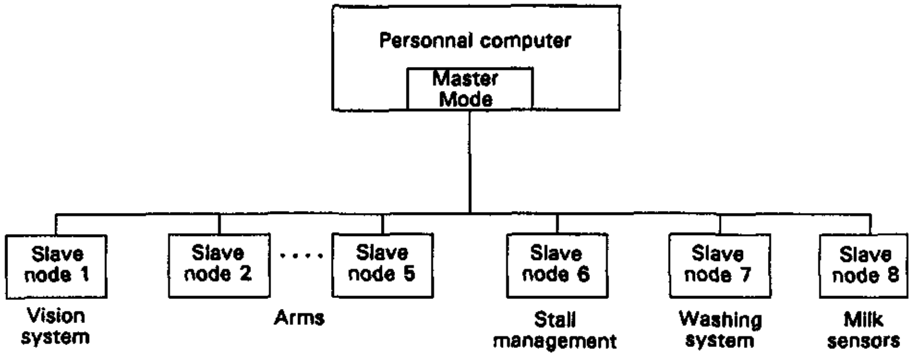


Figure 3. The system architecture.

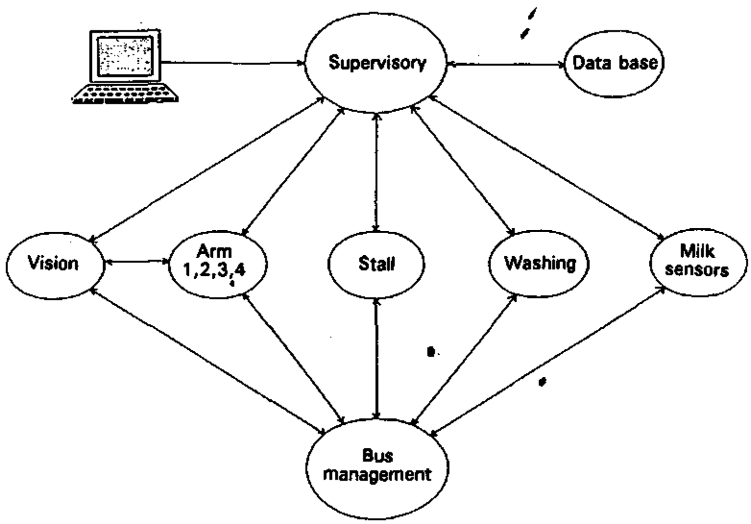


Figure 4. Management of the tasks.

For example, the vision task, is responsible for finding the co-ordinates of the four teats and an arm task takes care of fitting up and removing the teat cup using information derived from a dialogue with the vision task.

The real time aspect of the operating system enables us to follow the teats moves precisely and to respond at once to a message such as "impossible destination for the arm" or "defective sensor".

Results

Experiments have been carried out in 1990 and 1991 on a group of seven cows milked three times a day. These experiments enabled us to confirm some choices we made:

- we noticed no transmission error in the network during a two months period: this way of communicating is quite reliable;
- the multi-tasking real-time operating system succeed in controlling the vision system and the arms simultaneously, and in managing the errors quickly.

The teat detection system associating the global sensor, the local sensors and computations has given very satisfying results (Table 1). We observed some failures in cows with black teats.

Table 1. Success rates of the vision system for the four teats.

Teat	Front Right	Front Left	Rear Right	Rear Left
Success rate (%)	99.1	98.2	97.1	98.7

The results of fitting-up the teat cups depends greatly on the cow (from 41.7% to 78.9%). Success is defined as the fitting-up of the four teat cups without any human help, in less than one minute. Mechanical problems are the main reasons for failure.

To improve our milking robot we have to work on several aspects such as mechanical problems, increasing robot swiftness (by giving more intelligence to the units, for example) and improving the vision system.

AIMS project, a new concept?

The live trials enable us to gain experience and knowledge about system requirements. It also gives us is the change of testing new techniques, especially the performance of our detection sensors and architecture system. The robotic milking machine cannot be considered independent from other aspects of dairy production such as herd management and sanitary control (Ipema et al., 1987). This implies the conception of other sensors and the integration of specific software (Ordolf, 1989). This great amount of information will be processed by an expert system able to provide comprehensible and relevant data to the breeder, the target of the MAINS project.

Robotic and sensors

The robotic system is designed to find the teats and take care of teat fitting-up. We have to be able to complete new tasks, for example teat cleaning and teat disinfection. Given our initial technological choices we are able to achieve this (vision techniques and four-arm manipulators). The manipulators will become multi-tasks. New trials are planned for 1993. This will study:

- adaptive command with neural networks;
- increase accuracy of vision techniques with two laser beams;
- measure dirtiness of teats with colorimeter to pilot teat cleaning.

Robotic, cow welfare and cow behaviour

Introducing robotic equipment on a dairy farm means there must be actual information on:

- behaviour of the herd (e.g. learning period, ethology of individual cow, the relations the herd has with the milking robot);
- cow welfare (e.g. relations of cow traffic, feed ingestion, pathology and the introduction of a milking robot) (Rossing et al., 1985).

Milk management

A milking robot will be successfully accepted by a farm if the problem of milk management is solved. We have to develop research on:

- measurement of milk quality (cell count, fat content, protein content) in real-time with reliable sensors (Onyango, 1988; Maatje & Rossing, 1976; Poutrel, 1979);
- automatic sampling;
- adapt milking technology to milking frequency, teat congestion, milk yield, milking duration (Armstrong, 1976). To achieve these targets we have to change vacuum level, pulsation rate, teat cup conception (Bramley, 1987);
- provide an efficient teat stimulation compatible with the robotic process (Jorgensen, 1990).

Herd management

The progress of automation in dairy farms increases management activities. The main problems are now to manage new types of data, its volume and its interpretation. The farmer-machine interface should be useful and easy to understand.

We have chosen to increase research in this area , cooperating with scientists from different disciplines (economy, ergonomics, zoology, physiology) and by using new tools (fuzzy logic and neural networks).

Conclusion

The development of research in the "milking robot field" requires information from many different fields and from scientists with many different background. The constitution of a formal group at the European level will be an efficient solution, if it can be implemented successfully and swiftly.

References

Armstrong, D.V., 1976. Milking machine detachers: effect on production and udder health. Extension Bulletin Q24, University of Arizona, Tucson, Arizona, U.S.A.

Artmann, R., 1990. Konzepte und Entwicklungen zur Automatisierung des Melkens. In: Robotereinsatz in der Landwirtschaft am Beispiel des Melkens; Tagung Braunschweig-Völkenrode. VDI/MEG Kolloquim Landtechnik, Düsseldorf, Germany 9:45-69.

Bramley, A.J., 1987. The relative importance of milking machine factors in mastitis. In: Proceeding of the International Mastitis Symposium. MacDonald College, Quebec, Canada, p. 142.

Ipema, A.H., E. Benders & W. Rossing, 1987. Effect of more frequent daily milking on production and health of dairy cattle. In: Proceedings of the third symposium Automation in Dairying. IMAG, Wageningen, The Netherlands, p. 283-293.

Jorgensen, K., 1990. Teat udder cleaning. Bulletin of the IDF 247:49-51.

Maatje, K. & W. Rossing, 1976. Detecting oestrus by measuring milk temperatures of dairy cows during milking. Livestock Production Science 3:85-89.

Marchal, P., 1990. The French milking robot. In: Robotereinsatz in der Landwirtschaft am Beispiel des Melkens; Tagung Braunschweig-Völkenrode. VDI/MEG Kolloquim Landtechnik, Düsseldorf, Germany 9:181-187.

Onyango, L.M., 1988. A low maintenance conductivity sensor for detecting mastitis. Journal of Agricultural Engineering Research 40:215-224.

Ordolf, D., 1989. Voraussetzungen und Grundhalgen automatisher Milchgewinnung. Forschungsbericht Agrartechnnik des Arbeitskreises Forschung und Lehre der MaxEyth–Gesellschaft, Hohenheim, Germany. MEG-schrift 191, 188 pp.

Poutrel, B., 1979. Valeur de la mesure de la conductivité du lait pour la détection des infections mammaires de la vache. Bulletin de la Société des Vetérérinaires Praticiens de France 63(8):609-613.

Rossing, W., A.H. Ipema & P.F. Veltman, 1985. The feasibility of milking in a feeding box. IMAG, Wageningen, The Netherlands. Research Report 85-2.

Design features of the Silsoe automatic milking system

M.J. Street, R.C. Hall, D.S. Spencer, A.L. Wilkin, T.T. Mottram & C.J. Allen

AFRC Silsoe Research Institute, Wrest Park, Silsoe, Bedford MK45 4HS, United Kingdom

Summary

The Silsoe Automatic Milking System is described to indicate how the engineering components function and how they are combined to form a system. The components include, the stall, sensors, robot and teat cup magazine. The processes are described briefly with reference to the control software. The performance and success rate is commented upon.
Keywords: milking, automatic milking, robotic milking, robots, pneumatic robots, milking systems.

Introduction

The Silsoe Automatic Milking System 'AMS' is intended to be an unattended unit available for most of the 24 hours and allowing controlled but voluntary attendance by the cows. The system consists of a stall to give some degree of cow control, an associated robot to carry out the preparation and milking operations, milking equipment, and computers to control the processes.

The stall is adjustable in length and width to keep the free movement of the cow within the working range of the robot, a step for the front legs is used to obtain better udder presentation. A pneumatic robot is used to pick up four teat cups, one at a time, and apply them in sequence to the teats. The present robotic arrangements could be extended to service 2 or 3 tandem stalls. Five computers are used to control the AMS which is currently only operated under human supervision. The future addition of intelligence to the computer systems will allow them to cope with problems, unexpected events, and to initiate human intervention.

The first Silsoe Milking System

The first MK1 robot system was developed to test and prove techniques. The stall was simple with just length and width adjustments. The robot was pneumatic and carried a single teat cup that could be applied to all four teats in sequence. Teat location was by combining stored data giving teat co-ordinates related to the cow body and the body position sensed in the stall using mechanical contact levers. Using the data obtained, it was possible to steer the robot arm carrying the teat cup to the approximate position of the teat. Local sensors on the end effector could then detect the presence of the teat and adjust the robot arm to centralise the cup on the teat and allow attachment with a final lift. During the attach phase the body position sensors were actively providing dynamic signals to control the movement of the robot and so maintain the local sensors in the region of the teat.

During the trials of the Mk1 robot a number of cows were successfully milked one teat at a time. The techniques were proven and showed the way for subsequent developments.

The Mk2 System

The Mk2 system (Figure 1) is designed to attach all four teat cups sequentially using a single robot arm. The cups are held inverted in a magazine at the opposite side of the stall to the robot. The robot end effector has the means of gripping and releasing the teat cups, a wrist action for inverting and shifting the cups to get the best orientation for attachment, and a means of local sensing that does not impede the mechanical operations.

The Mk2 robot (Street, et al., 1990) was a new design and an attempt was made to keep the mass and inertia down, and the arm as simple as possible. All joints are simple pivots and cylinders are small to maintain short pneumatic time constants. The general design principle is shown in Figure 2. The range of movement is greater and the dynamic performance is considerably better than the Mk1 robot. A rotation axis has been fitted in the base to rotate the robot from underneath the cow.

The position of the cow in the stall is sensed using mechanical paddles pressed on the cow using air springs, potentiometers connected to the paddles provide the electrical signal outputs (Figure 3). The paddles are retracted by reversing the effect of the air springs. One split paddle is used on the rump of the cow for the x, position and a pair of paddles on the flanks for the, y, position. The direct contact with the cow also allows the sensors to provide dynamic movement information.

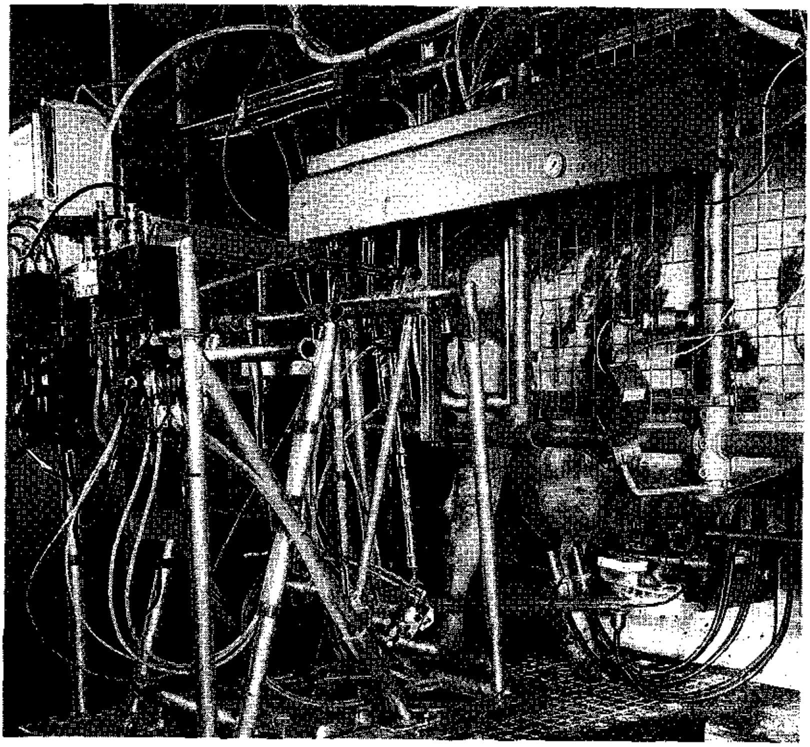


Figure 1. The Mk2 System.

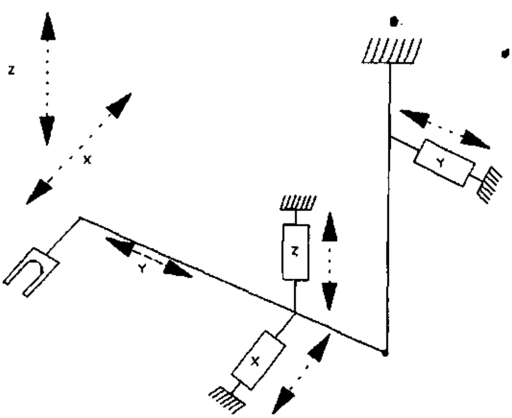


Figure 2. Mk2 robot principle.

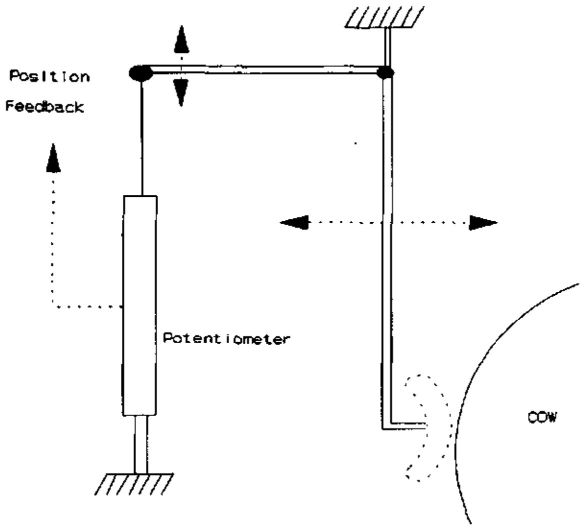


Figure 3. Cow posotion sensor.

The teat cups are held retracted into a magazine by the tension applied to the milk and pulsator tubes using a roller and teat cup removal (TCR) vacuum cylinders (Figure 4). Each cup and milk tube assembly is independent and feeds a separate quarter milking jar. Information from load cells in each jar is used for yield measurements and to initiate the individual cup detachment and retraction to the magazine.

The robot end effector is open ended and can slot over the teat cup, a small pneumatic gripper holds the cup at pick up and whilst attachment takes place. The end effector is mounted on the robot arm using a 45° pivot (Figure 5). A 180° rotation on this pivot inverts the teat cup and also changes the direction of the end effector for best access to the teats. The cups are put on in the sequence shown in Figure 6 to avoid collisions and entangling of the milk tubes. Once cups are on the teats then the gripper is released and the robot can proceed to pick up the next teat cup. Each TCR cylinder is released as the gripper slots onto the teat cup, the cup and milk tubes are then pulled out by the robot. Milking vacuum is applied as the cup nears the teat and attachment is signified by sensing the vacuum level changes in the milk tube.

A matrix of 8 infra-red light beams is arranged across the top of the end effector to detect the teat and allow correction of the robot position to centralise the cup on the teat. The arrangement of beams is open ended and skewed to allow collection and release of the teat cup, the matrix is therefore not related to the axes of the robot and a look up table is required to provide the x and y data.

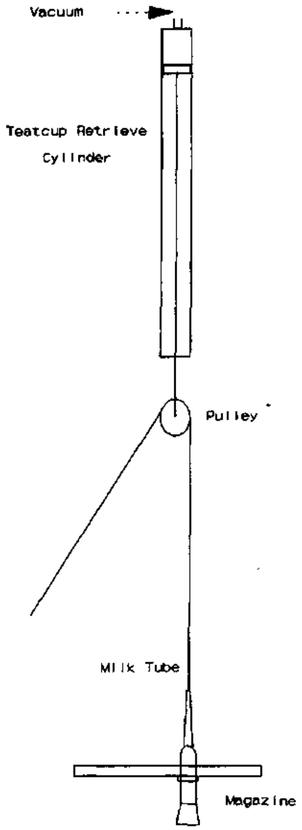


Figure 4. Milk tube and teatcup retraction.

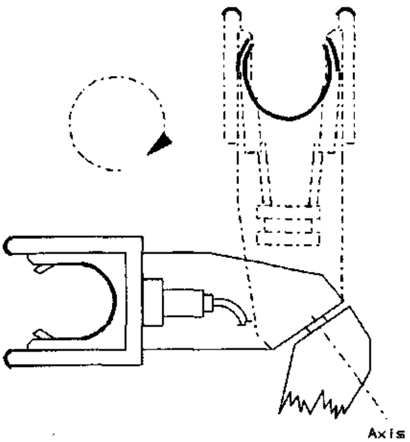


Figure 5. End effector.

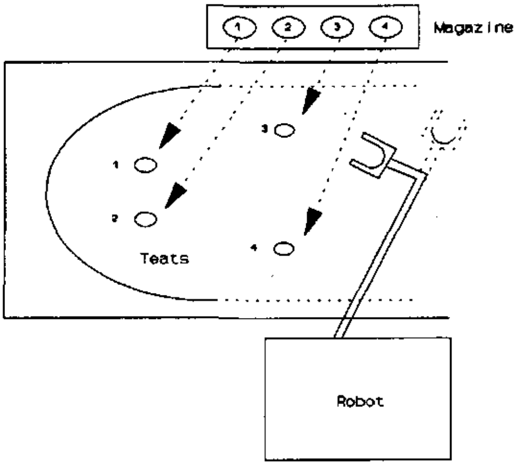


Figure 6. Attachment sequence.

Co-ordinates for each teat on each cow are maintained in a database associated with the management system. The co-ordinates are initially generated by steering the robot to each teat using a joystick and then pressing a button which automatically corrects the data before storing. The data is referenced to the rump for the x axis to the centre line of the cow for y axis, and to the floor for height z. For attachment the co-ordinates from the database are combined with the cow position information to provide the approximate location for each teat. The robot then moves the cup to this position and if the teat is within the sensor area, 80 mm × 80 mm, a correction can be made and the cup attached. The teat co-ordinate sets for each cow may be single or multiple allowing a choice depending on the yield of the cow and time since last milking. As experience is gained, interpolation between co-ordinate sets to suit the elapsed period may be adopted. The corrected co-ordinates gathered during attachment are returned to the database to be used in an updating operation.

System Control

Five computers are used in the AMS. It is expected that some functions currently performed in separate computers will be integrated into a single computer as the software is established and finalised. The management system (Spencer & Street, 1992) includes the database and could service a number of milking units. Management functions include decisions on accepting a cow for milking, prompting test procedures, assessing health status of cow, dumping milk etc. It will normally provide the management intelligence. The management system searches the database for teat co-ordinates and does any necessary processing before sending the data to the Robot control.

The processing for robot control is shown in Figure 7. The numerous inputs to calculate the robot position for the teat target phases of the operation are summed in the robot position generation to give rectangular *x, y, z* co-ordinates within the working area of the robot, these co-ordinates move with the cow and therefore require a dynamic response. The cups in the magazine and the home position are in fixed locations and to avoid disturbing step movements by the robot when changing target, rate limits are applied. The final stage is to convert the rectangular *x, y, z* co-ordinates in millimetres into polar type co-ordinates in robot numbers. The positioning process is initiated by a timer every 20 ms. Typical cow movements have been measured at up to 100 mm/sec, so the software contribution to the robot tracking error is only 2 mm. The pneumatic response of the robot adds up to 200 mm to the tracking error. Violent cow movements, coughs etc., cause a transient loss of the target teat.

The cup attaching process is controlled by a separate software task which monitors the end effector sensors, decides on cup lifting and applies a controlled jitter to aid the attachment operation. In addition this separate task also monitors the vacuum levels in the milk tube and controls the teat cup release and gripper mechanisms.

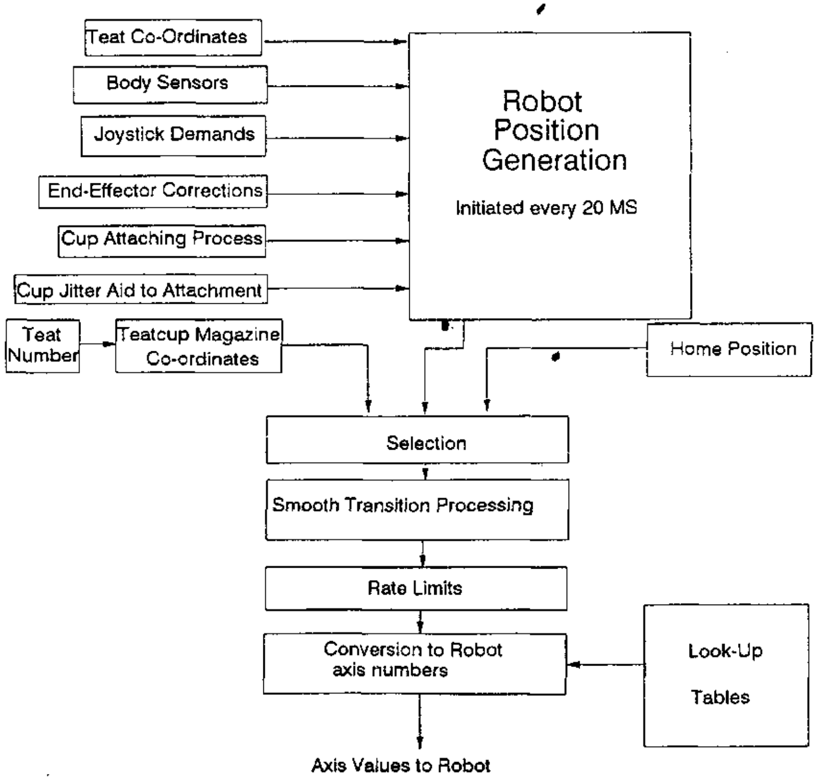


Figure 7. Robot positioning process.

Comment on Operation

The system described has now been under development and in intermittent use since March 1991, more continuous formal trials were carried out in November 1991 (Allen et al., 1992).

Cows learn quickly what the procedure is and after just one or two visits most cows are quite content with the operation and will take up the appropriate position with the front feet on the step. The robotic operation of transferring a teat cup to the teat takes an overall time of about 15 seconds + attachment time, best times are therefore 17 seconds, and typical times about 20 seconds. The total robotic operation is about 80 to 100 seconds which is acceptable within the total milking period and would permit other stalls to be serviced. The magazine technique is straightforward, and has given no problems with extraction or retraction of the teat cups. The sequence of teat cup placement avoids collision and has only rarely been upset by the cow stepping over or standing on the milk tubes.

The pneumatic robot provides some significant benefits. Occasional kicks, some vicious, have never caused any damage in the year of operation. Kicks and treading on the robot arm have occurred during attachment operations but the robot has sprung back on removal of the leg and attached the cup. This performance could not be guaranteed for a single try but it is easy to program additional attempts after a failure. During the attachment, movements of the cow are dynamically tracked by the robot using information from the body sensors. Only for rapid movements of the cow does the teat escape the end effector for a brief period until the robot catches up and the process of attachment can continue.

The passive concept of controlling cow posture (Mottram, 1992) does occasionally lead to cows rear legs being in the way or the front legs not being on the step. This can lead to failure, but the robot actions sometimes prompt the cow to move to a suitable stance for successful attachment. Occasionally errors occur in the teat location which result in the end effector missing the teat, no common cause is obvious and other sensing techniques are being considered to provide corrective positional data at the start of each milking.

Trials in November 1991 using 10 cows on 3 times a day milking for 12 days, resulted in an 85% success rate for attaching individual teat cups. Approximately half the failures were due to errors in teat location and the remainder due to engineering or software bugs.

Conclusions

The Mk2 Silsoe milking system has now been in operation for over one year. The physical arrangement of the system components permits effective automatic teat cup attachment and milking to take place. The pneumatic robot performs adequately and provides some significant benefits in terms of robustness and recovery from potentially damaging events. The teat location techniques need some enhancement before acceptable performance is achieved.

References

Allen, C.J., T.T. Mottram, A.R. Frost, M.J. Street, R.C. Hall & D.S. Spencer, 1992. Field trials of the Silsoe automatic milking system. In: A.H. Ipema, A.C. Lippus, J.H.M. Metz & W. Rossing (Eds.): Proceedings of the International Symposium on Prospects for Automatic Milking, EAAP publication No. 65, Pudoc Scientific Publishers, Wageningen, The Netherlands, p. 72-79.

Mottram, T.T., 1992. Passive methods of modifying cow posture for automated and robotic milking systems. Journal of Agricultural Engineering Research, 52.

Spencer, D.S. & M.J. Street, 1992. The design of the management system for the Silsoe automatic milking system. In: A.H. Ipema, A.C. Lippus, J.H.M. Metz & W. Rossing (Eds.): Proceedings of the International Symposium on Prospects for Automatic Milking, EAAP publication No. 65, Pudoc Scientific Publishers, Wageningen, The Netherlands, p. 309-314.

Street, M.J., R.C. Hall & A.L. Wilkin, 1990. A pneumatic milking robot, structure, performance and first results. In: Robotereinsatz in der Landwirtschaft am Beispiel des Melkens; Tagung Braunschweig-Völkenrode. VDI/MEG Kolloquim Landtechnik, Düsseldorf, Germany 9:188-201.

Evolution of Düvelsdorf milking robot

M. Dück

Düvelsdorf & Sohn GmbH & Co. KG, Stellenfelde 24, 2802 Ottersberg-Posthausen, Germany

Summary

In 1986 Düvelsdorf started developing a milking robot. After considering several systems for attaching the teat cups, a system with linear axes was evaluated. A combination of using stored data, ultrasonic waves and light barriers was found to be a good solution for locating teats. In spring 1989 the first cow was milked by the robot. In 1990 the system was installed in the Institute for Milk Production of the Federal Dairy Research Centre, Kiel. Up to December 1991 roughly 14 000 milkings had been done. The complete system, including the software of the controlling unit, is currently being improved for installation on a commercial farm.
Keywords: milking robot, linear axis, ultrasonic sensors, light barriers.

Introduction

During the early eighties a discussion of automation in dairying started in Germany. Some of our customers inquired about milking robots and so Düvelsdorf decided to develop an automated system for milking. Nearly all of these potential clients use a loose housing barn for their cows and so the system had to be able to be installed in an existing milking parlour. Our philosophy is that fully automated milking systems should not lead to more production and industrialization of dairy farming but to lightening the farmer's workload (Dück, 1991).

Hardware of the Düvelsdorf milking robot

In 1986 it was proposed to create an underfloor milking system, where a fully movable robot arm was installed under the floor of the milking parlour. After a cow stepped in the milking box, two lids would open and expose the robot arm. This idea was rejected, because it was expected that the robot arm would get dirty.

In summer 1986 the idea of using a linear system for moving the robot hand was born. After testing several types of these systems, a system able to work in a range up to 10 m was evaluated (Figure 1). Its X axis can be installed parallel to 4 milking boxes, whose form is identical to the form of conventional tandem boxes. All axes of the linear system are driven electrically by frequency controlled three-phase current motors. To minimize electric power and torque for the Y axis (height), this axis is held by a pneumatic cylinder in such a way that only the movement of the Y axis must be done by the electric motor, while the weight of the arm is held by the pneumatic system.

A robot hand with tongs and sensor systems is attached to the end of Z axis. Using this hand the milking robot can grip a teat cup in the teat cup magazine and bring it to a teat. The teat cups are connected to the claw by a long "short milk tube", combined with the short pulse tube. This combined tube can be moved actively by special drives, which allow the teat cups to be zoomed in and out (Düvelsdorf, 1989). The rest of the milking plant is more or less conventional parts of milking machines, except that behind the claw two milking systems are installed with lines, end units and tanks (one for saleable milk and one for rejected milk) (Dück, 1991; Scheidemann, 1990).

The motors of the linear system and the drives for the special short milk tube are electrically powered; every other movement is controlled by pneumatic power (e.g. the movement of doors, valves, tongs of the robot hand, and the jets, by which the teat cups are closed and connected to the system for cleaning the milking machine).

Figure 1. Milking robot with the linear axes.

Sensor systems

So far, sensor systems have been installed for animal identification, teat location and controlling udder health. The conventional FARMMASTER responder system made by Düvelsdorf is used for animal identification. To control udder health the conductivity of the first 10 squirts is measured individually for every quarter.

As expected, most problems arose with the teat locating system. In 1986 we began with a system of several light beams and light barriers in different positions to the teat. The apparatus had four light barriers, and was installed near the mouthpiece of the teat cup. In a second step the facilities of image processing were evaluated. But by 1988 we had been unable to locate teats by image processing in real time with affordable processors. So we looked for another sensor system.

Figure 2. Robot hand with sensor system.

We found the solution in a combination of stored data, ultrasonic sensor and a frame with light barriers (Figure 2). Before first milking, data on teat position are taught. To apply teat cups the robot hand with one cup moves to an area under the cow, depending on the stored data. In the second step this defined area is scanned with the ultrasonic sensor, which is installed on the robot arm. The size of the area is normally 10 by 12 cm and can be changed. After getting a reflected signal of the ultrasonic waves, the robot arm moves with the teat cup under the teat and lifts a frame with light barriers. Normally the teat is now in the frame of 7 by 7 cm, the position of the teat cup will be adjusted by data from the frame with the light barriers, and the teat cup is moved upwards. During this the light barrier frame comes down to its resting position (Scheidemann, 1990).

Milking routine

When a cow comes to the milking parlour it is identified and, if ready for milking, it will be allowed to enter the milking box. Therefore we recommend a cowshed with divided areas for feeding and drinking on one side and resting and concentrate dispensing on the other side (Figure 3). Access between the feeding and the resting area should be via one-way doors; for going from the resting to the feeding area there should be a selection system with one exit to the milking parlour and one exit directly to the feeding area. After entering the milking box the teat cups are applied one by one as described before. When a cup is fixed on the teat, 10 squirts are milked and then the pulsator stops in the rest phase of the pulsation cycle. A conductivity meter in the claw measures the conductivity of this presquirting from every quarter. The milk of this presquirting, and if necessary all milk of a cow, can be drained to a special second line for reject milk. After attaching all the teat cups and after measuring all conductivities, normal mechanical milking starts. Due to the system of applying single teat cups, there is the potential to individually remove the teat cups per quarter after the quarter milk flow falls to a value of 50 g/min. But so far we have not tested the removal of individual teat cups per quarter. In the latest version of the robot, only the quarter individual pulsator stops in the rest phase, when the milk flow decreases to the threshold.

By combining a linear system with a more or less conventional milking machine to an automatic teat cup applier, the robot is used only for attaching the teat cups. During milking and during teat cup removal the virtual robot can work on the next cow in another milking box.

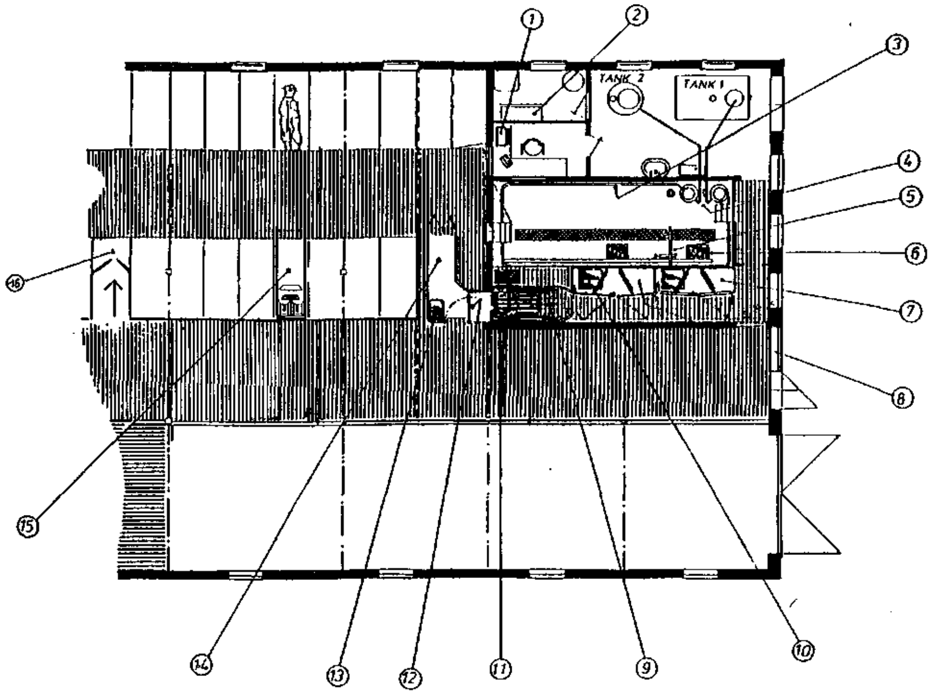


Figure 3. Recommended layout of a cowshed. 1 = controlling unit; 2 = Robot controlling system; 3 = two milking lines; 4 = two end units; 5 = robot; 6 = teat cup terminal; 7,8 = milking box; 9 = service box; 10 = formed floor; 11 = teat washing system; 12 = selection gate; 13 = cow identification; 14 = selection box; 15 = feeding box; 16 = one-way-gate.

Preliminary results

In spring 1989 the first cow was milked fully automatically by the Düvelsdorf milking robot. During the following months the test programme was extended to 6 cows, which were milked irregularly by the milking robot. In this period the cows were guided to the milking box by our staff. During 1990 the robot was installed on the experimental farm of the Institute for Milk Production in Schädtbek near Kiel. There the complete system was improved and adapted for an experiment with more than 40 cows over a whole lactation. This experiment started in December 1990 and was terminated 1 year later in December 1991. During the experimental period the complete hardware and software was tested, studies on animal behaviour were carried out and many values and samples were collected to give the first results for automatic milking with regard to milk yield, fat and protein contents, udder health (somatic cell count) and quality of cleaning.

During the experiment the hardware and software generally withstood the test. We had to change a pump for emptying the pressure line and to modify the drives for the milk tubes. To improve the results of attaching teat cups when the cow was moving in the box during teat location, a second ultrasonic sensor was installed to register the position of the cow.

Not all the results were as expected or as wished (Ordolff, 1989; Nuber, 1989). It seems, that an uncomfortable milking box which must be reached by a ramp, and a nonoptimal arrangement of different functional areas in the cowshed can probably reduce the frequency of voluntary visits. Values of milk yield and milk composition seem to be negatively influenced by the lengthy processes of taking samples, applying teat cups and stimulation in this experiment.

The preliminary results of monitoring udder health show that the status of udder health is not negative influenced. It seems, that the somatic cell count as a parameter for udder health can be reduced by voluntary milkings with a robot (Kremer & Ordolff, 1992).

Prospects

At the moment we are extending the system to a second milking and installing it on a commercial farm. A selection box at the entrance of the milking parlour, and a box for udder cleaning by rotating brushes between the entrance and the milking box are also being developed and will be installed. The time taken to apply the teat cups could be reduced by improving the software of the controlling unit. Work on this should have started in spring, but unfortunately were delayed until autumn this year. It now seems that the Düvelsdorf milking robot will start work under practical conditions on a normal farm early in December 1992.

References

Dück, M., 1991. Funktion und Möglichkeiten des Melkroboters. VDI/MEG Kolloquium Agrartechnik 10:65-68.

Düvelsdorf & Sohn GmbH & Co. KG, 1989. Deutsche Patentanmeldung 39.31.769.

Kremer, J.H. & D. Ordolff, 1992. Experiences with continuous robot milking with regard to milk yield, milk components and behaviour of cows. In: A.H. Ipema, A.C. Lippus, J.H.M. Metz & W. Rossing (Eds.): Proceedings of the International Symposium on Prospects for Automatic Milking, EAAP publication No. 65, Pudoc Scientific Publishers, Wageningen, The Netherlands, p. 253-260.

Nuber, B., 1989. Simulationsstudien zum automatischen Melken. Thesis, University Hohenheim p. 75-78.

Ordolff, D., 1989. Voraussetzungen und Grundlagen automatischer Milchgewinnung. Habilitation University Hohenheim, p. 111-133.

Scheidemann, B., 1990. Ein kartesisch arbeitender Melkroboter - Aufbau und Erfahrungen. In: Robotereinsatz in der Landwirtschaft am Beispiel des Melkens; Tagung Braunschweig-Völkenrode. VDI/MEG Kolloquim Landtechnik, Düsseldorf, Germany 9:221-227.

Robotic milking system (RMS): design and performance

R. van der Linde & J. Lubberink

Gascoigne Melotte B.V., Gildenweg 2, 8304 BC Emmeloord, The Netherlands

Summary

In 1981 Gascoigne Melotte decided to start a development leading to a complete automation on dairy farms. During 1984 this GM 2000 system started its completion by initiating the R & D of the Robotic Milker System (RMS). The state of development at the moment is, that since December 1989 the RMS has been milking over 25.000 cow milkings realized at the Waiboerhoeve, a Livestock Experimental Station at Lelystad, the Netherlands. A similar model has been installed at the Clarksville Research and Education Centre, Maryland State, USA.
Keywords: Robotic milker, pneumatics, pre-identification, teatcup positioning, preparation brush, sensing devices.

Introduction

It started in 1983, the year in which Gascoigne Melotte decided to take on a project to create a machine that attaches clusters automatically.

The Gascoigne Melotte R&D department had been successful in producing a development philosophy during the previous years regarding on-farm automation based on individual cow identification consisting of a computerized feeding and milk yield registration system connected to a management program. The development of a robotic milker was a logical next step. The name for the entire lay-out is GM 2000 consisting of (Figure 1):

- GM milking technology;
- ID 2000 computerized feeding system based on individual cow identification;
- MR 2000 milk yield registration system;
- FM 2000+ Dairy farm management program.

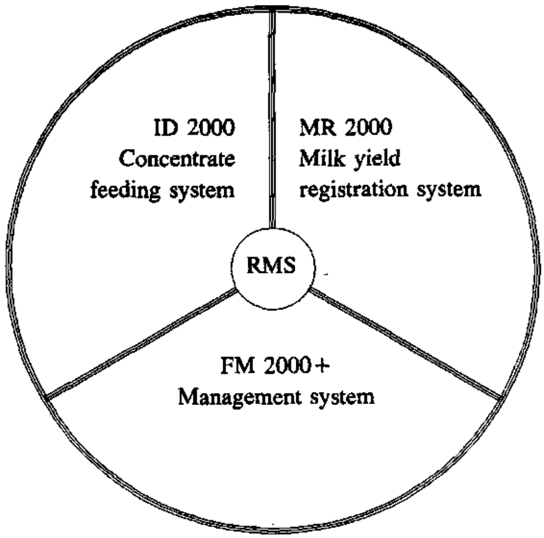


Figure 1. The Gascoigne Melotte Robotic Milking System as an integral part of the GM 2000 system.

GM Milking technology

For their milking systems Gascoigne Melotte have designed lately non-polluting vacuum pumps, high capacity milk pumps, big bore vacuum- and milk pipelines, pulsation systems, high performing liners and claw pieces. Parlour automation such as gentle cluster removal systems, cow traffic systems and an electronic milkmeter based on the Archimedes law.

ID 2000 feeding

The ID 2000 feeding station fitted with an aerial loop identifies each animal wearing a transponder. The latest version of this identification device is an implantable. The system acts as an information store, is IBM compatible and works independently so that the PC is not on-line and thus liberating it for other tasks such as wordprocessing or bookkeeping.

MR 2000 milk yield registration

Recording of milk yields may be done manually in the parlour according to the recorderjar-reading using a MR 2000 display- and keyboard box. For automatic recording a milkmeter is needed. The display- and keyboard box is equipped with a number of LED's warning lamps to communicate important attention facts to the milker.

FM 2000+ management program

The FM 2000+ management program is a software package developed to the specifications of a standard information model of the Dutch TAURUS organization. The FM 2000+ includes information functions and disciplines required to aid the manager of the dairy farm and is developed for all IBM compatibles with a 10 MB harddisk at least.

General

Each part of the system will work independently from the others. Therefore it is not important with which part of the system one starts. Each separate part can be integrated to what already exists.

The Robotic Milking System (RMS)

December 4, 1989 was the first day that the RMS milked a cow without the help of a milker. Ever since the system has been milking nearly every day. At the moment the RMS has been working for about one thousand days. About 25 000 cow milkings have been realized until now. The number of cows being milked during the past 3 years has varied between 3 and 16. There were periods when cows were milked 3 times per day or that cows could frequent the RMS at free will, during which time one cow visited the RMS 6 times per day.

This practical experience has had a positive effect on the design and the development although there are still parts of the system which need to be refined. The technical concept has proven itself sufficiently.

The Robotic Milking System is a single unit module consist ing one milkstation for milking one cow at a time. It is especially developed to fit into a normal loose housing barn and for small as well as large farms.

The capacity is estimated to be 100 milkings per day per unit. Depending on the state of lactation the number of milkings may vary between 1 to 4 per day meaning that a Robotic milker would be able to milk about 30 to 40 cows per day.

From the cow's udder the milk passes through the milkmeter and is kept in a collecting jar until the cow has finished milking. Quality is checked electronically. In the case of good quality the milk is transported through a precooler into the bulktank at a temperature of 4 degrees C.

If however the milk is contaminated it is rejected and pumped from the holding jar into another vessel. If the quality is acceptable it can be applied for other purposes e.g. feeding calves.

The system will not accept cows during the wash-periods. Number of washings can be variable but will be standardized on 3 times a day.

A short rinsing-cycle is provided to wash only the cluster, milkmeter and holding jar after milking an animal treated with medication.

Characteristics of the RMS

All moving parts are controlled by compressed air for it is fast acting, easy to install because of its flexible connection tubes and not disturbing to electronics.
Furthermore it is non polluting.

Each RMS unit consists of 1 master- and 4 slave controllers. In case more RMS units are used for one herd of dairy cows, all master controllers are connected to a maincontroller. A multitasking program takes care of controlling all RMS units. The PC (with a capacity of at least 10 MB) may be used for other tasks (e.g. wordprocessor, bookkeeping) without interfering with the RMS control.

Pre-identification

For admittance to the holding pen the pre-identification selects cows to be milked from the ones presenting themselves too early for milking. The latter ones are guided back to the herd. Most cows seem to wear a biological watch since experience teaches us that they present themselves nearly always on time.

After the loop identification the cows to be milked are admitted into the holding pen. To avoid overcrowding, the manager can set a maximum, meaning that cows to be milked can be guided back to the herd when there are too many cows already in the holding pen. This is to avoid long waiting periods.

Milking station

The Milking Station is equipped with an entrance- and an exit gate. Depending on the circumstances, gates may be fitted either on the left or the right side of the milking box. Once a cow is inside the station it will be identified again as due to the holding pen, cows may not present themselves in the same order. After identification, feed will be dispensed as in the ID 2000.

Adjustment of the length of the box along with the vertical adjustment of the manger is a feature to comfort the cow during her presence in the box.

As the udder is approached from behind the hindlegs are spread by upwards moving footplates to enable the passage of the brush- and cluster assembly. This also reduces the risk of kicking the cluster (Figure 2).

To position the udder correctly the cow is gently centred by two plates located on both sides of the pinbones and another pair of plates on the sides of the animal. However cows are able to move as they would do in a herringbone parlour.

- Identification
- Start feeding
- Moves forward
- Position legs
- Position legs
- Position cluster prtection

- Udder preperation with rotating brush

- Milking
- Measuring milk
- Conductivity
- Milk yield recording

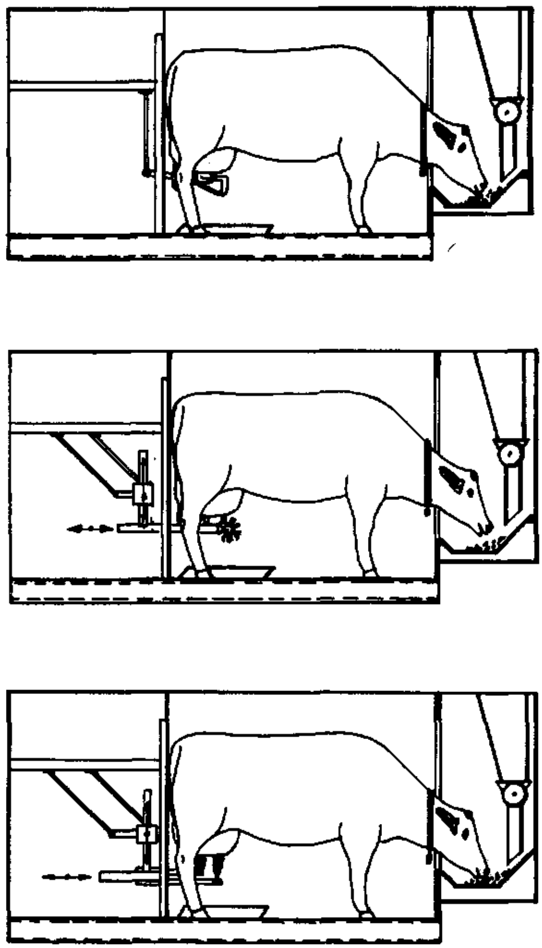


Figure 2. Preparation and milking.

Attachment arms for udder preparation and milking

Udder preparation

The cleaning and preparation of udder and teats must be carried out separately. This is to avoid the risk of contaminating the milk with traces of dirt and foremilk. Therefore the RMS is designed with separate devices for preparing and milking consisting of two robotic arms: one for tracking the udder preparation brush and the second for the cluster assembly. The brush is automatically positioned by the setting of the cluster. (see Cluster attaching).

The system features a program which follows the contour of the udderbottom. The brush passes the udder at an adjustable number of times. Using water is an option. By experience it is now known that passing the brush 6 times back and forth and applying water onto the brush during the first stroke give acceptable results.

A study was carried out to investigate the effect of the cleaning efficiency of the brush. A paper will be presented during this symposium with details of the results.

Udder approach

The cluster approaches the udder from behind and between the hindlegs. This is considered the safest for the equipment. This was also experienced in side by side parlours when compared to herringbone- or tandem parlours. A result of this approach is that little or no sensing devices are required to position the cluster as this approach brings the cluster directly under the udder and in immediate proximity of the teats.

Cluster attaching

The RMS attaches the cluster using the pinbones as a reference to locate the udder. This is done by means of a vertical plate that is held lightly pushed against the hind part and therefore constantly following the animal in her lengthwise movements. The X and Z co-ordinates of the cluster are stored in the computer's memory. The cluster position is realized by using LED's.

For positioning the teatcups the teat co-ordinates are stored in the computer's memory as well. This is a very direct way of attaching. The teat co-ordinates of a cow may vary slightly from day to day. Therefore a preprogrammed correction can be performed by the computer. Automatic teat location will be more accurate when a correction per cow is made by the system on a continuous basis. This is part of our ongoing development.

Originally the positioning of the teatcups was also done by using LED's, but as being very susceptible to muck, water etc. they have lately been replaced by a hallswitch system. After activating the air-presscilinders of any of the teatcups either in the X, Y or Z direction, the teatcup stops at the required position. The system also provides the option to localize the teatcup any moment after attachment which is important to detect whether the teat had moved the teatcup. The system may use this information for updating the position for the next attachment.

Teat attachment

In order to compensate for any axial misalignment of teat and liner, the latter is equipped with an inflatable ring that swells under airpressure to reduce the linermouth aperture from 70 to 30 millimetres at the moment that the teat is just entering. This has the effect of centring the teat and the venturi action of the air being drawn in by the milking vacuum ensure a clean penetration.

The advantage of connecting the teatcups using an active system is that it allows the animal to move, within certain limits. As the cows are fed in the milking station teats are always moving. Small movements however do not interfere with the attachment of the teatcups. An advantage is that all teat-cups are attached simultaneously thus equalising milking time.

The system allows for 3 attempts to attach the cluster. Should it then fail the cow would be allowed to leave the milking station and the farm manager will be warned.

Milk transport

In order to avoid the increase of lipolysis the design of the RMS keeps the milklines as short as possible. The milk is transported as a solid column from collecting jar to milkpump assembly.

Sensing devices

With robotic milking sensing devices are indispensable. The RMS therefore is provided with mastitis- and temperature detecting sensors. Detection of developing udder inflammation is shown up at an early stage. The farm manager will be alerted by the system and he can decide whether the milk is to be added to the bulktank or to be rejected.

It is also necessary to detect the milking vacuum level, the level of airpressure for the RMS pneumatics, the milk flow per quarter (to detect whether a teat is producing milk) etc. The system is also provided with an error display system to check the function of each part of the RMS. According to the type of error there will a print-out warning or in urgent cases a audible alarm.

Profitable investment?

A major consideration at the outset of any development project is the return on investment that the product will eventually represent. This will give economists an interesting exercise but while we await their evaluation our thoughts are these.

Trials indicate an increase of milk yield when cows are milked 3 or 4 times per day. We can anticipate a 10 to 15% increase in yield when using a RMS. In most good commercial farms this would mean approximately 800 kg of milk per cow per lactation. Part of this extra value is needed to cover the extra costs of feeding and other expenses. The other part makes the acquisition of a RMS attractive especially when the dairyman who is contemplating a parlour update will already have to spend an appreciable sum to equip himself with a state of the art parlour, feeding and management system. His possibility of choice is now wider since for his cows the RMS option compares with a fully automated parlour.

In case of fixed milk quota, cow numbers may need to be reduced due to improved individual performances and to remain within quota limits. This reduction in numbers also reduces the general overheads such as veterinary fees, manure handling, housing etc. More time is liberated for the dairyman to attend to the profitable running of his farm; surely a good investment.

Conclusion

Whether cows are attracted by the concentrate feed or by the comfort derived from the relief of pressure in the udder, we now know that they accept robotic milking. The trial, in which cows could enter the RMS by their own free will, confirms that the prospects for robotic milking are very hopeful.

Since January 1990 there has been a regular check on milk quality. Somatic cell counts have averaged 150 000 and sometimes have been below 50 000. When operating normally Total Bacterial Counts were around 8000, but readings well below this to a minimum of 600 were frequent. From these results it can be deduced that "robot" milk can be of high quality.

The social aspects are also of substantial importance. When equipped with robotic milking the farm manager does not need to milk at fixed unsocial hours. And will benefit from more flexible use of his time, improving his quality of live.

The development is not finished yet. However the experience of the last 3 years indicates that RMS milking is possible and will be available for dairy farms within a relatively short time.

Automatic milking: reality

J. Bottema

Prolion Development, Kromme Spieringsweg 289-B, 2141 BS Vijfhuizen, The Netherlands

Summary

Automatic milking is now becoming reality. Five Prolion automatic milking systems are currently (August 1992) working daily, milking approximately 150 cows automatically. For these systems to function, various choices had to be made. To be able to score the performance of the systems an AMS-performance routine had to be created. The systems are now achieving 90 to 100% automatic milking.
Keywords: automatic milking system, robotic milking, performance, adaption, implementation, milking frequency.

Choices

After several years of development automatic milking is now (August 1992) reality on 2 experimental farms and 3 commercial farms. If it is to work on a farm not only does the AMS have to have a good attachment system, but it also must be a total system. Several choices had to be made:

- Cow friendliness. Since the cows should return unprompted they have to be treated in a friendly and gentle way. This means no active fixation.
- Sensing udder and teat position. A cow always needs to be able to move. A sensing system controlling the attachment robot is necessary to locate and follow her. Teat positions are unpredictable. They always have to be measured.
- Automatic milking is much more than attachment, it has to be a total system, handling and controlling the total milking process.
- The automatic milking system has to be able to interact with cow behaviour. It should not only handle the ideal situation but also has to be able to cope with less than ideal (i.e. realistic) situations. This means it has to be an intelligent system.
- Automatic attachment means knowing whether a handling has been successful, and retrying if necessary. Retrying can involve re-checking teat positions, or making more attempts to attach an individual teat cup.

- Automatic milking does not mean an unmanned farm. We want the farmer to check the system and his herd at least twice per day for half an hour. If necessary, the system will alert the farmer to come and check. This should not happen more than once a month.
- The "window principle" (Figure 1) has been introduced to make the daily routine in milk frequency clear to cow and farmer. This means the farmer has to decide which cows should be milked three times per day, and which cows should be milked twice.

  The milking interval of the cows milked three times is scheduled at the most optimal interval (8 hours). Cows milked twice are scheduled at unequal intervals, as is common practice nowadays.

  During the day there are time windows in which the cows should be milked. This enables a cow to be milked every day at almost the same time. The farmer has an easy overview of the cows' attendance.

Time windows for milking 3 times a day:

4:00 h 7:00 h 12:00 h 15:00 h 20:00 h 23:00 h

Time windows for milking 2 times a day:

7:00 h 10:00 h 17:00 h 20:00 h

Moments for sercvice:

10:00 h	15:00 h	23:00 h
System cleaning	System rinsing	System cleaning

——— not to be milked

═══ milking moments (windows)

Figure 1. Window principle. Milking moments (time windows) for a 80-cow herd with 40 cows milked 3 times a day and 40 cows milking twice a day with a 2 stand AMS (average capacity 14 cows/hour).

- To prevent cows that have just been milked from lying down immediately after milking, they should be led to food after leaving the AMS. Prior to milking the cows may have been in a lying area, or outside (pasture). Pasturing fits very well into milking by the window principle.

- The AMS first priority is to be a milking system: this means the amount of concentrate given has to be limited, and it is not a farm management system. It supplies the farmer with information and warnings (management by exception) about the milking process.

Most of this information fits the Taurus protocol (e.g. milk yield, mastitis detection, temperature). Other information, such as milk frequency and moment of milking are, so far, strictly AMS and have not yet been incorporated into the Taurus protocol.

- To be fitted into the on-farm infrastructure some processes have to be adapted to the AMS routine (such as the milk collecting system, production control and cow traffic).
- The commercial goal is to have farmers buying such a system. The farmer must be able to handle the system: he must know how to operate it, obtain the information required and intervene if necessary. Of course, the price of such a system has to be compatible with the price of alternatives.

On farm

An automatic milking system (Figure 2) is installed on the IMAG-DLO experimental farm. IMAG-DLO does a lot of research on cow behaviour and on farm implementation and has checked the sensing performance of the system, model 1990, too (Hogewerf et al., 1992).

A second AMS has been installed on Prolion's own test farm, where a small herd of approximately 15 cows is kept. Technical innovations are tested here in collaboration with the R&D and marketing departments.

Three systems have been installed on commercial farms. They are total systems in which the whole milking process is arranged and controlled. They comprise 2 stands with one attachment robot (including e.g. vacuum pump, compressor, water heater, system to cool milk to 4 °C, milk separation system, teat cleaning system, dimensions: 7.50 m × 2.40 m; see also Figure 2).

Since the milk flow should be directed downwards, and the entrance of the cows should be easy, a small pit must be constructed to hold the milking equipment of the AMS.

All systems on commercial farms were installed in May/June 1992. After a careful start they are now totally integrated into the daily farm routine. On all three farms the cows are milked twice per day. Milking is done automatic, but under guidance of a system supervisor. This ensures all necessary feedback is gathered.

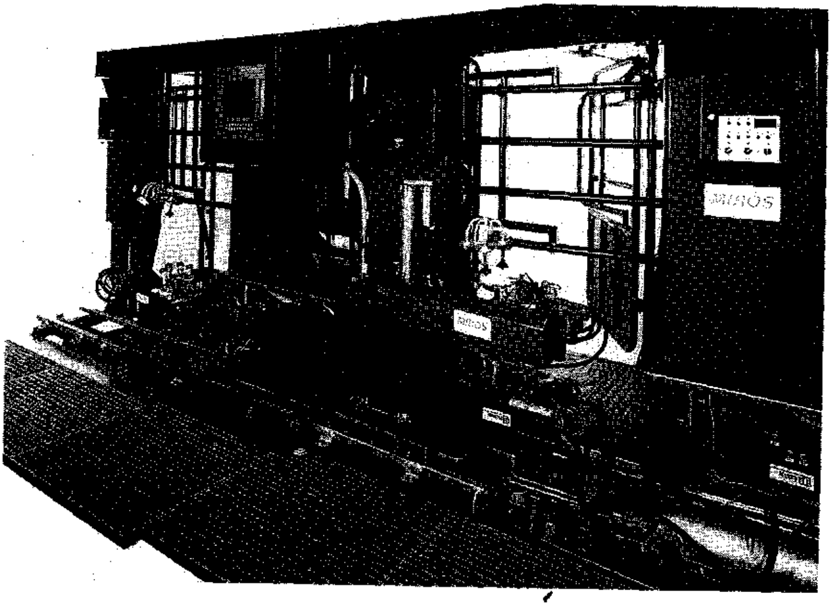


Figure 2. Overview of the automatic milking system.

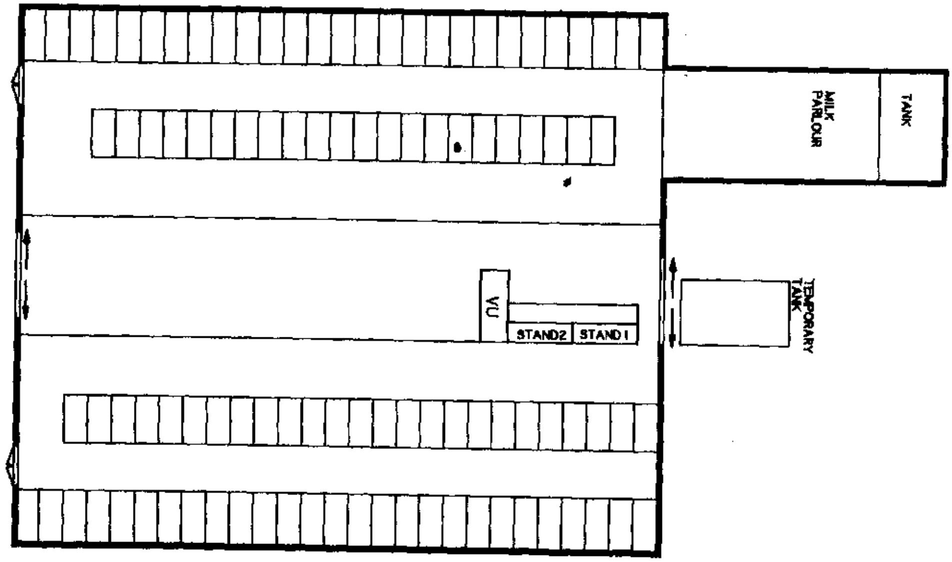


Figure 3. Layout of the cubicle house with AMS system 1 installed in the feeding alley.

System 1

This system was installed in May in the feeding alley of the cubicle house (Figure 3). The herd was split into two groups of approximately 45 cows. Both groups had their own milk tank. This enabled "conventional" milk to be collected separately from "automatic" milk. Three times per week the quality of the milk of both tanks is checked and compared on cell count, bacteria, freezing point and acidity of fat (Table 1).

Table 1. Milk quality of "automatic" milk and "conventional" milk. CC = Cell Count (× 1000 per ml); BC = Bacteria Content (× 1000 per ml); FP = Freezing Point (°C); AF = Acidity of Milkfat (meq. per 100 g of fat).

	Automatic				Conventional			
Date	CC	BC	FP	AM	CC	BC	FP	AM
17/8	159	9	-0.509	0.39	189	6	-0.511	0.53
18/8	151	17	-0.526	0.51	467	4	-0.512	0.75
20/8	121	4	-0.522	0.43	179	2	-0.518	0.57
24/8	143	11	-0.519	0.41	177	18	-0.515	0.60
25/8	269	39	-0.525	0.41	141	2	-0.515	0.54
27/8	112	6	-0.514	0.44	180	1	-0.517	0.52
31/8	137	3	-0.529	0.43	195	6	-0.505	0.61
01/9	214	8	-0.517	0.35	169	7	-0.512	0.42
03/9	126	13	-0.518	0.36	194	2	-0.512	0.52
05/9	115	13	-0.518	0.34	175	4	-0.518	0.56
08/9	192	17	-0.521	0.37	125	8	-0.512	0.55
10/9	108	9	-0.516	0.43	215	8	-0.512	0.47
14/9	141	4	-0.521	0.42	219	6	-0.512	0.55
15/9	141	4	-0.524	0.34	211	5	-0.525	0.57

Initially there were some problems with bacteria due to poor connections in the milk lines and the shape of the rubber rings. After these were solved no further problems arose.

In September the AMS was moved to a brand new cubicle house, where no alternative milking installation is present (Figure 4).

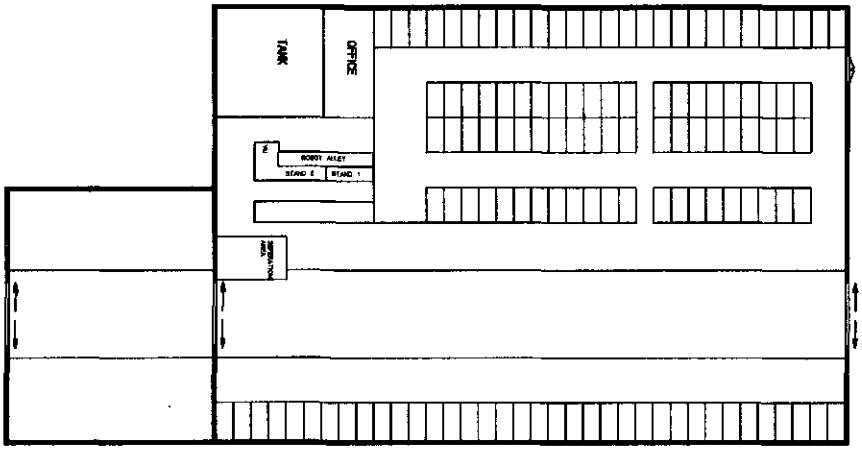


Figure 4. Layout of the new cubicle house with system 1 and no alternative milking installation.

System 2

On this farm the system has been installed in the former double 4 herringbone parlour (Figure 5). One side has been rearranged to accommodate the AMS. In the start-up period the cows were milked on the remaining side of the herringbone parlour and in the AMS. Since August all cows have been milked in the AMS.

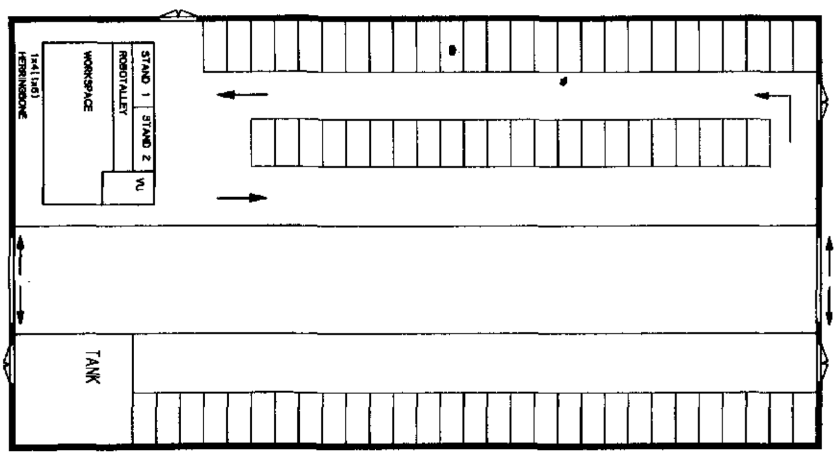


Figure 5. Layout of the cubicle house with the AMS system 2 installed in the former double 4 herringbone parlour.

System 3

On this farm a new cubicle house was erected to supplement the existing cubicle house. A special area was created for the AMS (Figure 6). Almost 40 cows are milked automatically. This number is increasing steadily.

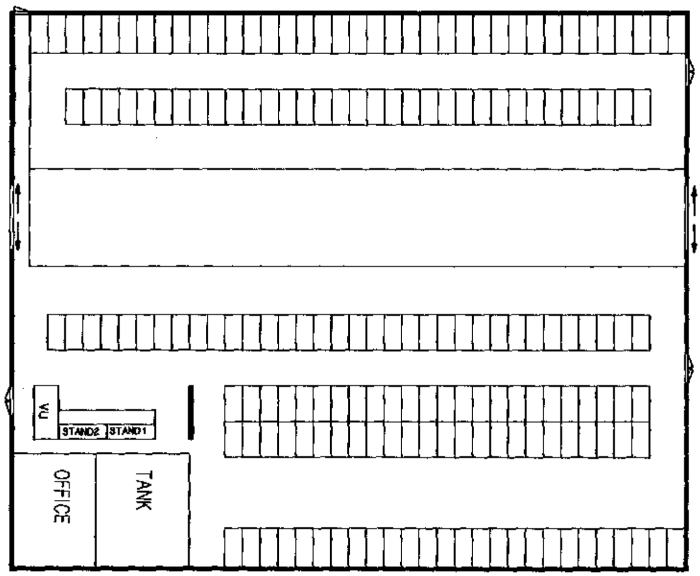


Figure 6. Layout of the cubicle house with AMS system 3.

Cow criteria

Before installing the AMS the herds on the farms were checked on udder shape and teat positioning. The AMS should be able to milk at least 85% of today's herd, but does not have to be able to automatically attach teat cups to cows with extremes in udder and teat positioning. The cows were checked on the following criteria:

- height;
- distance between front teats;
- distance between rear teats;
- angle of teats;
- general imbalance (rear teats at different height than front teats);
- individual imbalance (one teat at different height);
- teat length.

Cows that fit all the criteria are considered to be green cows (i.e. suitable for automatic milking). If a cow does not fit the criteria she is considered to be a red cow: not to be milked automatically (can be milked in AMS, though with manual attachment). Some cows vary in score from green to almost red, or score red on one criterion. These are considered orange cows. They might be totally green, when milked three times per day, or small system improvements might put them into the green category.

The three herds vary from 85 to 93% green cows. The criteria are regularly evaluated, and modified if necessary.

Installation and implementation

Before an AMS is installed the farmer has to have provided the general conditions stipulated in the pre-installation manual. A system is installed and connected in two days, then checking can start. A week after installation, implementation can start. This is done by starting with 5 cows and regularly adding more cows to the AMS herd. In general the cows soon become used to the system; in two to four days they are reporting unprompted.

Initially problems occurred due to software bugs and improperly functioning components. These problems have been solved now. Some modifications for obtaining improvement have been tested on Prolion's test farm and have already been installed on the farms or will be soon.

Few problems of breakdowns have occurred. In general, the cows are at ease, and when they kick they do no harm. The Prolion service organization is on 24-hour standby to solve problems when necessary.

Performance

To measure performance a routine had to be developed; the following items are part of the performance measurement:

- way of attachment: automatically, minor manual help or manual;
- number of attempts needed for attachment, in which every movement above minimum (1) is considered an extra attempt.

Minor manual help means help in attaching one cup, usually because too much time has already been taken. After final adjustment this will no longer be necessary.

The system supervisors have to enter a score for each milking into a special computer program. Once a week these data and all other feedback are evaluated.

As regards performance 85 to 95% of all milkings of the green herd are now totally automatic. There are occasional 100% scores. The average number of attempts required for attachment varies from 1.5 to 2.2. The upcoming modifications will bring the performance closer to a consistent 100%.

As regards capacity, the two stand systems have reached an average of 12 to 14 cows per hour (very productive cows). The highest capacity reached was 19 cows per hour. So far the cows have always been milked in the AMS and have never returned to the traditional parlour.

Continuation

The results of the last months have given Prolion confidence to continue their commercial efforts to have more systems installed in 1992 and the beginning of 1993.

Combining knowlegde and technology is the key issue in developing an automatic milking system. Collaboration with centres of expertise is essential to achieve success. In collaboration with institutes, new research plans are being made in which not only Dutch institutes but also other European and North American Institutes are participating (e.g. Eureka project CIMIS with IMAG-DLO, Manus-Holland, Sagem, Cemagref, Diablo Manus and Prolion). It will be most interesting for this project to succeed by cooperation between companies, institutes and farmers. In general this will lead to even more research needs and opportunities, involving exciting and, hopefully, new partners.

As regards market acceptance, it is clear that an automatic milking system performing well and sold at the right price creates a market demand.

References

Hogewerf, P.H., P.J.M. Huijsmans, A.H. Ipema, T. Janssen & W. Rossing, 1992. Observations of automatic teat cup attachment in an automatic milking system. In: A.H. Ipema, A.C. Lippus, J.H.M. Metz & W. Rossing (Eds.): Proceedings of the International Symposium on Prospects for Automatic Milking, EAAP publication No. 65, Pudoc Scientific Publishers, Wageningen, The Netherlands, p. 80-90.

Field trials of the Silsoe automatic milking system

C.J. Allen, T.T. Mottram, A.R. Frost, M.J. Street, R.C. Hall & D.S. Spencer

AFRC Silsoe Research Institute, Wrest Park, Silsoe, Bedford, MK45 4HS, United Kingdom

Summary

An experimental milking parlour has been developed by Silsoe Research Institute to test elements of automated milking. Ten cows were milked three times a day for twelve days. A pneumatic robot attached teat cups in series by means of a two stage operation. After picking up the teat cup it was driven to a teat position co-ordinate stored for each cow at the beginning of the trial. Attachment was completed by moving the robot so that the position of the teat in a sensor array was central over the teat cup to which vacuum was applied. The legs of the cow were unrestrained, although the posture was modified by means of a 200 mm step beneath the front feet. On 66% of cow visits all four teat cups were attached successfully. Of the 1440 attempted teat cup attachments 84% were successful, and there were only 21 collisions with the cows' legs. The reasons for failures are analysed and strategies to improve reliability are discussed.
Keywords: automatic milking, robotic, pneumatic, cows, milking.

Introduction

The development of automatic milking has moved on from speculation about its possibility to the development of reliable techniques, as shown by papers at this conference and by Schillingmann & Mottram (1992). Street et al. (1992) reported the development of the Silsoe Research Institute automatic milking system which uses a pneumatic robot, cow position monitoring, stored teat position co-ordinates and an LED sensor. This system relies on the fast dynamic response of a compliant robot arm to attach teat cups in series to the teats of a cow restrained by passive means. Mottram (1992) demonstrated that passive methods could induce a cow to stand in postures which would improve the accessibility of the rear teats. Only limited progress could be achieved until facilities for experimental work with significant numbers of cows were commissioned by Silsoe Research Institute in 1991. Engineering development had reached a stage where it became possible to test some key features of the system.

The objective of this experiment was to test some of the underlying assumptions of the Silsoe Research Institute automatic milker. First, that the method of teat location, dynamic tracking of the cow movement, and teat cup attachment operated satisfactorily. Success was described in terms of the percentage of attachments successfully completed. Secondly, that teat position co-ordinates would remain valid for more than a few minutes. This could be assessed by recording the teat positions at which successful attachments were made and determining any trend over time. Finally, that passive posture methods would allow teat cup attachment, this being assessed by the number of collisions between the robot and the legs or body of the cow. In addition, the possibility of the cow preventing the milking process by kicking off teat cups or becoming entangled in the milking pipelines needed to be assessed.

Materials and methods

Twelve cows were drawn at random from a group of 30 late (8th month) lactation Friesian Holsteins. They were of various ages (between 2nd and 9th lactation). One of the cows was rejected because the rear teats were touching each other, previous experience having indicated that this would make teatcup attachment very difficult. Another cow was rejected arbitrarily to leave 10 cows for the trial. None of the cows had previously been milked by the automatic system. Late lactation cows were chosen because their udders are well hidden by the legs and there is little turgid pressure to displace the teats at intervals between milkings.

The cows were introduced to the system three days before the trial. First with the gates open to allow free passage from the preparation stall back to the collecting yard (Figure 1), they were driven through nose to tail. Each cow was then made to pass through the system once on its own, stopping in the milking stall to receive some concentrated feed and to have a transponder attached for identification purposes. The day before the trial was started each cow was again made to pass through the system once, again stopping in the milking stall, but on this occasion the robot was taught the positions of each cow's teats while the cow ate concentrates. The feed trough was positioned to ensure that the cow registered in the mid range of the cow position sensors, the feed trough position was stored for each cow.

The cows were kept in a yard bedded with straw adjacent to the collecting yard for the duration of the experiment. They were collected manually before each milking session. The cows received a bulk ration of silage in the bedded area and 500 g of concentrate feed at each milking. The willingness of cows to volunteer to pass through the system was not tested, if they failed to move from one point to another the supervisors ensured that they did so. For example, it was frequently necessary to persuade cows to leave the milking stall after milking.

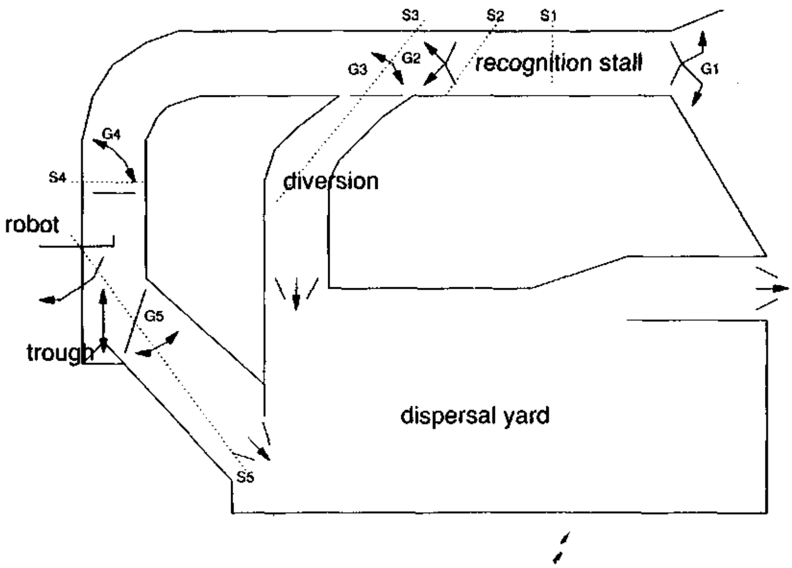


Figure 1. Schematic plan view of the Silsoe Research Institute automatic milking development system (not to scale).

The robot and its operations are described in detail elsewhere (Street et al., 1992). The robot was trained manually by being steered to each of the teats of every cow and the co-ordinates recorded. Two sets of teat and body positions were collected for each cow. One was collected 6 hours after milking and the other 12 hours after milking. The robot controller used these stored teat positions to give a starting point for each teatcup attachment. The set of co-ordinates used at each milking depended upon the time interval since the last milking. During attachment the body position was used to calculate an offset from the stored positions. By the end of the trial teat positions were being used which had been recorded 14 days previously. Database features of the Silsoe Research Institute system are reported by Spencer & Street (1992).

Milking of the cows commenced at 07.30 h, 13.30 h and 19.30 h daily, milking intervals were of 12, 6 and 6 hours respectively. For each animal at each milking the sequence of events was identical. The entry gate to the preparation stall (G1, Figure 1) opened automatically to admit a cow, all the other automatic gates remaining closed. Each cow had a transponder collar and was identified by the system as it entered the recognition stall. The presence of the cow in the recognition stall was detected by a reflective photocell (S1, Figure 1). A delay of 60 s allowed the cow's teats to be examined and cleaned manually, and a sample of foremilk was taken and inspected for signs of mastitis. Gate G3 and photocells S2, S3 which control the passage of the cow through a diversion race were not used in this trial.

The recognition stall exit gate, G2 and the milking stall entry gate G4 both opened, allowing the cow into the milking stall, simultaneously the feed trough was moved to its rear position and a small amount of feed dispensed. As the cow entered the stall it interrupted light beam S4. The trough then moved forward drawing the cow onto the step. When S5 detected the presence of the cow in the stall and S4 was clear, gate G4 was closed. The trough was moved to the stored position for the individual cow. Feed was dispensed to the cow in a slow trickle for 300 s to keep the cow's head in the trough and her body position relatively constant.

With the cow in the stall the robot began its operating sequence (Street et al., 1992). Obstructions of the LED matrix were checked automatically, the body position sensors moved to make contact with the cow and the robot arm moved from the parked position to attach the teatcups. The robot took the teatcups, one at a time, from a magazine and attached them to the teats in the order left rear, right rear, left front, right front before returning to the parked position. Vacuum and pulsation were applied as soon as the teat cup was removed from the magazine. The teat cup was released from the robot gripper when the vacuum in the milk line indicated that the teat cup was sealed. After attachment the teat cups hung free with milk and pulse pipes hanging in a loop to the teat cup magazine. Each teat cup was removed individually when cessation of flow was registered at any time after a 90 s let down delay. When all of the teatcups had been removed the teats were sprayed with a proprietary teat disinfectant, gate G5 opened and the trough moved to its extreme forward position. The exit of the cow into the dispersal yard was registered by S5 and the system prepared for the next animal.

Comprehensive data were collected so as to analyse causes of failure. At each milking the feet positions, teat visibility, attachment success were manually recorded. The system automatically recorded the cow identity, the time of entry, the time taken to attach each teat cup, the co-ordinates at which successful attachments were made and the time of exit from the system. When a failure occurred a detailed sheet was used to record the mode of failure.

Results

Failure to attach a teatcup was classified into one of three categories; operational failure, conceptual failure, and positional failure. Operational failure was an element of the system failing to perform the task for which it was designed. For example, a failure due to a mechanical breakage, or a computer crash would have been placed in this category. A conceptual failure was defined as one which was caused by an occurrence which the system was not designed to accommodate. The causes of failures in this category included: spurious teat location signals caused by a continuous stream of milk issuing from the teat and obstructing the light beam matrix, spurious teat location signals due to collision with the front edge of the leg, or the teatcup entering the light beam matrix, a teat being beyond the reach of the robot and the inability of the system to recover from kicks administered by the cow to certain parts of the mechanism. Positional failure was defined as a failure of the robot to carry the teatcup to the correct position for attachment to the teat, for no apparent reason. These failures could have been either operational or conceptual. On the majority (68%) of occasions cows were successfully milked completely automatically. The percentages of visits during which given numbers of teatcups were attached are shown in Table 1.

Table 1. Percentages of visits during which given numbers of teatcups were attached (total number of visits = 360).

Number of teatcups attached	0	1	2	3	4
% of visits	3	6	9	14	68

Table 2. Percentages of successful and failed teatcup attachment attempts (total number of attempts = 1440).

Successful attachment	84%
Operational failure	6%
Conceptual failure	2%
Positional failure	8%

The total number of attempted teatcup attachments was 1440 (4 teats × 360 visits). The categories of successful attachments and failures are shown in Table 2.

There were 110 positional failures. Table 3 shows how they were distributed amongst the cows. The percentages of the failures that occurred with each cow are shown in ascending order.

Table 3. Percentages of positional failures that occurred with each cow, in ascending order (total number of positional failures = 110).

Cow number	1	2	3	4	5	6	7	8	9	10
%	2	3	4	4	5	11	12	12	13	33

The modal attachment time was 25 s per teatcup, and a typical total time for the entire attachment process was 2 minutes.

For 338 (94%) of the 360 visits to the stall the cows stood in the correct position, with their front feet on the step. Most of the 22 failures to stand on the step were in the first 4 days of the trial. In the last 8 days there were only 2 failures out of 240 visits. Both of the rear teats were visible on 297 (88%) of the 338 occasions that the cow stood on the step. Teat visibility varied between cows: one cow was responsible for 30% of the cases of obscured teats, whereas the teats of some cows were always visible when they were on the step. If the cow failed to stand on the step she was prompted to do so by the observer so as not to prejudice the attachment attempt.

Discussion

If it is assumed that all of the teatcup attachment positional failures were conceptual rather than operational, a total of 10% of attempts failed for conceptual reasons. The remaining 90% of attempts were either successful or failed for reasons which are easily understood and can be easily rectified. Operational failures should become less frequent as the milking system becomes more highly developed. Some of the causes of operational failure were identified during the trial and could be rapidly corrected after the trial. The high number of cows milked totally successfully indicates that failures tended to be grouped. After all it would be possible to claim 75% attachment success and not milk a single cow completely. When one teat cup failed to attach it was probable that attempts on other teats would also fail. This indicates that there was an offset error affecting all the teats on that particular occasion.

There are insufficient data from which to draw any firm conclusions regarding the distribution of positional failures amongst the cows, but it can be seen in Table 3 that one cow was associated with 33% of these. This cow did not apparently behave in a unique way in the stall, and did not present the robot with a particularly difficult tracking task, nor was the cow's udder peculiar in any way. It was however observed that on the 4 visits when at least 3 teatcups were not attached, the positions at which the robot attempted to attach the teatcups were all displaced approximately the same distance and in the same direction with respect to the actual teat position. All 4 of these occasions were during the morning milking session. This suggests strongly that the stored teat positions used for this particular cow for the morning milking contained an offset error.

Positioning of the cows was not rigidly controlled and the cows had considerable freedom to adjust the position of the feet and to support their weight by leaning against the sides of the stall. This may have been a factor in inducing positional errors. Whilst a change in posture might not have been indicated by a change in foot position which was recorded it might have affected the relationship between the movement of the body position sensors and the teat positions. Further experiments are required to determine whether the source of the positional errors is the cows posture in the stall.

A possible cause of the positional errors may be changes in udder morphology these may be predictable due to the turgid pressure of milk filling the udder between milkings. This was unlikely to be a problem on the trial as cows in late lactation where change due to milk fill is minimal were used at fixed milking intervals. Change in udder morphology may be less predictable being due to asymmetric forces imposed when the cow is lying. The effect of this was minimised because the cows were gathered and stood for some minutes before milking commenced allowing the udders to regain their normal shape.

The teat positions were recorded once at the beginning of the trial and yet the number of positional errors did not increase as the trial progressed. The total numbers of cows milked per day completely automatically did not diminish as the trial proceeded. It would have been reasonable to suppose that errors would increase with the length of time since the recording of the teat positions but this was not the case. Of course, it was not intended that a single set of teat positions for a particular milking interval would suffice throughout lactation. The robot would be trained with the co-ordinates of the cow's teats as she entered the system at the start of lactation. Thereafter a rolling average of the teat positions can be created, based on the positions at which the robot successfully attaches teat cups.

The trial provided some evidence to support the previous finding that the probability of the teats being visible is increased when the cow is standing with its front feet on a step. Mottram (1992) showed that an step of 100 mm would increase the visibility. It seems likely that the higher the step the greater is this effect. The visibility of the rear teats is a good indication as to the likelihood of the leg lying in the path of the robot. Of the 21 cases of contact, 16 occurred when the rear teats were obscured.

On 21 visits to the stall the robot collided with the cow's leg because it lay in the path of the robot. Any contact, however slight was regarded as a collision. The usual result of the collision was that the cow was prompted to move its leg, frequently this allowed a successful attachment to the teat. Sometimes the collision involved the cow's leg blocking the LED array at its mouth, this was registered by the robot system as the teat position. The action of the robot was then to move to try and centralise the perceived teat in the array by pushing forward. At this point the cow would usually move its leg away causing the LED array to clear, this then prompted the robot to make a second attempt. On the second attempt the robot would move the end effector to the stored teat position co-ordinate and restart the operation. The robot only made two attempts at each teat.

It seems likely that rarer modes of failure will be identified as the number of attachments increases. Total reliability is unlikely to be achieved when so many factors relating to cow behaviour cannot be controlled. The cows used in this experiment are probably not typical of the generality of cows because they are handled constantly for other experiments. There was little reluctance to enter the stall and few incidents where the cow was not milked out due to interference with the milk pipes. Further experiments may be needed to develop methods of dealing with kicking or premature removal of the teat cups. It is unlikely that attempts to actively control the cow's posture or leg position will be attempted as even where total control of the cow's body position is attempted, compliance cannot be guaranteed. For example, it would be better to detect the presence of a leg in the path of the robot and either wait for the leg to move or stimulate the cow to move its leg with a non-intrusive stimulus than to attempt to force the leg out of the path of the robot.

The failures that were clearly conceptual have indicated further areas where research and development are required. These include ensuring that the light beam matrix of the local teat detection system does not interpret spurious interruptions as being due to the presence of a teat, increasing the range of movement of the robot, and improving the ability of the robot to withstand kicks from the cow.

The occurrence of conceptual failures should also decrease as greater operating experience is gained and the system becomes more highly developed. However the unpredictability of animal behaviour means that there will always be the possibility of a novel set of circumstances arising which the system was not designed to accommodate. It will therefore be necessary to develop procedures for ensuring that anomalies are detected, and appropriate action taken. The action will clearly depend on the circumstances, but the possibilities include aborting and restarting the attachment process, releasing the cow and allowing it to return to the stall for another attempt, and summoning human assistance.

Conclusions

The Silsoe Research Institute automatic milking system can successfully milk 66% of cows automatically and attach teat cups to cows 84% of the time. Stored teat positions can be used for milkings at fixed intervals for several days in late lactation. Passive methods can be used to induce cows to stand in postures which do not obstruct the path of the robot to the udder in late lactation cows.

References

Mottram, T.T., 1992. Passive methods of modifying cow posture for automated and robotic milking systems, Journal of Agricultural Engineering Research (in press).

Schillingmann, D. & T.T. Mottram, 1992. Automatic milking; Development of a robot system and ultrasonic teat location, Journal of Aricultural Engineering Research (in review).

Spencer, D.S. & M.J. Street, 1992. The design of the management system for the Silsoe automatic milking system. In: A. Lippus & J. Metz (Eds.): Proceedings of the International Symposium on Prospects for Automatic Milking, EAAP publication No. 65, PUDOC, Wageningen, The Netherlands, p. 309-314.

Street, M.J., R.C. Hall, D.S. Spencer, A.L. Wilkin, T.T. Mottram & C.J. Allen, 1992. Design features of the Silsoe automatic milking system. In: A. Lippus & J. Metz (Eds.): Proceedings of the International Symposium on Prospects for Automatic Milking, EAAP publication No. 65, PUDOC, Wageningen, The Netherlands, p. 40-48.

Observations of automatic teat cup attachment in an automatic milking system

P.H. Hogewerf, P.J.M. Huijsmans, A.H. Ipema, T. Janssen & W. Rossing

DLO Institute of Agricultural Engineering (IMAG-DLO), P.O. Box 43, 6700 AA Wageningen, The Netherlands

Summary

Two of the tests carried out since the automatic milking system was installed on the IMAG-DLO experimental farm in 1990 are described. The first test (8 to 26 April 1991) involved 13 cows and the second (18 to 22 November 1991) involved 16 cows. They were milked three times a day (at intervals of 4, 8 and 12 hours). During these periods the system automatically recorded the coordinates at which teat cups were successfully attached and the time taken for attachment. At each milking attachment success was manually recorded. The success rate of attachment was 64% in the first test and 89% in the second test. The tests indicate that, at that moment, the automatic system was not suitable for all cows. It was possible to attach teat cups in less than a minute, but the mean time in the second test was three minutes. An on-line database with teat positions would help improve attachment procedure.
Keywords: automatic milking, reference sensor, fine sensor, teat positions, milking interval, robot.

Introduction

In recent years prototypes for automatic attachment of milking units have been developed in a number of countries (Anonymous, 1990). Although all these systems have the same aims (the complete automation of the milk process, to produce milk in an efficient way, taking human and animal welfare in account) the principles and the techniques used are different. In the mid-1980s IMAG-DLO started to develop an automatic milking system. Development was accelerating when IMAG-DLO embarked on a joint project with a development company. The first system developed by this company was installed in mid-1990 on the IMAG-DLO experimental farm. Before it can be introduced on commercial farms, this system has to be tested in a practical situation, to investigate: optimization of the technical performance, integration into the farm, animal welfare, capacity and cow specifications. Since 1990 IMAG-DLO has carried out various tests on these topics. This paper describes two tests which were necessary to find out about the system's performance, the cow specifications and the time needed for attachment.

Description of the system

The complete automatic milking system installed on the IMAG-DLO experimental farm comprises: two boxes where cows are milked and fed, a milk installation, a robot arm equipped with sensors for locating the teats and a milk rack with disconnection apparatus (Klomp et al., 1990). The tests focused on the performance of the sensors, the robot arm and the milk rack.

In the teat cup attachment system two sensor units search for the teats. The first unit (two ultrasonic sensors with diverging fields) has to find the front right teat as a reference. Therefore this unit is called the reference sensor. The second sensor unit, an ultrasonic sensor that moves up and down and has a rotating field, measures the distances and the angles between the teats and the reference teat. This sensor is called the fine sensor. Figure 1 shows the sensor positions schematically.

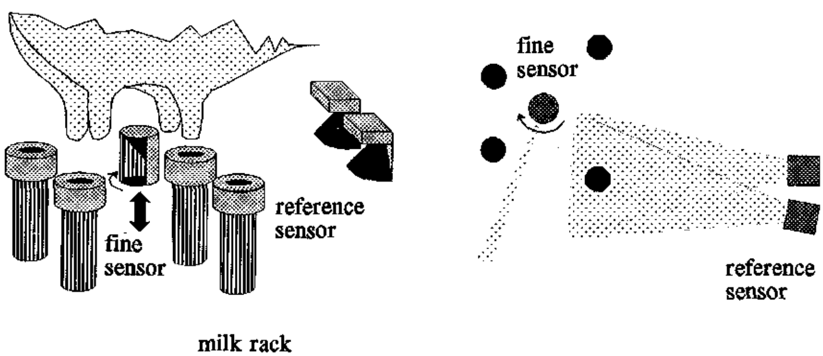


Figure 1. Ultrasonic sensors of the automatic milking system. Cow positioning according to Figure 3.

The robot arm and the working area of the tool centre point (TCP) of the robot arm are shown schematically in Figure 2. The TCP is the reference point of the robot control units, physically it is the point where the robot arm is connected to the milk rack. The movement of the TCP of the robot arm is restricted to the working area. The shape of the working area (see Figure 2) has been chosen so as to minimize the chance of hitting the cow. Point A is the rest position of the robot arm, point B is the rest position of the milk rack. When the robot arm is activated, it first moves from A to B and fetches the milk rack. Once the milk rack has been fetched the robot arm moves to point C. Between B and C the movement of the robot is restricted to a very narrow path. From point C the search for the reference teat (for instance, point E) starts with the reference sensor. When the reference teat has been found the system starts searching for the other teats with the fine sensor. During this sensing period the robot arm with sensing units follows the position of the reference teat (locking on the movement of the reference teat). The expected TCP position during this phase is in the middle of the working area. When all the teats have been found the attachment of the four teat cups begins. The teat cups are fixed to the udder by moving upwards and applying vacuum. The teat cups are put on the udder in the following order: right rear, left rear, left front and right front. Attachment is detected with vacuum sensors. During the attachment the teat cups are locked in a vertical position and are moved around with the robot arm. Once a teat cup has been attached it can move freely.

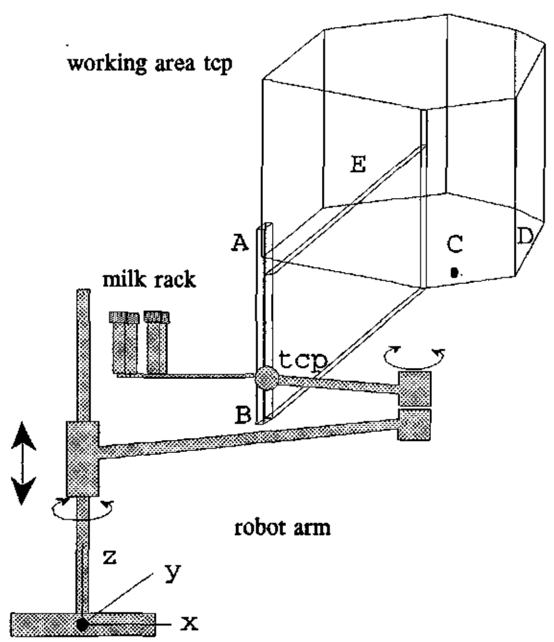


Figure 2. The robot arm with milk rack and the working area of the tool centre point of the robot arm. Symbols are defined in the text.

When all the teat cups are attached the robot arm disconnects and moves back to its rest position. If the cow moves around too much during attachment, the robot arm with milk rack moves to the position D (where the cow cannot hit it) and starts the procedure again from point C. At the end of the milking the milk rack is disconnected autonomously and returns to its rest position B.

The cow positioning (Figure 3) is controlled by the length of the milking box, by moving the feed trough and with fences on each side of the cow (to centre the cow). A special metal plate spreads the hind legs. To obtain a better udder presentation and more room for the robot arm, the cow stands with her fore legs on a platform.

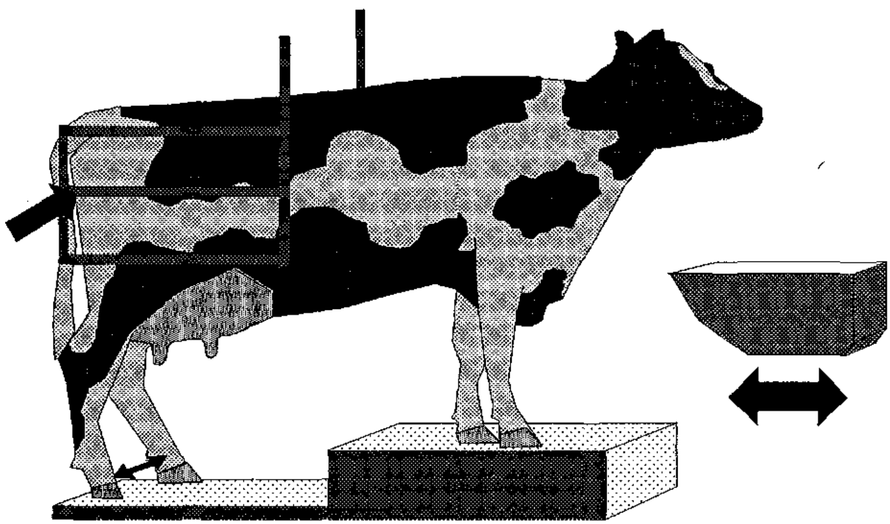


Figure 3. Cow positioning in the milking robot.

Materials and methods

In this paper the results from two field tests are described. In both tests high-yielding Holstein-Frisian/Frisian-Holstein (HF/FH) cows were used. The first test was in the period from 8 to 26 April 1991. Then 13 cows were milked three times a day at more or less fixed intervals. The first milking was allowed between 06.00 h and 10.00 h, the second between 10.00 h and 14.00 h and the third between 18.00 h and 22.00 h. In the group of cows there was one cow in her fourth lactation, three in their third, 8 cows in their second and one cow in her first; one cow was in the first half of her lactation and 12 were in the last part of their lactation. The second test was in the period between 18 and 22 November 1991. Then 16 cows were milked at the same milking intervals as in the first test. One cow was in her fifth lactation, one cow in her fourth, four cows in their third, six cows in their second and four cows in their first lactation; seven cows were in the first part of their lactation and nine in the last part of their lactation. Before the tests the animals were allowed a few days to get used to the milking box. During these days the cows could walk through the milking box freely and were allowed to eat concentrates from the feed trough. During these habituation periods in both tests one cow was removed from the test because of her behaviour.

The aim of the first test was to get an idea about the performance of the system and the cow specifications, the aim of the second test was to get an idea of the time necessary for attachment and more detailed information about system performance. Data from the successful attachments were stored automatically. The coordinates of the position where the reference teat was found and the offsets from the other teats with respect to the reference teat were stored. The number of attempts necessary for attachment was recorded. During the second test too the time necessary for attachment was recorded and whether a teat was in the middle of the teat cup or was sucked in during attachment. The problems associated with unsuccessful attempts were recorded. The decision to stop the automatic procedure was made by a person observing.

Results

First test

Table 1 gives the attachment results. The success rate is the number of attachments which were succeeded (after one or more attempts). The success rate for the second daily milking (interval approx. 4 hours) was statistically significantly higher than that of the other milkings. Attachment to cow 629 was difficult because of her behaviour (statistically there is a significant difference ($p < 0.05$) in success rate compared with all other cows). In cow 728 (and 718 more or less) the problem with attachment was an oblique reference teat, which creates problems for the reference sensor (the reference teats of these cows pointed backwards). Attachment to cow 623 was difficult because of her deep udder (distance between the floor and the reference teat from this cow was less than 300 mm). On average, 4.6 attempts were necessary for successful attachment. For the first daily milking 5.8 attempts were necessary on average, for the second and third 3.4 and 4.9 respectively were necessary. In cow 725 at the second daily milking 14 attempts were necessary for 13 milkings. During the test some technical problems affected the results negatively.

Table 1. Success rate (%) of teat cup attachment in experiment 1.

Cow	Automatic milkings, milking no:			
	1	2	3	All
440	71.4	100.0	64.3	78.6
623	21.4	42.9	35.7	33.3
629	7.1	0.0	35.7	14.3
639	35.7	71.4	64.3	57.1
711	71.4	85.7	92.9	83.3
716	71.4	71.4	85.7	76.2
718	57.1	85.7	64.3	69.1
720	64.3	71.4	50.0	61.9
724	85.7	92.9	71.4	83.3
725	71.4	92.9	71.4	78.6
728	50.0	42.7	28.6	40.5
730	71.4	85.7	71.4	76.2
905	71.4	100.0	71.4	80.1
All	57.7[a]	72.5[b]	62.1[a]	64.1

[a,b] statistically significant difference ($p < 0.05$)

Figure 4 gives the locations of the reference teats of all the cows during successful attempts with respect to the working area. The volume of this working space is rather small (180 mm in the length and upwards direction of the cow and 120 mm in the width direction). The shape of the area is oval because the cows have more freedom of movement in the length direction than in the width. The area where the teats were found is not in the centre of the working area; this is probably because the fences flanking the cow push the cow to one side.

In Figure 5 the place where the rear and the left front teats (teats one to three) were found on all the cows in all the successful attempts is given with respect to the reference teats (teat four). m1-m4 give the positions of the teat cups during the search phase and s1-s3 give the mean position where teats one to three were found. Sc gives the position of the fine sensor. The position of teat cups m2 and m3 differ from the mean teat positions s2 and s3. This is not desirable, because during the attachment of teats two and three it is difficult for the reference sensor to keep in track with teat four and hence there is more failure during attachment of those teats.

mean x = 407.1 (s.d. = 43.4)
mean y = 936.2 (s.d. = 30.2)
mean z = 773.5 (s.d. = 40.4) not drawn

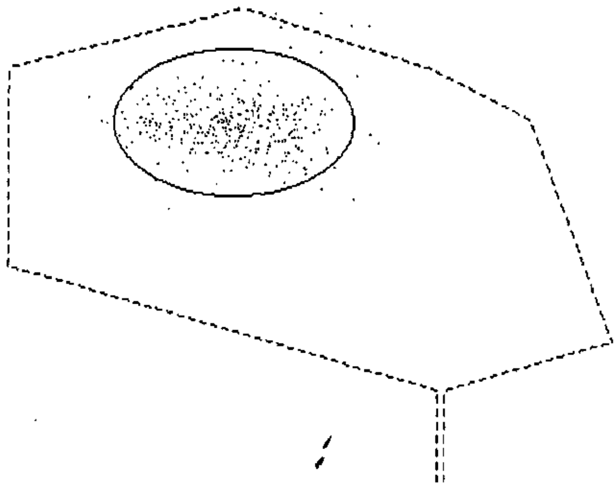


Figure 4. Location of the reference teats with respect to the working area (first test).

	mean		s.d.	
	x	y	x	y
s1	-104.8	43.7	21.1	12.5
s2	-97.6	135.2	24.4	20.8
s3	12.5	174.5	20.2	21.9

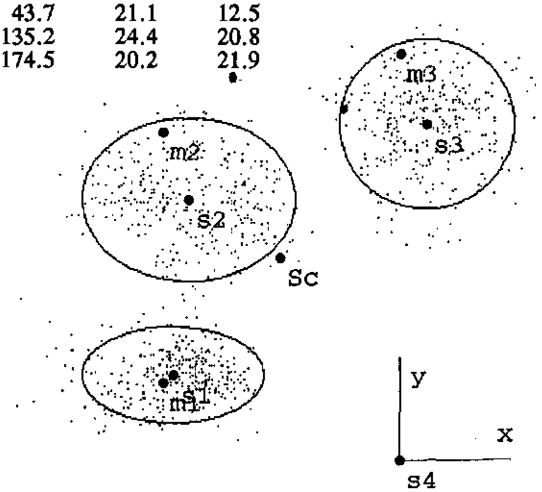


Figure 5. Places of the rear and left front teats with respect to the reference teat (first test).

Second test

After the first test some technical adjustments were made. The position of the teat cups in the milk rack was changed to correspond more with the mean positions of the teats. The construction of the fine sensor was also changed, because in the first test it had been found to be very vulnerable. The height of the platform for the fore legs was increased from 100 mm to 150 mm (Figure 3).

Table 2 gives the overall results from the second test. There were technical problems with the robot during three milkings. Therefore the data from these three milkings were disregarded. During the test the success rates were: 100% for five cows, 91.7% for six cows, 83.3% for one cow, 75.0% for two cows and 66.7% for two cows.

Table 2. Results from experiment 2.

Daily milking no.	1	2	3	All
Success rate (%)	79.2	93.8	90.0	88.5
Attempts necessary for an automatic milking	3.7	5.3	4.7	4.6
Time necessary for a successful attachment (sec)	156	202	191	187
Automatic attachment at once (%)	29.2	17.2	21.3	21.9
Time necessary for attachment at one go (sec)	37	32	34	35

In some cases, during the attachment the teat was not exactly in the middle of the teat cup, but was sucked in. In 10.6% of such cases teat one was sucked in, in 15.7% teat two, in 29.4% teat three and in 1.0% teat four. The high incidence of teats sucked into teat cup three is attributable to the construction of the fine sensor. The fine sensor does not move up and down perpendicularly but at an angle. This angle causes the fine sensor to make a measurement error which is especially important in teat three (Figure 6).

Figure 7 gives the place where the reference teats were found for all the cows and all the successful attempts, with respect to the working area. The shape of the area where all the reference teats were found is the same as in the first test. The area where the teats are found is more in the centre of the working area (a change in the mean Y value in the figure). This is because the fences flanking the cow now pushed her more to the middle of the working area. The change in the mean position of where the reference teats were found (in the X and Z directions) is probably because the fore legs are standing higher.

distance between sensor and teat a:
distance between sensor and teat b:

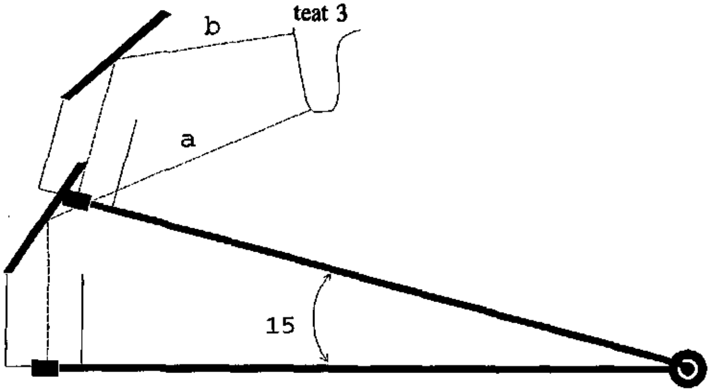


Figure 6. Measurement error from fine sensor.

mean x	= 407.1	(s.d. = 43.4)	
mean y	= 936.2	(s.d. = 30.2)	
mean z	= 773.5	(s.d. = 40.4)	not drawn

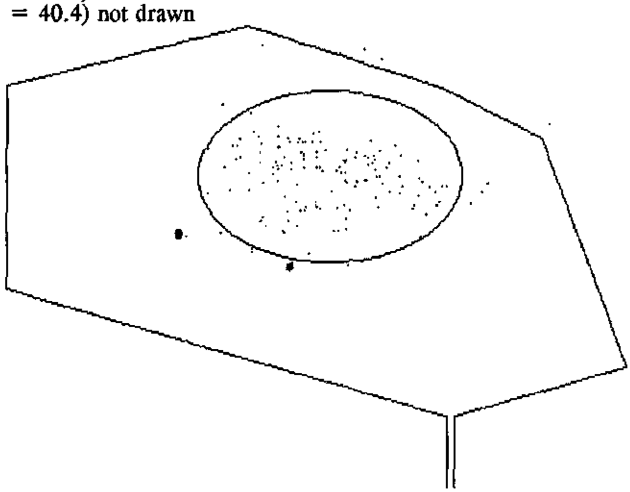


Figure 7. Location of the reference teats with respect to the working area (second test).

In Figure 8 the place were the rear and the left front teats (teats one to three) were found in all the cows and all the successful attempts is given with respect to the reference teats (teat four). Points s1-s3 and m1-m3 differ less from each other than in the first test. The shapes of the areas where teats one, two and three are found (Figures 5 and 8) are attributable to the udder expanding during the day.

	mean		s.d.	
	x	y	x	y
s1	-121.4	-69.4	20.1	13.9
s2	-131.8	24.6	28.3	27.2
s3	-26.6	72.9	14.1	29.4

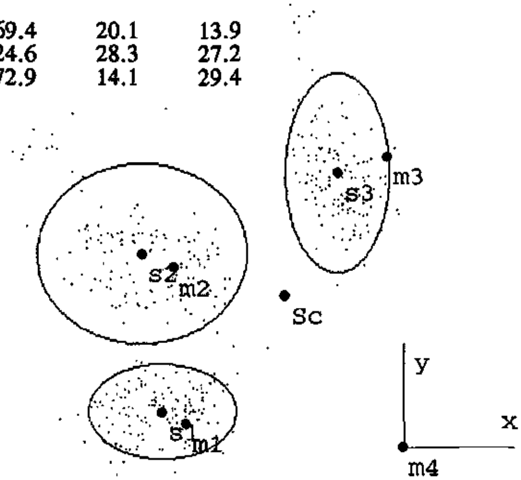


Figure 8. Places of the rear and left front teats with respect to the reference teat (second test).

The mean time necessary for attachment (this is the time between the moment the robot arm starts to move until the last teat is attached) was three minutes. The mean time necessary for attachment which succeeded at one go was 40 seconds.

Four pre-attachment phases were distinguished:

1. searching for the reference teat;
2. locking on the reference teat;
3. searching for teats one to three;
4. attachment of the teat cups.

With unsuccessful attempts it was recorded in which phase something went wrong. In 40% of the cases something went wrong during phase one, 18% during phase two, 25% during phase three and 17% during phase four. If something went wrong during phase one then the cause of failure was also recorded. Causes of failure of the system were:

- failure to find the reference teat (49%);
- failure to find the reference teat because of movement of the cow (1%);
- a rear teat found instead of the reference teat (10%);
- a rear leg found instead of the reference teat (39%).

These causes were specific to certain cows.

Discussion

These tests done at the IMAG-DLO experimental farm indicate that the automatic milking system tested was not suitable for all cows. Table 1 shows the great differences in successful attachment to the various cows participating in the first test. These differences have to do with the behaviour of the animals, shape of the udder and the directions of the teats and the distance between the teats and the floor. Increasing the height of the platform under the fore legs partly solved this problem. Comparing the tests it should be kept in mind that two different groups of cows were observed. The experiences from the first test on relevant cow parameters was used when composing the group for the second test, so as to improve the success rate of the automatic milking system.

The tests show that the cows must meet certain criteria. The reference teat must not deviate more than 10 degrees from the straight vertical position, especially in the backwards direction. The distance between the floor and the reference teat must be at least 300 mm. The area where the reference teat is found is rather small (180 mm × 120 mm × 180 mm). The siting of the area depends on the construction of the milking box.

Several minor technical adjustments would improve the performance of the system. The construction of the fine sensor should be improved. A first improvement would be to have a sensor which covers an angle between −7.5 degrees and 7.5 degrees instead of 0 to 15 degrees.

The number of successful attachments increases when the interval between the milkings is less than 8 hours. When these systems are working in practice the milking interval can normally be kept in this range (if cows are milked more than twice a day). The time needed for attachment depends on the number of attempts and is, on average, three minutes. However, even if this time is available it is too long. The attachments which succeeded at one go show that attachment within one minute is possible. Tests with an on-line database (per cow) with teat positions could help improve the performance of the system. The positions where the sensors start sensing the positions of the teats then fits more with that specific cow. The sensing area can be restricted, thereby reducing the chance of sensing a leg or a wrong teat.

Conclusion

These tests performed on the IMAG-DLO experimental farm indicate that the automatic milking system is nearly ready for introduction on commercial farms, although at the moment of the tests the system was not suitable for all cows.

References

Klomp, C., W. Jongkind, G. Honderd, J. Dessing & R. Paliwoda, 1990. Development of an autonomous cow-milking robot control system. IEEE Control Systems Magazine 10:11-19.

Anonymous, 1990. Robotereinsatz in der Landwirtschaft am Beispiel des Melkens; Tagung Braunschweig-Völkenrode. VDI/MEG Kolloquim Landtechnik, Düsseldorf, Germany 9, 252 pp.

2. Milk quality

Physiological response of dairy cows to milking

M.J. Paape*, A.V. Capuco*, A. Lefcourt*, C. Burvenich** & R.H. Miller*

* *USDA-Agriculture Research Service, Milk Secretion and Mastitis Laboratory, Beltsville Agricultural Research Center, Beltsville, Maryland 20705, U.S.A.*

***State University of Ghent, Department of Veterinary Physiology, Biochemistry and Biometrics, Ghent, Belgium*

Summary

Milking triggers a cascade of humoral, neurological, and cellular events. Oxytocin release from the posterior pituitary causes contraction of the myoepithelial cells surrounding the mammary gland alveoli, forcing milk through the duct system and into the mammary cistern. Prolactin and cortisol are released during milking and may play roles in maintenance of lactation and modulation of immune function.

Studies on isolated smooth muscle from the bovine teat with the radioligand binding technique in combination with pharmacological work on the cows teat 'in vitro' and 'in vivo', resulted in a better understanding of the adrenergic regulation of teat motility and milk evacuation in dairy cows. From pharmacological studies on living cows and isolated teat muscle preparations, it was concluded that both α- and β-adrenergic receptors are present in these muscles. These receptors are responsible for the adrenergic regulation of the teat motility, and probably play a major role in controlling milk flow.

During machine milking teat canal keratin is eroded from the canal. Keratin functions as a barrier to bacterial penetration of the gland. Loss of keratin during milking may serve to flush the canal of adherent bacteria. During the first two hours after milking the teat canal is susceptible to penetration and represents a period of risk to intramammary infection.

The mechanical action of the milking machine causes the migration of neutrophils from blood and into the mammary gland. Neutrophils are phagocytic cells whose primary function is the ingestion and killing of bacteria. Thus, after each milking neutrophils migrate into mammary tissue providing protection against establishment of infection. More frequent milking could enhance this defense mechanism.

It would appear that milking impacts a number of physiological events that play important roles in intramammary defense against infection. These events need to be considered when attempting future changes in milking procedures and milking machine design.

Keywords: oxytocin, prolactin, glucocorticoids, teat canal, keratin, adrenergic receptors, mastitis, leucocytes, milk somatic cells.

Introduction

This paper examines the physiological and morphological responses to milking in relation to efficiency of milk removal and its impact on mammary defence mechanisms against mastitis. The effect of milking on release of hormones from the pituitary and adrenal glands, the role played by the autonomic nervous system, the dynamics of teat canal contraction, keratin removal and regeneration, and how milking generates the chemotactic signals which result in the migration of leucocytes from blood to milk will be discussed. As more frequent milking, possibly as a consequence of robotic milking, appear to be the direction the dairy industry is heading, we also examine how frequent milking impacts on these responses, and the role played by these responses on intramammary defence against mastitis.

Hormonal response to milking

Teat stimulation results in a patterned neural and endocrine response designed, at least in part, to facilitate milk removal and to increase, or sustain, milk production. In terms of milk removal, the most important effect is termed the milk ejection reflex (Lefcourt & Akers, 1983). This reflex causes milk stored in alveoli of the mammary gland to be transferred to the cistern of the gland. Only cisternal milk is available to the offspring or to the milking machine. The primary mechanism of this reflex is the release of oxytocin from the posterior pituitary in response to stimulation of the teat. Oxytocin causes myoepithelial cells surrounding the alveoli to contract, forcing milk stored in the alveoli into the mammary ducts which in turn drain into the mammary cistern. Teat stimulation also causes a decrease in sympathetic tone in the mammary gland as evidenced by a decrease in the rate of contractions of the teat-sphincter muscle (Lefcourt, 1982), a decrease in resistance of mammary ducts (Grosvenor & Findley, 1968), and an increase in mammary blood flow (Gorewit et al., 1989; Houvenaghel, 1971).

Historically, there has been some question as to the quantity of oxytocin necessary for efficient milk removal and to whether milking machines provide adequate teat-stimulation. In cows selected for milk production, apparently only a very small increase in peripheral oxytocin is necessary for efficient milk removal (Gorewit & Gassman, 1985; Mayer et al., 1991). Large increases in oxytocin in response to teat-stimulation may serve other purposes, such as facilitating bonding to offspring (Pedersen & Prange, 1985).

Prolactin is also released in response to teat stimulation. In some species, this release of prolactin is essential for maintenance of lactation and the magnitude of response is related to production levels (Ostrom, 1990). However, the importance of prolactin release during lactation in cows is not clear. Pharmacological suppression of prolactin release during lactation has only a minor effect on milk yield (Karg & Schams, 1974). In contrast, increased prolactin levels are often correlated with increased milk yields. In particular, the increase in milk yield associated with increased photoperiod is highly correlated with prolactin levels (Tucker, 1988).

For cows, teat-stimulation also results in the release of cortisol. However, this increased cortisol does not seem to play a direct role in milk removal or production (Mayer & Lefcourt, 1987). Glucocorticoids, including cortisol, are known to modulate immune function. It may be that cortisol released in response to teat stimulation alters immune-based mammary defense mechanisms (Munck et al., 1984). For example, this response may alter neutrophil infiltration rate or killer-cell cytotoxicity.

Finally, milk removal may have direct, local effects on the mammary gland. It has been suggested that milk contains substances inhibitory to milk production and that more frequent removal of milk reduces the effect of this substance (Wilde & Peaker, 1990).

Neurological response to milking

Linzell (1974) observed that frequent removal of milk from a transplanted denervated gland increased milk yield in that gland. This indicates that the removal of milk from the alveoli 'per se' is an important factor controlling milk secretion and that all mechanisms which facilitate milk removal from the mammary gland favour total milk yield. The sympathetic system (nerves, pre- and post-synaptic receptors) within the mammary gland has no direct effect on milk synthesis. However, it controls mammary blood flow, teat contractions and milkability. Beta-receptors are located on the myo-epithelial cells indicating that the sympathetic system might also interfere with the local action of oxytocin. Bovine teats are provided with longitudinal smooth muscles in the walls of the teat cistern and circular smooth muscles around the teat canal. Longitudinal muscles in the walls of the teat cistern show spontaneous rhythmical contractions. Smooth muscles around the teat canal act as a sphincter. Selective activation of β-receptors provokes relaxation of the teat and opening of the streak canal (Vandeputte-van Messom et al., 1984). The teat contractions are coordinated waves originating in the teat base and ending in the tip. The velocity of these waves is about 20 mm/s (Lefcourt, 1982). In most cases sphincter contraction occurs synchronously with teat contraction (Bernabé & Peeters, 1980). Consequently, if spontaneous milk leakage exists, it has to occur mostly during the relaxation phase of the teat.

In cows, it has been generally accepted that the teat sphincter does not relax during milking. Nevertheless there may be a slight change in the tone of the teat muscle. Lefcourt (1982) suggested that teat stimulation reduces sympathetic tone in the mammary gland and that this reduction could be the result of an autonomic reflex. Houvenaghel (1971) observed that during machine and hand milking there was an increase in mammary blood flow. This might also indicate a decrease in the sympathetic tone in the udder during milking.

In order to identify and quantitate adrenergic receptors present in teats of lactating cows, a technique was developed using membranes of smooth muscle from the wall of the teat cistern. With the use of specific radioactively labelled drugs, α- and β-adrenergic receptors were directly identified and characterized in these membrane preparations (radioligand binding studies). Results demonstrated that the $\alpha 1$, $\alpha 2$- and $\beta 2$-adrenergic receptors showed all the characteristics generally accepted as criteria for receptors in other tissues (Roets et al., 1988).

The muscle surrounding the teat canal is kept under constant tension by impulses from the autonomic sympathetic nervous system (Peeters et al., 1949). The motility of the longitudinal smooth muscles can be registered indirectly under physiological conditions by enclosing the teat in a cylindrical plexiglass cup sealed to the udder, and by recording the variations in air pressure induced by the movements of the teat in the chamber.

Selective activation of α-receptors induces contraction and shortening of the teat and closure of the streak canal. Pretreatment of cows with the α-blocking substances phentolamine or prazosin abolished the α-agonist-induced contractions (Vandeputte-Van Messom et al., 1982).

The $\beta 2/\alpha 2$-receptor ratio in the teat influences milk evacuation and milkability (Roets et al., 1988). The number and ratio of both α- and β-receptors differ in different animals. This receptor distribution in the bovine teat is, to a great extent, responsible for the differences in the rate of milking among cows.

A study was performed in which different types of milk flow patterns, characteristic for slow, intermediate and fast milkers, were distinguished. It was found that milking time was positively correlated (r= 0.78) with the $\beta 2/\alpha 2$-adrenoceptor density ratios in teat tissue (Roets et al., 1988). A good correlation was also found between the $\alpha 2$-adrenoceptor density and the peak flow rate. No correlation was found with the $\beta 2$-adrenoceptors. Fast milkers have a low $\beta 2/\alpha 2$-ratio. An important finding is that peak flow rate, a parameter which is correlated with the $\beta 2/\alpha 2$-ratio, is highly heritable in dairy cattle. The degree of heritability is higher than noted for milk fat and milk protein. In a study performed by Vandeputte-van Messom et al. (1990) milk flow rates in cows were highly repeatable within a cow, but varied markedly among cows. No significant differences in the density of $\alpha 1$- and $\alpha 2$- adrenoceptors and $\beta 2$-adrenoceptors were found between fore and rear teats. After milking, a reduction of 52% in total udder area bounded by the teats was observed. Teat volume decreased with 30% after milking. Apart from the length of the udder, no significant relationships were observed between udder size and milk flow rates. As expected, high $\alpha 2$-adrenoceptor densities were associated with short milking times and high milk flow rates. The $\beta 2/\alpha 2$-ratio was significantly correlated with all milking parameters, stripping yield and udder index. A significant relationship was also observed with the size of the teat (length, volume, diameter, circumference), and udder area. Large udders and teats were related with a higher $\beta 2/\alpha 2$-ratio and adversely affected milk flow during milking.

Teat canal response to milking

The teat canal represents the first line of defense against invading mastitis pathogens. The canal averages 8.6 mm in length and 1.2 mm in diameter, when distended by milk flow (Comalli et al., 1984). Between milkings, the canal is substantially occluded over a distance of a few mm (Schultze et al., 1978). The teat canal is occluded by an oily wax-like material that contains long chain fatty acids and basic proteins that in vitro are bactericidal to environmental pathogens and bacteriostatic to contagious pathogens (Adams & Rickard, 1963).

The effect of machine milking on dilation and closure of the teat canal has been investigated (Schultze & Bright, 1983). In order to measure this phenomenon an assay that measured streak canal penetrability was developed. Closure of the canal was determined by depositing 1.0 microgram of *Escherichia coli* endotoxin in 2.5 microliters of sterile, distilled water at a depth of 3 mm into the streak canal of 33 cows after each of 5 successive morning milkings. Endotoxin was implanted immediately after milking or after a 10- to 120- minute delay. Penetration of endotoxin through the duct results in mild, transient inflammation, detected by elevation of the Wisconsin mastitis test score in subsequent quarter milk samples. Increase in the effectiveness of the streak canal as a barrier to endotoxin penetration began soon after removal of the milking machine and progressed slowly during the first 30 minutes. After 120 minutes, the likelihood of penetration decreased about 72% to 76%. The authors attributed the decrease in penetrability of streak canals during the first 2 hours after milking to contraction in diameter of the canal. These data suggest that the first 2 hours after milking may be a period of great risk to intramammary infection. Current herd management practices encourage cows to remain standing for a time after milking.

Effect of milking on teat canal keratin

In cross-section, the canal is stellate-shaped, and is lined with material, referred to as keratin, that is derived from the teat canal epithelium. The teat canal epithelium is a keratinized stratified squamous epithelium with many attributes of other keratinized epithelia. Briefly, cells which arise from the germinal layer keratinize as they are moved toward the lumen, where a continuous process of desquamation occurs. It is these mature keratinized cells and surrounding material which compose the "keratin" layer that nearly occludes the ductular lumen except during milking.

It is clear that the keratin lining of the teat canal plays an important role in resisting microbial invasion (Capuco et al., 1992a; Murphy, 1959). This resistance has been attributed to its physical properties and to its potential antimicrobial properties. Physically, keratin appears to entrap bacteria, preventing their entry into the mammary gland (Newbould & Neave, 1965). Serial sectioning of the teat end has indicated the teat canal epithelium contains longitudinal folds arranged in a corkscrew fashion, which may further enhance its attributes as a physical barrier against bacterial penetration (Van Der Merwe, 1985). Chemically, both protein and lipid components of keratin have been reported to be bactericidal or bacteriostatic. Keratin contains cationic proteins reported to be bactericidal and anionic proteins reported to be bacteriostatic (Hibbit et al., 1969; Senft et al., 1990). Xanthine oxidase, an enzyme required for bactericidal activity mediated by the lactoperoxidase system, is also a protein component of keratin (Collins et al., 1988). Additionally, lactoferrin appears to be an antimicrobial component of keratin which can be increased by mammary inflammation (Jack et al., 1992; unpublished data). Antibacterial activity has also been ascribed to C_{12} to C_{18} fatty acids present in keratin (Adams & Rickard, 1963). However, antimicrobial effects of keratin lipids probably are minor, considering the low concentration of fatty acids found in keratin (Bright et al., 1990; Senft et al., 1990). Early reports in the literature which indicate that lipids are the primary components of keratin are clearly erroneous and inconsistent with the recent values reported by several laboratories.

Not unlike other keratinized epithelia, teat canal keratin in lactating cows exists in a dynamic state of loss and renewal. During conventional machine milking, a substantial portion of the keratin layer is eroded from the teat canal (Table 1). This effect is not due to differences in moisture content of the keratin before vs. after milking (data not shown). Clearly, the quantity of keratin lost during milking must be replaced before the next milking, if the quantity of keratin in the teat canal is to be maintained at a constant, or nearly constant, amount. Additionally, the concentration of lipid differs in keratin collected before vs. after milking. Such an effect could be due to a non-homogeneous distribution of lipid within the keratin layer combined with the loss of keratin which is closest to the lumen during milking. In contrast, the concentration of protein in keratin (averaged 33% based on keratin wet weight) collected before milking did not differ from that collected after milking (Jack et al., 1992).

Table 1. Effects of conventional milking on quantity and composition of teat canal keratin in Holstein cows.

Time relative to milking	mg keratin P (wet weight)	μg lipid/ mg keratin
Before	3.0[a]	21[a]
After	1.6[b]	37[b]

[a, b] statistically significant difference in column ($P < 0.05$).

One might hypothesize that by minimizing keratin loss during milking, resistance to mastitis will be enhanced. In apparent contradiction to this hypothesis are reported effects of pulsationless milking. In the absence of pulsation, more keratin appears to be present in the teat canal (Hamann, 1987), yet the mammary glands tend to be more susceptible to mastitis (Bramley et al., 1978). The primary function of pulsation during machine milking is to minimize teat end damage such as edema, congestion and petechial haemorrhages (Reitsma et al., 1981; Hamman & Mein, 1988). We recently demonstrated that during pulsationless milking, 40% less keratin was removed than with conventional milking, yet mastitis incidence was increased dramatically (Capuco et al., 1992b). As suggested by others, loss of keratin during milking may serve to flush the teat canal of adherent bacteria. However, teats which were milked without pulsation became cyanotic in response to milking. The influence of pulsationless milking is undoubtedly due to the effects of edema and cyanosis on the teat end rather than alterations in the keratin layer per se. Preliminary morphological analysis of the teats of 2 cows slaughtered 2 h after milking suggest that pulsationless milking increased patency of the teat canal. Numerous investigators have demonstrated that the ability of the teat canal to resist bacterial invasion is compromised in those teats which have patent teat canals (Murphy, 1944; Dodd & Neave, 1951; Grindal & Hillerton, 1991), and under physiological conditions which increase patency of the canal (Comalli et al., 1984; Schultze & Bright, 1983). It is most likely that greatest resistance to mastitis will be achieved by a milking system which minimizes keratin loss and teat end damage.

Leucocyte response to milking

The leucocyte population in normal bovine milk includes the polymorphonuclear neutrophil leucocytes (PMN), lymphocytes, eosinophils, and macrophages. Because PMN and macrophages are avid ingestors of milk fat globules and casein, their morphology in milk differs from their morphology in blood. When examined with the light microscope, these cells show numerous clear vacuoles in their cytoplasm. These vacuoles have been identified by transmission electron microscopy as phagolysosomes that contain milk fat globules or casein micelles (Paape & Wergin, 1977).

Epithelial cells are also found in milk. Identification of these cells is difficult because in the light microscope they appear similar to macrophages. Thus, either electron microscopy or monoclonal antibodies to the cytokeratin in epithelial cells are used to confirm their presence (Miller et al., 1991). Because of the presence of epithelial cells in milk the term "milk somatic cells" was introduced and is now used internationally as the accepted terminology when referring to cells in milk (Paape et al., 1963).

In milk from normal non-infected lactating glands the macrophage is the predominant cell type (35 - 79%), followed by neutrophils (3 - 26%), lymphocytes (16 - 24%), and epithelial cells (2 - 15%) (Lee et al., 1980, Miller et al., 1991). Total milk somatic cell counts from non-infected glands are low, averaging 50 000/ml (Paape & Weinland, 1988). During clinical and subclinical mastitis, the percentage of neutrophils together with the total milk somatic cell count increases (Schalm et al., 1971). Because of the relationship between leucocytes in milk and bovine mastitis, the United States Public Health Service will lower in July, 1993, the maximum acceptable concentration in mixed herd milk to 0.75 million somatic cells/ml of milk from 1.0 million cells/ml. The International Dairy Federation has established 0.4 million cells/ml as the upper limit for normal milk.

Polymorphonuclear neutrophil leucocytes and macrophages constitute the professional phagocytes of the bovine mammary gland. The neutrophil provides the first line of defense through its ability to phagocytose and digest mastitis pathogens. It has the ability to rapidly migrate from peripheral blood through endothelial gaps and tissue matrices. Neutrophils exhibit a directed migration toward chemical messages or chemoattractants. Potent chemoattractants for bovine neutrophils include C_{5a}, a cleavage product of the fifth component of complement, various lipopolysaccharides, and leukotriene B_4 (Paape et al., 1991).

The mechanical action of the milking machine also causes migration of PMN from blood. Immediately after machine milking concentrations of neutrophils in blood from the subcutaneous abdominal vein decrease, and concentrations in mammary lymph and milk increase (Table 2) (Paape & Guidry; 1969, Paape et al., 1985). Thus, the normally sterile mammary gland is provided with millions of neutrophils for defensive purposes. Further, newly synthesized milk leads to the removal of freshly migrated neutrophils, and further exudation of neutrophils into the newly formed milk in the alveoli (Schalm & Lasmanis, 1976). However, the ingestion of milk fat globules and casein by PMN leads to a loss in phagocytic and bactericidal functions and to their rapid deterioration and death (Paape & Guidry, 1977). More frequent milking should result in a flushing out of these compromised PMN, a resupplying of healthy PMN, and enhancement of protection against establishment of infection. This phenomenon could partially explain the reduced incidence of clinical mastitis for cows milked four times a day when compared to cows milked two times a day (Hillerton, 1991).

Table 2. Effects of milking on the concentration of leucocytes in blood and lymph and somatic cells in milk.

Time relative to milking	Subcutaneous abdominal vein	Efferent mammary lymphatic	Milk
	(cells/cmm)	(cells/cmm)	(cells $\times 10^6$/ml)
Before	8425[a]	451[a]	0.03[a]
After	7540[b]	1070[b]	0.15[b]

[a, b] statistically significant difference in column ($P < 0.05$).

The future

Future changes in milking procedures will probably include more frequent milking and/or use of robotic milking. It has clearly been demonstrated that more frequent milking results in increased milk production. However, the question remains: Is more frequent milking economically viable? Costs include increased labour and overhead and, perhaps, increased risk of mastitis. In high producing herds, 3× or 4× daily milking has been shown to be economically viable (Barnes et al., 1990; Gisi et al., 1986; Hillerton et al., 1990). In the future, automation of milking, i.e. robotic milking, has the potential to reduce labour costs and may result in greater acceptance of increased milking frequency.

Machine milking has been implicated in the establishment of new intramammary infections by allowing transfer of infectious organisms among quarters of individual animals and between animals (Spencer, 1989). There are many possible mechanisms of transfer including poor hygiene such as failure to wash teats before milking or to wash machines between milking individual cows. Vacuum fluctuations can cause reverse pressure gradients across the teat-end which in turn can propel contaminated milk droplets into the teat sinus. Poor design of milking machines, inadequate vacuum reserve, or malfunctioning equipment are frequent causes of vacuum fluctuations. However, when proper equipment and hygiene is used, the incidence of new mastitis infections due to machine milking is quite low. Under these conditions, more frequent milking is not likely to affect the incidence of new mastitis infections. In experimental trials, more frequent milkings were found not to affect new infection rates (Allen et al., 1986; Hillerton, 1991).

Robotic milking - potential problems

In terms of responses to milking and udder health, there are two additional problems which must be surmounted for robotic milking to be practical. The first problem involves the application of the milking machine to individual cows. Incorrectly applied teat-cups might result in a teat not being milked or, more likely, in liner-slip. Either condition would cause excessive vacuum fluctuation and increase the risk of new mastitis infections. For robotic milking to be successful, it may be necessary to select cows for udder and teat conformation.

The second problem is potentially more serious. Cows must adapt their behaviour to accept robotic milking. If cows are not comfortable with the process, milk production and health may be impacted. A more insidious aspect of this problem is the potential reaction of dairymen to undesirable behaviours. The response of an animal to the actions of a hurried, impatient, frustrated dairyman may be greater than the response to robotic milking itself. A similar problem occurs for animals subjected to electrical currents (stray voltage). Animals subjected to electrical currents during milkings often show abnormal behaviour which interferes with milking. Inappropriate responses of dairymen to this abnormal behaviour can exasperate existing problems, or cause new problems, which impact milk production and health (Lefcourt, 1991).

References

Adams, E.W. & C.G. Rickard, 1963. The antistreptococcic activity of bovine teat canal keratin. Amercian Journal of Veterinary Research 24:122-135.

Allen, D.B., E.J. Depeters & R.C. Laben, 1986. Three times a day milking effects on milk production reproductive efficiency and udder health. Journal of Dairy Science 69:1441-1446.

Bernabé, J. & G. Peeters, 1980. Studies on the motility of smooth muscles of the teats in lactating cows. Journal of Dairy Research 47:259-275.

Barnes, M.A., R.E. Pearson & A.J. Lukes Wilson, 1990. Effects of milking frequency and selection for milk yield on productive efficiency of holstein cows. Journal of Dairy Science 73:1603-1611.

Bramley, A.J., T.K. Griffin & R. Grindal, 1978. Some investigations on the effect of continuous vacuum milking on new infection of the udder. In: Proceedings of the International Symposium on Machine Milking, 17th Annual Meeting of the National Mastitis Council, Louisville, KY, USA, p. 291-300.

Bright, S.A., J. Bitman, A.V. Capuco, D.L. Wood & R.H. Miller, 1990. Methods of collection and lipid composition of teat canal keratin in dry and lactating cows. Journal of Dairy Science 73:98-106.

Capuco, A.V., S.A. Bright, J.W. Pankey, D.L. Wood, R.H. Miller & J. Bitman, 1992a. Increased susceptibility to intramammary infection following removal of teat canal keratin. Journal of Dairy Science (in press).

Capuco, A.V., G.A. Mein, S.A. Bright, S.C. Nickerson, L.J.W. Jack, D.L. Wood, R.A. Aschenbrenner, R.H. Miller & J. Bitman, 1992b. Influence of pulsation and non-pulsation milking on teat canal keratin and mastitis. Journal of Dairy Science 75:195 (Abstract).

Collins, R.A., K.R. Parsons, T.R. Field & A.J. Bramley, 1988. Histochemical localization and possible antibacterial role of xanthine oxidase in the bovine mammary gland. Journal of Dairy Research 55:25-32.
Comalli, M.P., R.J. Eberhart, L.C. Griel & H. Rothenbacher, 1984. Changes in the microscopic anatomy of the bovine teat canal during mammary involution. American Journal of Veterinary Research 45:2236-2242.
Dodd, F.D. & F.K. Neave, 1951. Machine milking rate and mastitis. Journal of Dairy Research 18:240-245.
Gisi, D.D., E.J. Depeters & C.L. Pelissier, 1986. Three times daily milking of cows in California dairy herds. Journal of Dairy Science 69:863-868.
Gorewit, R.C., M.C. Aromando & D.G. Bristol, 1989. Measuring bovine mammary gland blood flow using a transit time ultrasonic flow probe. Journal of Dairy Science 72:1918-1928.
Gorewit, R.C. & K.B. Gassman, 1985. Effects of duration of udder stimulation on milking dynamics and oxytocin release. Journal of Dairy Science 68:1813-1818.
Grindal, R.M. & J.E. Hillerton, 1991. Influence of milk flow rate on new intramammary infection in dairy cows. Journal of Dairy Research 58:263-268.
Grosvenor, C. & L. Findlay, 1968. Effect of denervation on fluid flow into rat mammary gland. American Journal of Physiology 214:820-824.
Hamann, J., 1987. Effect of machine milking on teat end condition - A literature review. in: Machine Milking and Mastitis. Bulletin of the International Dairy Federation 215:33-54.
Hamann, J. & G.A. Mein, 1988. Responses of the bovine teat to machine milking: measurement of changes in thickness of the teat apex. Journal of Dairy Research 55:331-338.
Hibbit, K.G., C.B. Cole & B. Reiter, 1969. Antimicrobial proteins isolated from the teat canal of the cow. Journal of General Microbiology 56:365-371.
Hillerton, J.E., C.H. Knight, A. Turvey, S.D. Wheatley & C.J. Wilde, 1990. Milk yield and mammary function in dairy cows milked four times daily. Journal of Dairy Research 57:285-294.
Hillerton, J.E., 1991. The effects of milking frequency on mastitis. In: Proceedings of the British Mastitis Conference, Stoneleigh, UK, p. 61-68.
Houvenaghel, A, 1971. Ph.D. thesis, University of Ghent, Belgium.
Jack, L.J.W., A.V. Capuco, D.L. Wood, R.A. Aschenbrenner, J. Bitman, S.A. Bright & R.H. Miller, 1992. Protein composition of teat canal keratin collected from lactating cows before and after milking. Journal of Dairy Science 75:195 (Abstract).
Karg, H. & D. Schams, 1974. Prolactin release in cattle. Journal of Reproduction & Fertility 39:463-472.
Lee, C.S., F.B.P. Wooding & P. Kemp, 1980. Identification, properties, and differential counts of cell populations using electron microscopy of dry cows secretions, colostrum and milk from normal cows. Journal of Dairy Research 47:39-50.
Lefcourt, A., 1982. Effect of teat stimulation on sympathetic tone in bovine mammary gland. Journal of Dairy Science 65:2317-2322.
Lefcourt, A.M. & R.M. Akers, 1983. Is oxytocin really necessary for efficient milk removal in dairy cows. Journal of Dairy Science 66:2251-2259.
Lefcourt, A.M. (Ed.), 1991. Effects of Electrical Voltage/Current on farm animals: How to detect and remedy problems. U.S. Government Printing Office, Washington, DC.
Linzell, J.L., 1974. In: Larson & Smith (Eds.): Lactation. Academic Press, New York and London.
Mayer, H.K. & A.M. Lefcourt, 1987. Failure of cortisol injected prior to milking to inhibit milk ejection in dairy cattle. Journal of Dairy Research 54:173-177.

Mayer, H., R. Bruckmaier & D. Schams, 1991. Lactational changes in oxytocin release, intramammary pressure and milking characteristics in dairy cows. Journal of Dairy Research 58:159-169.

Miller, R.H., M.J. Paape & L.A. Fulton, 1991. Variation in milk somatic cells of heifers at first calving. Journal of Dairy Science 74:3782-3790.

Munck, A., P.M. Guyre & N.J. Holbrook, 1984. Physiological functions of glucocorticoids in stress and their relation to pharmacological actions. Endocrine Reviews 5:25-44.

Murphy, J.M., 1944. The relationship of teat patency to udder infection. Cornell Veterinarian. 34:64-68.

Murphy, J.M., 1959. The effect of certain milk stresses to the bovine teat canal on infection with *Streptococcus agalactiae*. Cornell Vet. 49:411-421.

Newbould, F.H.S. & F.K. Neave, 1965. The effect of inoculating the bovine teat duct with small numbers of *S. aureus*. Journal of Dairy Research 32:171-179.

Ostrom, K.M., 1990. A review of the hormone prolactin during lactation. Progress in Food and Nutrition Science 14:1-43.

Paape, M.J., H.D. Hafs & W.W. Snyder, 1963. Variation of estimated numbers of milk somatic cells stained with Wright's stain or pyronin Y-methyl green stain. Journal of Dairy Science 46:1211-1216.

Paape, M.J. & A.J. Guidry, 1969. Effect of milking on leucocytes in the subcutaneous abdominal vein of the cow. Journal of Dairy Science 52:998-1002.

Paape, M.J. & A.J. Guidry, 1977. Effect of fat and casein on intracellular killing of *Staphylococcus aureus* by milk leucocytes. In: Proceedings of the Society for Experimental Biology and Medicine 155:588-593.

Paape, M.J. & W.P. Wergin, 1977. The leucocyte as a defense mechanism. Journal of the American Veterinary Medical Association Part 2, 170:1214-1223.

Paape, M.J., W.D. Schultze, A.V. Capuco & G. Astrom, 1985. Trafficking of leucocytes in the lactating bovine mammary gland. Kieler Milchwirtschaftliche Forschungsberichte 37:622.

Paape, M.J. & B.T. Weinland, 1988, Effect of abraded intramammary device on milk yield, tissue damage and cellular composition. Journal of Dairy Science 71:250-256.

Paape, M.J., A.J. Guidry, N.C. Jain & R.H. Miller, 1991. Leukocytic Defense mechanisms in the udder. Flemish Veterinary Journal 62:95-109.

Pedersen, C.A. & A.J. Prange, 1985. Oxytocin and mothering behaviour in the rat. Pharmacology & Therapeutics 28:287-302.

Peeters, G., R. Coussens & G. Sierens, 1949. Physiology of the nerves in the bovine mammary gland. Archives Internationales de Pharmacodynamie et de Therapie 79:75-82.

Reitsma, S.Y., E.J. Cant, R.J. Grindal, D.R. Westgarth & A. J. Bramley, 1981. Effect of duration of teatcup liner closure per pulsation cycle on bovine mastitis. Journal of Dairy Science 64:2240-2245.

Roets E., G. Vandeputte-Van Messom, C. Burvenich & G. Peeters, 1988. Adrenoceptor determination in lactating cows by means of the radioligand technique. In: Proceedings of the 4th Congress of the European Association for Veterinary Pharmacology and Toxicology, Budapest, Hungary.

Schalm, O.W., E.J. Carrol & N.C. Jain, 1971. Bovine mastitis. Lea and Febiger, Philadelphia, PA.

Schalm, O.W. & J. Lasmanis, 1976. Cytological features of bone marrow in normal and mastitis cows. Journal of the American Veterinary Medical Association 37:359-363.

Schultze, W.D., P.D. Thompson & S. C. Bright, 1978. Inflammatory response of the bovine mammary gland to an irritant in the streak canal. American Journal of Veterinary Research 39:785-790.

Schultze, W.D. & S.C. Bright, 1983. Changes in penetrability of bovine papillary duct to endotoxin after milking. American Journal of Veterinary Research 44:2373-2375.
Senft, B., F. Meyer & M.L. Hartmann, 1990. The importance of proteins of teat canal keratin in the defense mechanism of the bovine mammary gland. Milchwissenschaft 45:295-298.
Spencer, S.B., 1989. Recent research and developments in machine milking A review. Journal of Dairy Science 72:1907-1917.
Tucker, H.A., 1988. Photoperiodic influences on milk production in dairy cows. Recent developments in Ruminant Nutrition 2:46-56.
Vandeputte-Van Messom, G., J. Bernabé, C. Burvenich & G. Peeters, 1982. Effects of α-blocking agents on teat motility in lactating cows. Archives Internationales de Pharmacodynamie et de Thérapie 260:309-311.
Vandeputte-Van Messom, G., J. Bernabe, C. Burvenich & G. Peeters, 1984. Effect of prazosin on the function of the teat sphincter in lactating cows. Journal of Dairy Research 51:219-226.
Vandeputte-Van Messom, G., E. Roets, C. Burvenich & G. Peeters, 1990. Adrenoceptor distribution in the teat of primiparous cows in relation to udder characteristics. In: Abstracts of the International Congress Mastitis: Physiology or Pathology? Ghent 18-22 September, p. 162-163.
Van Der Merwe, N.J., 1985. Some observations on the morphology of the bovine teat canal (ductus papillaris mammae). Journal of the South African Veterinary Association 56:13-16.
Wilde, C.J. & M. Peaker, 1990. Autocrine control of milk secretion. Journal óf Agricultural Science 114:235-238.

A non-invasive method for measuring the compressive load on teats and the congestion of the teat ends during milking

O. Rønningen

Agricultural University of Norway, Department of Agricultural Engineering, P.O. Box 65, N-1432 ÅS-NLH, Norway

Summary

A system is being developed for measuring the compressive load exerted by the liner on the teats and teats' response to milking. It is based on dynamic stereophotogrammetry to obtain a dynamic three-dimensional numerical model of the liner surface, and on a set of calculations to derive the end parameters. The first part of the system functions satisfactorily. The second part, however, needs further development.
Keywords: milking machine, liner, compressive load, photogrammetry, image analysis.

Introduction

In a conventional machine milking system the movement of the teatcup liner is necessary to massage the teat end. The massage is necessary to obtain a high instantaneous milk flow-rate (Williams et al., 1981) and to prevent oedema and haemorrhage in the teat tip, thereby maintaining the defence mechanisms against mastitis (Mein et al., 1986; Hamann, 1990).

The end parts of the liner cannot massage the teat. Teats which are too short to reach the effective part of the liner (Rasmussen et al., 1989), or teats which are so long that they reach below that part (Mein et al., 1986), will not have efficient massage. A Norwegian field study (Rønningen & Reitan, 1990) indicated the relationship between teat lengths and effective liner lengths. In that study it was concluded that 10 - 40% of the cows had fore teats penetrating so deeply into the liners at the end of milking that there was insufficient or no massage. This wide range of 10 - 40% reflects the lack of precise knowledge of the ability of the various liners to provide teat end massage. This is the justification for the work on liner characteristics described below.

Literature review

Many attempts have been made to measure the pressure exerted by the liner on dummy teats (Caruolo, 1983; Szlachta, 1985; Rasmussen et al., 1989) in order to find liner characteristics. These methods have been useful in demonstrating the differences in compressive load in different liners or locations in a liner with one type of "teat", but they are not adequate to predict the real level of compressive load on a live teat.

Williams & Mein (1982) made a comprehensive study on the forces acting on the teat during milking, and suggested that a compressive load of about 10 kPa was necessary to avoid congestion of the teat end. Their compressive load calculations were based on the bending of the liner round the teat, as read out from x-ray prints. This method gives relevant results, but it is laborious, and the x-ray method is only a laboratory method.

Gates & Scott (1986) measured teat load (suction and compressive load) directly with small pressure transducers mounted in the liner. This method can also give relevant data, but has some disadvantages. Every liner to be investigated has to be specially prepared, and then there is always the risk of interfering with its properties. We also know that a large part of the liner's length has to be investigated, so many transducers will be needed in each liner.

Choice of strategy

The main aim of the project was to study liners generally, to increase our knowledge of this most important part of the milking machine. The first specific task was to find a way of measuring the compressive load on teats in liners at various distances from the end of the teatcup, and with this information to assess an effective length of liners.

The parameter of interest is the compressive load on teats under normal working conditions, that means with the liner mounted in a proper shell, with pulsation and with a lactating teat. Clearly, the shape of the teat (in the massage phase) determines the magnitude of the compressive load. Further, we know that teat sizes and shapes vary from cow to cow and between breeds, and also that their elastic properties vary greatly (Balthazar & Scott, 1978). This implies that before we can make any device to put into a liner to measure compressive load, we need to know the shape of the compressed teats for the relevant breed. However, if one knows the shape of the teat in a collapsed liner, it is possible to calculate the compressive load (Williams & Mein, 1982).

We decided on the following strategy for measuring compressive load: recording a numerical model of the liner surface and analysing the forces acting on the liner, including the forces acting between the teat and the liner.

A numerical description of the liner's surface

In the massage phase the liner moulds to the teat, which means that the inner surface of the liner corresponds with the outer surface of the teat. The distance between the teat surface and the outer liner surface is thus the thickness of the liner wall. We worked out a method to describe this outer surface numerically. It uses methods used in land surveying. By means of recently developed video and computer techniques it is possible to automate the process. The chosen method can be described as dynamic stereophotogrammetry with automatic digital image processing.

Photogrammetry is a contactless measurement and therefore enables the research to be done without disturbing the liner's function. A disadvantage of the method is that it requires a large amount of primary data and complex processing before the end results are ready. Automatic digital image processing solves that problem. Image processing also requires video techniques which, as a spin-off, enable dynamic measurements to be obtained within the limitations of the video system, that is up to 50 images per second.

The system of measuring is briefly described below. Maalen-Johansen (1992) gives a detailed description of the system.

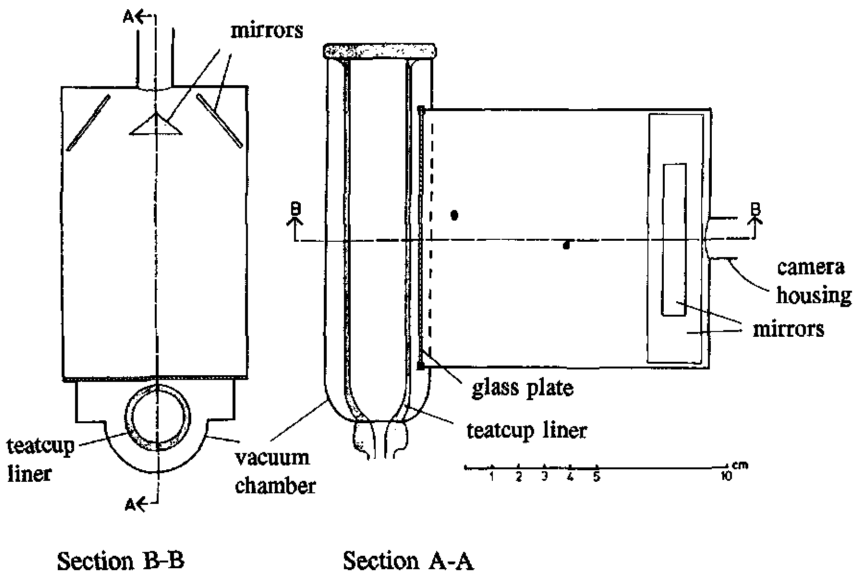


Figure 1. Sketch of the camera rig (Maalen-Johansen 1992).

The camera rig

Stereophotogrammetry requires two images of the object acquired from two camera positions. A camera rig with a set of mirrors and a miniature TV-camera was rigidly mounted to the teatcup shell. Figure 1 shows a sketch of the rig. The TV-image is split in two halves, each showing the same section of the liner. The two halves have different virtual camera positions, and will therefore together represent the basis for a three-dimensional numerical description of the liner's surface.

Image acquisition

The liner movements under milking are recorded on a video tape recorder. A personal computer with a frame grabber card is used to process the play-back from the tape. The frame grabber card is set up to acquire 32 images continuously at a rate of 25 images per second. The result from one period of recorded liner movements is a sequence of images covering slightly more than one pulsation cycle.

Automatic target determination

To determine the three-dimensional co-ordinates of points on the liner surface, we have to know the position of corresponding points in the two image halves. It is not possible to detect points on an evenly dark rubber surface. Therefore we have to put targets on the liner. Circular white targets of 1.5 mm diameter with a spacing of 6.5 mm are used. These targets are easily recognized in the images. An automatic computer program has been made to scan the images. This process yields a list of image co-ordinates for all targets in all the 32 images in a sequence.

Calculation of 3-D co-ordinates

There are about 15 parameters in the system that have to be determined for the calibration. This is accomplished in a calibration routine with a special calibration frame replacing the liner in the teatcup. The calibration and computation of model co-ordinates are standard methods in land surveying. After the computation we end up with a result which is illustrated in Figure 2 and can be described as being a numerical description of a section of the liner's surface repeated at constant time intervals, over slightly more than one pulsation cycle.

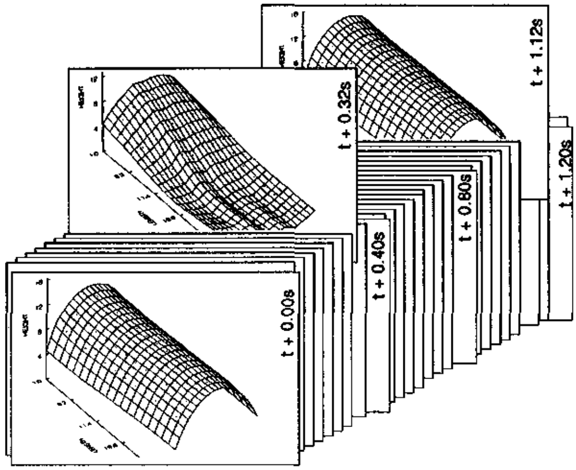


Figure 2. The dynamic surface model. Results from measurements on a live teat. The three visible three-dimensional charts show the surfaces of respectively open liner, collapsed liner and open liner.

Calculation of parameters of liner characteristics

From the dynamic numeric surface model there are numerous possibilities of deriving parameters for liner characterization. In order to concentrate on the initial objective of the project, the search for parameters has been restricted to compressive load on the teat tip and to finding some measure of the volume of the teat tip. The latter parameter would be very useful, because it expresses an immediate reaction to the exposure during milking, similar to cutimeter measurings (Hamann 1985). Another parameter for the immediate teat end response, which may be very interesting in this context, is the teat hysteresis (Reitsma & Gupta 1987).

The first method for calculating compressive load on the teat tip was based on the same mechanical model as that used by Williams & Mein (1982). Knowing the distance between targets on the liner in collapsed phase and in neutral position enables the local strain in the liner to be calculated. This strain and the curvature of the liner surface are inputs in the formula for the calculation of the compressive load.

The teat tip volume calculations are tricky. The result largely depends on what section of the teat is included in the calculation, and that in turn depends on the location of the teat end. However, the calculation of a volume, a cross-section or a diameter can be done very easily. Once it has been decided under which part of the liner the measurements shall be taken. So far, the best suggestion is to calculate the mean "diameter" under an area of fixed size where the compressive load has its highest value.

Results

The calculations of compressive load were tested on a rigid plastic teat. Figure 3 is a graphic representation of topographic models and compressive load. The results look promising, with the liner surface following the teat surface, and with the magnitude and location of the compressive load as expected.

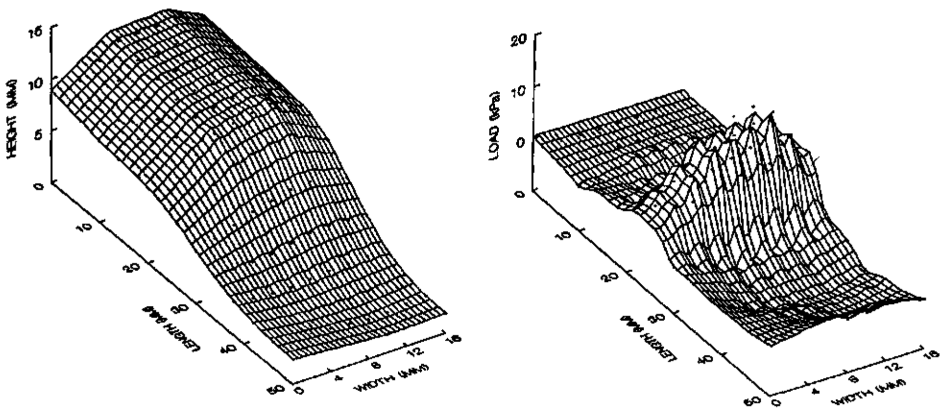


Figure 3. Liner surface and compressive load exerted on a rigid plastic teat.

The next step was to test the method on live teats. The teats had a wedge shape in the collapsed liner, and that shape gave very low calculated compressive load. With these low values of compressive load the relative errors of the estimated compressive loads were too high to enable the teat end location to be reliably determined. A conclusion so far is that we have to look for more sophisticated methods for calculation.

Further work

We now (mid-summer 1992) have a good method for obtaining a dynamic surface model of the liner. We have plans to make a new generation of camera rig, smaller, no heavier than an ordinary teatcup shell, and adjustable for different liners.

Further, we have to improve the calculations of parameters concerning compressive load and teat response before we can start investigations.

The first trial of the method will be on a herd at the Agricultural University of Norway where a correlation has been found between increasing prevalence of subclinical mastitis and increasing length of fore teats and decreasing length of rear teats (Klemetsdal et al. 1992). We will investigate if the mastitis status can be explained by the compressive load on teats or by other parameters that can be derived from liner surface models.

References

Balthazar, J.A. & N.R. Scott, 1978. Response of the dairy cow's teat by the finite element analysis. In: W.D. Schultze, J.W. Smith & P.D. Thompson (Eds.): Proceedings of the international symposium on machine milking, 17th Annual Meeting of National Mastitis Council, Inc. National Mastitis Council Inc., Washington, USA, p. 63-79.

Caruolo, E.V. , 1983. Measuring force of massage produced by the teatcup liner. Journal of Dairy Science 66:2441-2445.

Gates, R.S. & N.R. Scott, 1986. Measurements of effective teat load during machine milking. Transactions of the ASAE 1986:1124-1130.

Hamann, J., 1985. Measurement of machine milking induced teat tissue reactions. Milchwissenschaft 40:16-18.

Hamann, J., 1990. Responses of bovine teat to physical forces applied during machine milking with regard to new infection rate. In: Proceedings from the seminar Machine milking and mastitis. National Institute of Animal Science, Foulum, Tjele, Denmark, p. 27-42.

Klemetsdal, G., K. Reitan & O. Østerås, 1992. Correlation between udder morphology and mastitis. Faginfo nr. 13 1992. SFFL, Ås, Norway, p. 115-120.

Maalen-Johansen, I., 1992. Close-range videometry. Design and calibration of a mono-camera system for dynamic purposes. International Archives of Photogrammetry and Remote Sensing, 28(V) (in press).

Mein, G.A., M.R. Brown & D.M. Williams, 1986. Effects on mastitis of overmilking in conjunction with pulsation failure. Journal of Dairy Research 53:17-22.

Rasmussen, M.D., E.S. Frimer, N.E. Jensen & L. Kaartinen, 1989. The correlation between compressive load of the teatcup liner, teat length, udder health and performance of milking. National Institute of Animal Science, Foulum, Tjele, Denmark. Report No. 729, 4 pp.

Reitsma, S.Y. & R. Gupta, 1987. Teat hysteresis and other teat properties affecting bovine mastitis. In: International mastitis symposium. MacDonald College, Quebec, Canada, p. 11-43.

Rønningen, O. & A.D. Reitan, 1990. Teat length and penetration into teatcup during milking in Norwegian Red Cattle. Journal of Dairy Research 57:165-170.

Szlachta, J., 1985. Effect of geometrical and mechanical parameters of the teat liner on the intensity of teat massage. In: J. Wisniowski (Ed.): Proceedings of the V International symposium on mastitis control. Bydgoszcs, Poland, p. 473-483.

Williams, D.M, G.A. Mein & M.R. Brown, 1981. Biological responses of the bovine teat to milking: information from measurements of milk flow-rate within single pulsation cycles. Journal of Dairy Research 48:7-21.

Williams, D.M. & G.A. Mein, 1982. Physical and physiological factors affecting milk flow-rate from the bovine teat during milking. In: K.L. Macmillan & V.K. Taufa (Eds.): Dairy production from pasture. Ruakura Animal Research Station, Hamilton, New Zealand, p. 42-74.

The influence of switch level in automatic cluster removers on milking performance and udder health

M.D. Rasmussen

National Institute of Animal Science, Department of research in Cattle and Sheep, Foulum, P.O. Box 39, DK-8830 Tjele, Denmark

Summary

The effect of a switch level of 200 g/min (group 200) or 400 g/min (group 400) in automatic cluster removers on milking performance and udder health was measured on 71 first lactation cows in their first 36 weeks of lactation and on 64 older cows in their first 12 weeks of lactation. Early removal of the milking unit reduced machine-on time by 0.5 min, slightly increased average milk flow rate, improved teat condition significantly and reduced the change in teat end thickness during milking of first lactation cows. Despite early removal of the milking unit, milk yield and composition remained the same in the two groups. Incidence and prevalence of subclinical mastitis were equal in the two groups. However, fewer older cows (insignificant) developed clinical mastitis in group 400. It is concluded, that the milking unit may be detached at a milk flow rate of 400 g/min instead of 200 g/min without negatively influencing milk yield. Machine-on time is shortened and teat condition improves whereas udder health does not seem to be influenced.
Keywords: automatic cluster removers, milk yield, udder health.

Introduction

End-of-milking detectors are used worldwide and about half of the cows in Denmark are milked with a milking unit equipped with an end-of-milking flow rate detector. Traditionally, a cow has been regarded as sufficiently milked when milk flow rate drops below 200 g/min. However, the question of whether or not this switch level is the best alternative, remains open.

A calculation from milk flow curves of first lactation cows showed that a milk yield was 0.13 kg less when the milking unit was detached at 400 g/min instead of at 200 g/min. Machine-on time would have been reduced by 0.4 min at the same time. In a pretrial to the experiment reported in this paper a change- over experiment was set up with 24 older cows, using periods lasting 4 weeks. Cows were milked with a high line milking system and with automatic cluster removers (ACR's) detaching either at 200 g/min or at 400 g/min. Milking vacuum was 48 kPa and the vacuum in the cluster immediately before detaching at 200 g/min was 1.1 kPa higher compared with detaching at 400 g/min. After milking with an ACR detaching at 400 g/min instead of 200 g/min machine-on time was reduced by 0.8 min ($P<0.05$), milk yield was slightly higher, but more quarters became newly infected ($P<0.05$). However, teat end erosions or hyperkeratosis of cows being milked by the 400 g/min ACR were less severe ($P<0.05$). A significant interaction between switch level and number of milkings per day was present ($P<0.05$), and there was no difference in teat end erosions between groups if cows were milked 4 times per day. This interaction may be due to a long-term effect of 4 times daily milking which could not be changed by removing the milking unit earlier for just 4 weeks. An unexplainable increase in the cell count of not infected cows was noted in the periods when cows were milked with the 400 g/min ACR.

The objective of this experiment was to determine the effect of detaching the milking unit at 200 g/min or at 400 g/min on milk yield, milk composition, milking performance, milkability and udder health of cows not exposed to any of the switch levels within the same lactation.

Materials and methods

One hundred and thirty five Danish Holstein cows at the national Research Centre Foulum, Denmark, were included in this experiment. Treatments were started at calving and lasted 36 weeks for first lactation cows and but only 12 weeks for older cows.

Treatments were group 200: milking with ACR's with a switch level of 200 g/min and a delay time of 18 s, and group 400: milking with ACR's with a switch level of 400 g/min and a delay time of 12 s.

First lactation cows and older cows were milked separately in tie-stall barns with a high line milking system and using the standard milking routine (Rasmussen et al., 1990). Cows of the two groups were mixed throughout the barn. Three milking units of each type (UNICO1, S.A. Christensen, Kolding, Denmark) were available in each barn. Cows were milked at 5 a.m and 4 p.m. The cows were fed a complete ration for ad libitum access.

Milk yield, milk composition and cell count were measured weekly. Machine-on time and milking performance were recorded every 4th week during an evening milking. Cow's temperament during premilking teat preparation, milking and detachment was scored on a 0 to 2 scale, 0: calm, 1: cow restless or raising a leg, 2: kicking the milker or milking unit.

Teat end diameter was measured every 4th week with the cutimeter (Hamann & Mein, 1988) immediately before machine attachment and immediately after detachment. Teat end erosions were scored every 4th week, 0: none, 1: white ring, 2: tendency and 3: severe. Milk flow curves were recorded once for older cows and twice for first lactation cows. Foremilk quarter samples were collected from the first week of calving and every 4th week thereafter. Clinically detectable changes of milk were recorded in connection with the sampling. Bacteriological and cytological examination of the milk samples and identification of mastitis pathogens were performed. All clinical cases of mastitis were recorded and examined bacteriologically.

Results and discussion

The main results of the experiment are in Table 1. Overall machine-on time was reduced by 0.52 min by increasing the switch level from 200 to 400 g/min in which the decrease in the delay time accounts for 0.1 min. The reduction of machine-on time on first lactation cows in an advanced stage of lactation was equal in the two groups. The difference in machine-on time between groups was less than found by Sagi (1978) and in our preliminary experiment. Peak milk flow rate was not increased although average milk flow rate was 0.07 g/min higher in group 400 compared to group 200 and caused by a higher flow rate towards end of milking.

Milk yield and milk composition were not influenced by treatment group (Table 1, Figure 1) as indicated in our change-over experiment. In a short- term experiment, Sagi (1978) observed a slightly lower (not significant) milk yield of cows milked by a 400 g/min ACR compared to a 200 g/min ACR, but the difference between the two treatments in amount of milk that could be milked out with one minute extra milking was only 67 ml/day. Cows that had subclinical or clinical mastitis within the first 10 days of lactation yielded 1.0 kg ECM (Energy Corrected Milk) less per day than uninfected cows. A puzzling interaction between group and infection status was present; uninfected cows produced most kg of milk in group 200 and infected cows produced most kg of milk in group 400. This interaction was not significant for kg of ECM, because of an opposite reaction of the fat percentage.

In the first four weeks of lactation cows were calm during premilking teat preparation, milking or detachment (an average of 55% of the observations on group 200 and 66% of the observations on group 400). The tendency of cows in group 400 to be calmer was not significant and with advanced stage of lactation the groups equalized.

Table 1. The influence of switch levels of 200 g/min and 400 g/min on milking performance and udder health of first lactation and older cows.

	1st lactation		Older cows	
Switch level, g/min	200	400	200	400
No. of cows	38	33	32	32
Machine-on time, min	5.54[a]	5.01[b]	7.90[a]	7.39[b]
Average flow, kg/min	1.73	1.81	1.63	1.70
Milk, kg	21.13	21.17	31.46	31.62
Fat, %	4.51	4.48	4.54	4.59
Cows restless during milking, %	56	50	56	59
Cows restless during detach., %	42	44	32	16
Teat end erosion front, score	1.5	1.3	1.9[a]	1.3[b]
Teat end erosion rear, score	1.3[a]	1.0[b]	1.7[a]	1.1[b]
Δ teat end thickness, mm	0.43[a]	0.24[b]	-0.40	0.81
Subclinical, % cows infected	37.0	45.7	40.3	39.1
Subclinical, % cows newinfected	16.4	15.3	15.0	14.8
Clinical mastitis / 100 cow days	0.17	0.25	0.90	0.29

[a,b] statistically significant difference within lactation $P<0.05$.

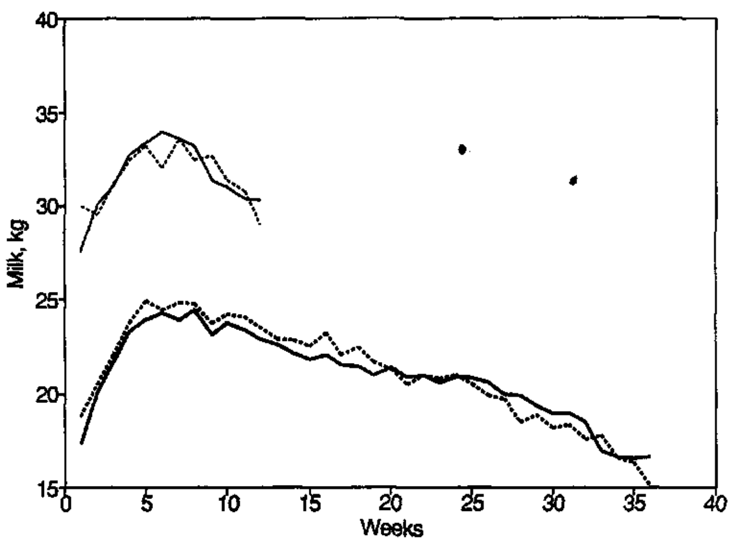


Figure 1. Milk yield of first lactation (lower curves) and older cows (upper curves) milked by ACR's detaching at 200 g/min (solid lines) or 400 g/min (dashed lines).

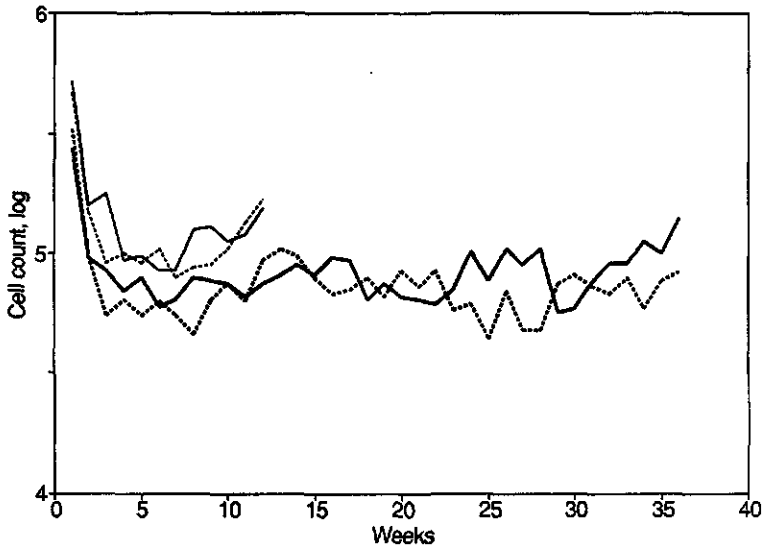


Figure 2. Cell count (log) of first lactation (lower curves) and older cows (upper curves) milked by ACR's detaching at 200 g/min (solid lines) or 400 g/min (dashed lines).

Significant differences in scores of teat ends were established after only four weeks of milking of older cows and after eight weeks milking of hind teats on first lactation cows. These differences between treatment groups clearly demonstrate that the last half minute of milking, when teats are becoming empty, is a sensitive period in terms of creating hyperkeratosis or teat end erosions. Teat end thickness increased during milking of teats on first lactation cows in group 200 compared to group 400 (Table 1). There were no significant differences in teat end thickness of older cows, although the trend seemed to be reversed. The smaller number of observations might account for this.

There were no differences between groups in the number of clinical cases of mastitis on first lactation cows or in subclinical udder health status of the cows. Percentage infected quarters increased with an increase in peak flow rate, and the highest infection rate was obtained by first lactation cows with high peak flow rates in group 400. However, there was a tendency for older cows in group 200 to develop more clinical cases of mastitis than group 400. The increase in machine-on time by detaching the milking unit at 200 g/min instead of 400 g/min is normally not regarded as over-milking. Natzke (1978) concludes that if overmilking is associated with mastitis its effects appear to be small. However, Østerås & Lund (1988) found a significantly higher frequency of *S. aureus* mastitis in herds with high line milking subjected to overmilking for more than one minute. Our experiment could only support this observation on subclinical cases of mastitis. The observation of a higher new infection rate of quarters and a larger cell count of uninfected cows of group 400 in the pretrial could not be repeated in this experiment. Moreover, there were no differences in cell count across the lactation (Figure 2). Consequently, it seems fair to state that for a herd comprising high and low peak flow rate cows at different number of lactation udder health will be not be influenced by different switch levels for ACR's in the interval from 200 to 400 g/min.

Conclusion

The milking unit can be detached at a milk flow rate of 400 g/min instead of 200 g/min without negatively affecting milk yield. Machine-on time is shortened and teat condition improved, whereas udder health does not seem to be influenced.

References

Hamann, J. & G.A. Mein, 1988. Responses of the bovine teat to machine milking: measurements of changes in thickness of the teat apex. Journal of Dairy Research 55:331-338.

Natzke, R.P., 1978. The relationship between overmilking and new infection. In: Proceedings of the International Symposium on Machine Milking. National Mastitis Council Arlington, VA, USA, 17:256-261.

Rasmussen, M.D., E.S. Frimer, Z. Horvath & N.E. Jensen, 1990. Comparison of a standardized and variable milking routine. Journal of Dairy Science 73:3472-3480.

Sagi, R., 1978. Milk flow rate and end of milking detectors. In: Proceedings of the International Symposium on Machine Milking. National Mastitis Council Arlington, VA, USA, 17:328-334.

Østerås, O. & A. Lund, 1988. Epidemiological analysis of the associations between bovine udder health and milking machine and milking management. Preventive Veterinary Medicine 6:91-108.

Measuring quarter milk electrical conductivity, milk yield and milk temperature for detection of mastitis

K. Maatje*, P.H. Hogewerf**, W. Rossing** & R.T. van Zonneveld**

* *DLO Research Institue for Animal Production 'Schoonoord' (IVO-DLO), P.O. Box 501, 3700 AM Zeist, The Netherlands*
***DLO Institute of Agricultural Engineering (IMAG-DLO), P.O. Box 43, 6700 AA Wageningen, The Netherlands*

Summary

In-line quarter milk conductivity (QMC) was measured in 65 cows over a period of 12 months and in 53 cows over 3 months to detect mastitis in dairy cattle. Data from the first year were used to develop algorithm and threshold values, which were then tested in the following period. Bacteriological examinations of quarter milk samples, cell counts and visual observations served as references for the conductivity measurements. High and low thresholds for QMC were determined in order to detect severe (clinical) and subclinical mastitis, respectively. The first should be considered for treatment during lactation and the latter for dry cow therapy. Daily milk yield and milk temperature measurements served to establish severity of mastitis. During the three-month period the algorithm and thresholds were tested in an on-line computer program for management purposes.
Keywords: dairy cows, mastitis detection, conductivity, automation.

Introduction

In order to identify animals suffering from clinical or subclinical mastitis in the case of automatic milking, an automatic system for mastitis detection will be indispensable. Generally a cost effective and rapid system for mastitis detection will have potential in mastitis control.

The economic impact of both clinical and subclinical forms of mastitis is large in the current dairy industry. Losses occur due to decreased milk production, treatment and labour costs, non-deliverable milk, veterinary fees, reduced milk price and increased risk of culling of the cow (Schakenraad & Dijkhuizen, 1990, Kaneene & Hurd, 1990).

In-line measuring of electrical conductivity in quarter milk will have good prospects in automatic detection of mastitis (Yamamoto et al., 1985, Rossing et al., 1989, Maatje et al., 1992). In the Netherlands for the purpose of measuring the in-line Quarter Milk Conductivity (QMC) during milking a sensor was developed to be built into the claw piece of the milking machine (Maatje et al., 1983).

During a trial of one year and a trial of three months, electrical conductivity measurements were carried out in order to detect clinical and subclinical mastitis. The aim of these investigations was to assess daily QMC measurements combined with daily milk yield and milk (body) temperature as a method of mastitis detection, which can indicate clinical (severe) mastitis at an early stage and subclinical mastitis at the end of lactation.

Material and methods

The system for measuring QMC, milk temperature and milk yield was installed in a six-point open tandem milking parlour at the experimental farm of IVO-DLO at Zeist, in which the cows were milked twice-daily. The cows were identified automatically. The first trial was carried out with 65 cows and with prototypes of the electrical conductivity sensors (Maatje et al., 1992). In the second trial with 53 cows, factory-made sensors for QMC and milk temperature were used (Figure 1).

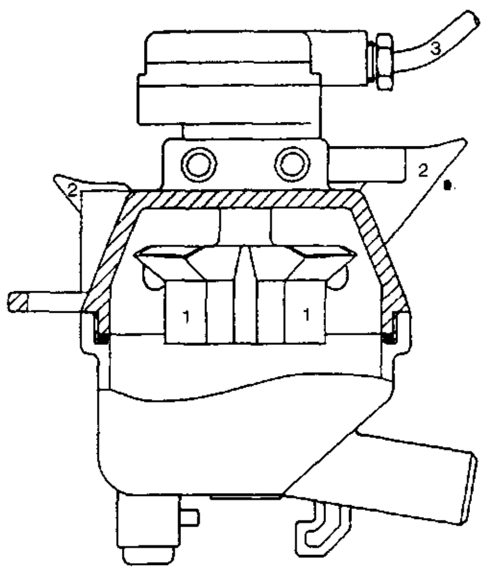


Figure 1. Cross-section of the milk claw showing the factory-made sensors measuring quarter milk conductivity. The temperature sensor has built into one of the conductivity cells. (1) cells with electrodes and temperature sensor. (2) short milk tube nipples. (3) wiring of the sensors.

During the first trial data were recorded for 12 months (1990). Every 2 months, quarter milk samples were taken for bacteriological analyses and somatic cell counts. During the following 3-month trial (1992) quarter milk samples were taken monthly. The laboratory examinations and clinical observations (deviant milk, swollen quarters) served as final checks for the development of the mastitis detection system.

In mastitis control, clinical mastitis is mostly treated during lactation and subclinical mastitis (if known) should be treated at the end of lactation. In line with this strategy of mastitis control, two threshold levels were tested in order to detect severe (clinical) cases of mastitis ("high threshold") and subclinical mastitis ("low threshold").

For testing the "high threshold" on the basis of laboratory examinations of the quarter milk samples, the animals were grouped into health categories according to IDF definitions:(1) mastitis (bact. pos., cell count >500 000/ml); (2) latent mastitis (bact. pos., cell count <500 000/ml); (3) secretion disturbance (bact. neg., cell count >500 000/ml; healthy (bact. neg., cell count <500 000/ml) (International Dairy Federation, 1981) and clinical mastitis (deviant milk, swollen quarters).

The necessity of dry cow therapy was also established by the results of the 2-monthly quarter milk samplings. On the basis of these data the cows were divided into three groups:

1. cows with mastitis (bact.pos., cell count >500 000/ml);
2. suspected cows (bact. pos. and /or cell count between quarters deviating > 200 000/ml;
3. healthy cows (bact. neg., cell count between quarters deviating <200 000/ml). This part of the research was carried out in the first trial only.

The algorithm and threshold values were developed in such a way that the number of false positive (increased QMC, no signs of mastitis) and false-negative detections (signs of mastitis present, QMC not increased) are minimized at an optimal ratio (Maatje et al., 1992). During the three-month trial the algorithm and threshold values were used in a computer program analysing the cow variables directly. After each milking an attention list for cows with deviating parameters was generated (Hogewerf et al., 1992).

Results

Efficacy of QMC

In Table 1 the cows are grouped in health categories on the basis of the 2-monthly and 1-monthly laboratory examinations (bacteriological examinations and cell count) of quarter milk samples. The number of cases is the number of cows present times the number of sampling days.

The incidence of clinical mastitis is also given for the 65 cows in 1990 and the three-month trial in 1992. In the three-month period there were only 2 cases of clinical mastitis. Also the cases of latent mastitis were totally different in both periods. The many cases of latent mastitis in 1990 were mainly caused by *Staphylococcus aureus*.

Table 1. Mastitis status of the experimental herd in 1990 and in the three months in 1992 on the basis of the 2-monthly (1990) and 1-monthly (1992) laboratory examinations of quarter milk samples and visual observations.

Category	Determination	Number 1990	Number 1992
Subclinical mastitis	laboratory	26[1]	18[1]
Latent mastitis	laboratory	106[1]	7[1]
Secretion disturbance	laboratory	42[1]	35[1]
Healthy	laboratory	200[1]	89[1]
Clinical mastitis	visual	25	2

[1] Cows × sampling days.

Table 2. Percentage of cows grouped in IDF health categories (Table 1) indicated by high thresholds for electrical quarter milk conductivity (QMC).

Category	Number exceeding high thresholds[1] (%) 1990	1992
Subclinical mastitis	53	67
Latent mastitis	11	57
Secretion disturbance	52	77
Healthy cows	4	9
Clinical mastitis	100	100

1

$$\frac{\text{running av. QMC (n=3) - running av. (n=3) lowest QMC}}{\text{running av. (n=3) lowest QMC}} \times 100 \geq 15\%$$

and two successive milkings:

$$\frac{\text{actual QMC - running av. (n=3) lowest QMC}}{\text{running av. (n=3) lowest QMC}} \times 100 \geq 20\%$$

The cow cases in the various health categories were compared with the QMC measured in parallel. The threshold values used were established empirically (Maatje et al., 1992). The results are given in Table 2. In both trials all cases of clinical mastitis were indicated when using the given threshold values. These threshold values also indicated about 50% and 70% of both subclinical mastitis and cases of secretion disturbance in the trials 1 and 2 respectively. The percentage of indicated cases of latent mastitis and healthy cows was fairly low in the first trial.

QMC of clinical mastitis quarters increased 35% on average, within cows compared to the lowest QMC. In many cases (nearly 65%) there was a rise in QMC before (14 days on average) clinical signs of mastitis appeared.

Milk temperature and milk yield

During the first trial, in 19 (76%) out of 25 cases of clinical mastitis there was also a significant deviation in milk temperature or both an increased milk temperature and a decreased milk yield (Table 3). In the second trial both cases of clinical mastitis were also accompanied by a significant rise in milk temperature and a decreased milk yield.

Table 3. Significant deviations of milk temperature and milk yield in cases of clinical mastitis.

	Number of days in lactation preceding clinical mastitis		
	1 - 7	≥8	all cases
Number of cases	7	18	25
no deviation	3	3	6
milk temp. only	3	8	11
milk yield only	-	-	-
both temp. + yield	1	7	8

Dry cow therapy

During the last two months of lactation the low threshold values were used in order to determine the necessity of dry cow therapy. Table 4 shows the number of cows of various thresholds selected for dry cow therapy.

If the low threshold is used, 100% of the cases of mastitis, 80% of the suspected cases, 20% of the healthy and 50% of all cows are indicated. That means that by adopting the 10% threshold, 50% of the cows need to be treated at the end of lactation. It is true that the false-positive detections are reduced if the higher thresholds (15%, 20%) are used, but the number of cows missing necessary treatment may increase.

Table 4. Cows selected out of 90 cows for dry cow therapy based on various thesholds for electrical quarter milk conductivity (QMC) during the last 2 months of lactation.

No. of times threshold exceeded[1]	threshold	Number of signalled cows		
		mastitis n=8	suspected n=32	healthy n=50
≥ 5	10%	8	26	11
≥ 5	15%	5	20	3
≥ 5	20%	5	11	2

1

$$\frac{\text{average QMC } (n=3) - \text{average lowest QMC } (n=3)}{\text{average lowest QMC } (n=3)} \times 100 \geq 10, 15 \text{ or } 20\%$$

Discussion

From our investigations into the correlations between subclinical mastitis and the applied thresholds for QMC, it appears that with low thresholds, percentages of true-positives and false-positives are high (high sensitivity and low specificity). Using higher thresholds and changing calculations (deviations between running averages), sensitivity is lower but specificity is higher (less false-positives). As subclinical mastitis is not often treated during lactation, detection is probably less relevant. However, detection of clinical (severe) mastitis is necessary, since this must be treated during lactation. When the high thresholds for QMC were applied, all cases of clinical mastitis were identified, while 50% of subclinical mastitis and secretion disturbances were indicated by these thresholds.

Moreover, it appeared (Table 3) that in many cases of clinical mastitis (76%) there was a significantly increased milk temperature or decreased milk yield. The combination of automatic collection and processing of QMC data, milk temperature and milk yield enables severe mastitis to be detected and treated. In many cases of clinical mastitis QMC was already deviating before clinical signs of mastitis appeared. In this way losses caused by mastitis can probably be reduced and chances of recovery increased.

In commercial herds, it is not normally known which cows are suffering from subclinical mastitis. For that reason it is currently recommended that all cows be treated at the end of lactation. This system for automatic mastitis detection offers the possibility of detecting which cows are suffering from subclinical mastitis. They can then be treated selectively with antibiotics at the end of lactation. Applying the lowest threshold (Table 4) guarantees that all subclinical cases and nearly all suspected cases are signalled. Increasing the threshold value introduces the probability of missing cases of suspected mastitis, but it also decreases the number of false-positives.

Conclusions

Research so far has shown that it is technically possible to perform in-line electrical conductivity measurements of milk from each quarter, milk temperature and milk yield during the milking process. The data can be collected and processed automatically by computer and integrated with other relevant data in a management system. A practical application of the system would be to use the thresholds for QMC during a cow's whole lactation period. When this threshold is exceeded, milk yield, both temperature and visual findings also have to be taken into account in determining the necessity of treatment. If the producer wishes to follow selective therapy, adopting the low threshold during the last two months of lactation should indicate the cows which need to have dry cow therapy.

References

Hogewerf, P.H., K. Maatje & W. Rossing, 1992. Computer aided system for health and reproduction control in dairy cows. In: A.H. Ipema, A.C. Lippus, J.H.M. Metz & W. Rossing (Eds.): Proceedings of the International Symposium on Prospects for Automatic Milking, EAAP publication No. 65, Pudoc Scientific Publishers, Wageningen, The Netherlands, p. 483-490.

International Dairy Federation, 1981. Laboratory Methods for Use in Mastitis Work, Document 132, Brussels, Belgium.

Kaneene, J.B. & H.S. Hurd, 1990. The national animal health monitoring system in Michigan. III. Cost estimates of selected dairy cattle diseases. Preventive Veterinary Medicine 8:127-140.

Maatje, K., W. Rossing, G.J. Garssen & H.G. Pluygers, 1983. Automation of electrical conductivity measurements during milking. In: Proceedings of the Symposium Automation in Dairying. IMAG, Wageningen, The Netherlands, p. 89-100.

Maatje, K., P.J.M. Huismans, W. Rossing & P.H. Hogewerf, 1992. The efficacy of in-line measurement of quarter milk electrical conductivity, milk yield and milk temperature for the detection of clinical and subclinical mastitis. Livestock Production Science 30:239-249.

Rossing, W., K. Maatje, E. Benders, P.H. Hogewerf & W. Buist, 1989. Automatic mastitis detection in the milking parlour. Proceedings of 28th Annual Meeting of the National Mastitis Council, Tampa, USA, p. 58-67.

Schakenraad, M.H.W. & A.A. Dijkhuizen, 1990. Economic losses due to bovine mastitis in Dutch dairy herds. Netherlands Journal Agricultural Science 38:89-92.

Yamamoto, M., T. Kume, M. Nakano, Y. Obara, T. Kudo, T. Ichikawa & I. Notsuki, 1985. Automatic measurement of electrical conductivity for the detection of bovine mastitis. Kieler Milchwirtschaftliche Forschungsberichte 37:364-369.

Composite milk electrical resistance as a means for monitoring mastitis

E. Shoshani & A. Berman

Hebrew University, Faculty of Agriculture, Department of Animal Science, P.O. Box 12, Rehovot 76100, Israel

Summary

The relationships of composite milk electrical resistance, bacteriological state, CMT and SCC levels, and hourly milk production were examined in three groups of lactating Israeli-Holsteins differing in mammary health status. Major or minor pathogens or high CMT (or SCC) were not associated with larger milk yield variance over a 10-day period. Results suggest that an estimate based upon concomitant declines in milk production rate and ER provides a reliable indication of subclinical mastitis requiring intervention to prevent immediate milk losses.
Keywords: Dairy cow, milk, electrical conductivity, mastitis, SCC, CMT.

Introduction

It has been suggested that milk electrical resistance (ER) be used for the detection of subclinical mastitis (Fernando et al., 1985). Automated on-line ER measurement during milking enables the ER to be monitored, the data to be processed and possibly early subclinical mastitis to be detected almost in real time. Its adoption as a management tool for mammary health requires further assessment. Validation is required on differences in ER between infected and uninfected quarters and day-to-day changes in it, the effect of single quarter infection on composite milk conductivity and changes in milk conductivity relative to phase of milking.

The relationship between ER and mammary infection is not always consistent. Individual infected quarters were best detected by their ER deviating from that of other quarters ((Linzell et al., 1974). However, no clear differences from milking to milking in the mean and SD of ER were observed between infected and uninfected quarters (Fernando et al., 1985). Also, rather variable correlations were found between ER and SCC (Little et al., 1968; Wolfe et al., 1972). The accuracy of primary pathogen infection detection by ER was greater for post-milking strippings than for foremilk samples, 96.2% vs. 62.8% (Fernando et al., 1981). ER measured during peak milk flow was less accurate for pathogen detection than ER measured in foremilk or post-milking samples (Isaksson et al., 1987). Timing the measurement of ER during milking may be replaced, however, by processing of data obtained during the milking. The difference between individual quarters (infected vs. uninfected) in the means of the five highest conductivity values obtained during a milking provided a better separation between infected and uninfected quarters, but allowed for false high values (Datta et al., 1984). Accuracy of subclinical mastitis detection increased when the number of highest values stored was increased from 5 to 10 and to 20 as well as when the averages obtained during several consecutive milkings were compared (Datta et al., 1984).

The studies mentioned above stressed the differences between infected and uninfected quarters during single milkings of individual quarters. In commercial applications, measuring ER in individual quarters may considerably increase system costs. Measuring ER in composite milk reduces detection accuracy, but this might be compensated for by analysing consecutive milkings. This study examined the relationship between composite milk ER, milk yield, and pathogens present, SCC and CMT as parameters of mammary health. These were examined in two groups of cows with high and low incidence of bacterial infection, and in a third group in which concomitant declines in milk yield and ER were used to indicate subclinical mastitis.

Experimental procedure

Animals

The study was carried out in commercial herds of Israeli-Holstein cows, milked 3× daily, kept in a loose housing system which provided at least 10 m^2 shade/cow and an adjacent yard of similar area. Food was offered in mangers located in shaded or unshaded parts of the sheds. The shaded area was bedded with wheat straw or coarse sawdust.

Milking system data

In all 3 herds a computerized milking system (Zacham, Afikim, Israel) was used. Cows were identified by passive transponders, and individual milk yields, milk electrical resistance (ER), pedometer recordings and milking times were stored for every milking. Milk was measured volumetrically, by number of 200 ml volumes (±1%) that passed through the milk meter (±2), and milk yield as volume produced per hour interval between milkings was stored for each milking. Stainless steel electrodes located in a measuring cell sensed electrical resistance in each milk volume passed, and the highest value (±1 ohm) was stored.

Study 1

This was carried out in two herds, A and B, on one management group in each herd comprising 94 and 63 cows respectively, each group located in a separate shed. Milk yield data were collected during a 10-day period. On day 5, duplicate composite milk samples were aseptically collected after morning milking from each cow, to determine bacterial infection state and SCC. A cow was defined as "infected" if a pathogen was isolated from one sample. Cows were classified as infected with major pathogens, minor pathogens or none (Table 1) according to IDF (Bramley & Dodd, 1984). Bacteriological analysis was carried out in the Mastitis Laboratory (Veterinary Institute, Bet Dagan, Israel). SCC was determined by Fossomatic cell counter (±10%) at the Dairy Herd Association Laboratory. It is presumed that a cow's mammary gland is likely to be infected if the SCC count in its milk exceeds 5×10^5 (Bramley & Dodd, 1994, Isaksson et al., 1987). This value was therefore selected as threshold to define a cow as "responding" to a subclinical infection.

Study 2

This was carried out in herd C on 67 cows detected as "suspected" of undergoing a subclinical mastitis event during a 120-day period. A cow was defined as "suspected" by either of two criteria. The first, if for two consecutive milkings ER was 50% below the mean of 10 preceding days for the particular milking times. The second, if ER deviated as fore-mentioned for one milking and milk yield was 30% lower than the mean yield for the particular milking time over the 10 preceding days. Composite milk samples were collected for three consecutive days for bacteriological analysis. Cows were classified as "responding" to a subclinical infection if the CMT class of milk sample of one or more quarters was equal to or more than 2.

Statistical analysis

Data were analysed using the SAS General Linear Model (Anonymous, 1982; Wolfe et al., 1972) procedures and type III mean squares. Models included daily yield (or yield at given milking) as dependent variable and mean cow ER within cow day-to-day deviations of ER from mean as independent variables.

Results

In these herds, cows were kept grouped by order of calving, and left their group sometime before being dried off. As a result, between-cow variance was a significant to major component of variance in milk yield (Table 3). Due to this, there is little relationship between milk yield and infection state or SCC or CMT ranking within a group or between herds. The within-cow day-to-day variation in milk yield and in ER in all three herds was relatively small (Figure 1), suggesting that ER and milk yield are more or less stable over periods of days.

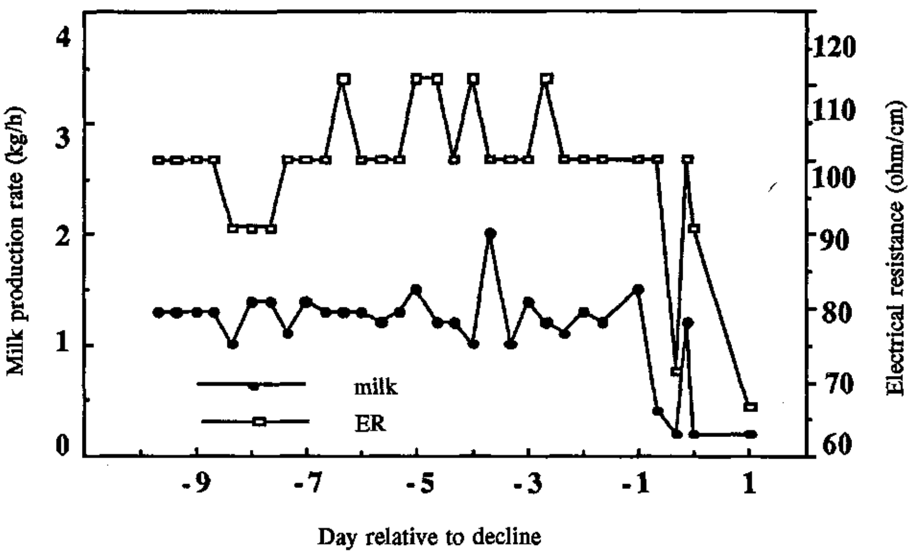


Figure 1. Typical hourly milk production rate and ER of composite milk in cow of herd C sorted for concomitant decline in milk production and ER.

In the three groups there were only small and statistically non-significant differences in hourly milk production rate and ER between milkings, i.e. between milk produced at different times during the day. ER was significantly lower in herd C (Table 1), for unknown reasons.

Infection effects. Mean milk yields and ER for the cows in the three herds were classified by type of bacterial infection found (Table 1).

In herd A only few cows were infected by major pathogens, while in herd B their incidence was rather high. Mean herd ER was not affected by ratio between bacteriological states. However, within each of the three herds, mean ER was lower in the presence of major pathogens, relative either to the presence of minor pathogens or to cases in which no pathogens were detected. The effect was statistically significant in herds B and C, in which animal number enabled statistical comparison. The effect of minor pathogens on ER, relative to uninfected animals, was smaller, and not consistent in the three groups. statistically significant difference was only found in group B.

Table 1. Mean milk yield (kg/cow-day) and milk resistance (ohms) by bacterial infection categories.

		Major path.	Minor path.	Not infected
Herd A	Yield	31.2 ± 0.5^{a}	27.8 ± 0.2^{b}	29.8 ± 0.4^{a}
	ER	81.3 ± 1.5^{b}	87.9 ± 0.6^{a}	89.6 ± 0.7^{a}
	N	2	55	37
Herd B	Yield	36.9 ± 0.9^{a}	33.9 ± 0.9^{b}	32.1 ± 0.7^{b}
	ER	84.6 ± 0.7^{a}	89.5 ± 1.2^{b}	94.2 ± 0.9^{c}
	N	23	16	24
Herd C	Yield	25.6 ± 0.5^{a}	26.2 ± 0.5^{a}	25.1 ± 0.6^{a}
	ER	72.2 ± 0.6^{b}	77.6 ± 0.4^{a}	77.7 ± 0.6^{a}
	N	8	40	19

[a,b] statistically significant difference ($P<0.05$).

A similar relationship was found when tests of mammary tissue response to infection (SCC in herds A and B, or CMT in herd C) were used for assessing mammary health; ER was lower in cows in which SCC was over 5×10^5 in herd A ($P<0.05$). In the other two herds, the number of animals in one of either categories precluded statistical inference (Table 2).

Table 2. Mean milk yield (kg/cow-day) and resistance (ohm) by response categories as assessed by $2 > CMT > 2$ (herd C) or by somatic cell count $5\times10^5 > N > 5\times10^5$ (herds A,B).

Response category		Herd A	Herd B	Herd C
1	Yield	27.8 ± 0.2^{a}	34.2 ± 0.5^{a}	32.7 ± 1.4^{a}
	ER	89.1 ± 0.6^{a}	89.4 ± 0.6^{a}	85.2 ± 1.0^{a}
	N	61	58	5
2	Yield	29.1 ± 0.3^{b}	36.1 ± 1.2^{a}	25.3 ± 0.3^{b}
	ER	85.4 ± 0.6^{b}	90.7 ± 2.5^{a}	75.8 ± 0.3^{b}
	N	33	5	62

[a,b] statistically significant difference ($P<0.05$).

Covariance of ER and milk yield

Covariance of ER and milk yield. The correlation between milk yield and ER was low in each of three herds ($R=0.05$; $P<0.05$). It comprises factors which vary from animal to animal (effects of genotype, lactation number and stage, presence and nature of infection), and environmental factors which vary from day to day and are common to animals in a group. Mammary health might be expressed in relationship of ER to milk yield in within-cow changes from day to day (Table 3).

Table 3. Mean squares (type III) of daily milk yield as function of cow, mean cow ER and day to day ER deviations from mean in the three herds (model R2=0.76-0.97, P<0.01) and coefficients or regression.

Model	Herd A			Herd B			Herd C		
Term	df	MS	P<	df	MS	P<	df	MS	P<
Cow	90	197	.01	78	185	.01	66	1689	.01
Mean ER	1	15.5	.01	1	54	.01	1	1975	.01
ER deviation	1	1200	.01	1	2.5	.40	1	1165	.01
Regression coefficients									
Mean ER		-.05			-.22			.28	
ER deviation		.42			NS			-.56	

The between-cow variance in milk yield is determined mostly by the composition of the groups, i.e. the variance in dairy merit, age and stage of lactation. It may therefore vary markedly from group to group. The cows in herd C were selected on the basis of concomitant declines of ER and milk yield from the mean. The negative effect of decline in ER on milk yield therefore results from the group selection method. It is, however, significant in that in such cows the mean milk yield increased with rising mean ER of the cow. This may result of an effect of lactation stage on mean ER or of a group characteristic. It is rather difficult to associate the bacteriological states of the three groups with the variation in effects of mean ER on milk yield.

Day-to-day changes in milk yield were significantly affected by mean ER in the three herds, the regression coefficient being significantly different from zero. However, similarly to the effect of mean ER, the coefficients relating milk yield to ER deviations were variable, and there was no apparent relationship between them and bacteriological state. Remarkably similar coefficients were obtained within each herd when cows were classified by types of pathogens detected or by level of response. This indicates that the coefficients are independent of the presence or nature of pathogens. In herd C, a concurrence of reductions in ER and milk yield reflected in their pattern following that event: mean ER and milk yield were significantly higher in the 10-day period preceding detection of a subclinical mastitis event (78.6±0.4 ohms and 27.7±0.4 kg, respectively) than in the 10-day following it (74.5±0.4 ohms and 23.6±0.4 kg, respectively). Of the cows identified as suspected of subclinical mastitis, 72% were found to be infected, 12% by major pathogens and 60% by minor pathogens. Also, in 93% of them a high response level was found. In the main, the results of milk yields at different milking times were similar to those of daily milk yield means.

Discussion

This study indicated that composite milk ER is lower in cows in which major pathogens were detected or a high responding level was found. This is in line with other studies (Eberhard et al., 1979, Rindsig et al., 1979). All cows in which major pathogens were detected had a high SCC count or CMT rank in their composite milk samples. The same was true for 92% of cows infected by minor pathogens and 93% of cows singled out as being suspected of having subclinical mastitis in herd C. These findings suggest that in the vast majority of cases the presence of either major or minor pathogens is associated with a high SCC or CMT.

Subclinical infection might be a short event, initiated by pathogen penetration and brought to an end by spontaneous recovery; it might also be an infection maintained over an extended period, with sporadic outbreaks during which mammary function is impaired and milk yield is consequently reduced (Bramley & Dodd, 1984). This might involve larger day to day variability in milk yield and probably concomitant changes in ER. In this respect it is significant that the cows sorted out as suspect in herd C did not differ from the other two groups in variability of milk yield. It is also significant that in about 30% of suspect cows of herd C no pathogens were detected in composite milk, although in 93% of them a high CMT level was found and the ER was markedly lower than in the randomly selected cows of herds A and B. This study suggests that neither the presence of pathogens nor a high SCC count or CMT level nor a mild reduction in ER necessarily indicates impairment of mammary function. However, a concurrent reduction in ER and milk yield probably indicates the onset of impairment to mammary function, which subsequently lasts for a period of days. This does not seem to be inevitably linked with detectable pathogens in composite milk samples.

References

Anonymous, 1982. SAS User's guide: Statistics, Version 5, SAS Institute, Cary, NC, USA.

Bramley, A.J. & F.H. Dodd, 1984. Reviews of the progress of dairy science: Mastitis control - progress and prospects. Journal Dairy Research 51:481.

Datta, A.K., H.B. Puckett, S.L. Spahr & E.D. Rodda, 1984. Real time acquisition and analysis of milk conductivity data. Transaction of the ASAE 27(4):1204-1210.

Eberhart, R.J., H.C. Gilmore, L.J. Hutchinson & S.B. Spencer, 1979. Somatic cell counts in DHI samples. NMC, Inc. 18th Annual Meeting, p. 32-90.

Fernando, R.S., R.B. Rindsig & S.L. Spahr, 1981. Effect of length of milking interval and fat content on milk conductivity and its use for detecting mastitis. Journal of Dairy Science 64:678-682.

Fernando R.S., S.L. Spahr & E.H. Jaster, 1985. Comparison of electrical conductivity of milk with other indirect methods for detection of subclinical mastitis. Journal of Dairy Science 68:449-456.

Isaksson, A. A.C. Philips, E. Goransson & H. Bjorkkenfeldt, 1987. The electrical conductivity of bovine milk in mastitis diagnosis. Acta Veterinaria Scandinavica 28:455-457.

Linzell, J.L., M. Peaker & J.G. Rowell, 1974. Electrical conductivity of foremilk for detecting subclinical mastitis in cows. Journal of Agricultural Science 83:309-325.

Little, T., C. Hebert & D. Forbes, 1968. Electrical conductivity and the leucocyte count of bovine milk. Veterinary Record 82:431-432.

Rindsig, R.B., A.R. Rodewald, A.R. Smith, N.K. Thomsen & S.L. Spahr, 1979. Mastitis history, california mastitis test and somatic cell counts for identifying cows for treatment in a selective dry cow therapy program. Journal of Dairy Science 62:1335.

Wolfe, R.R., S.C. Sharma & G.H. Ward, 1972. A method for electronic detection of bovine mastitis. Transactions of the ASAE 15:3:500-503.

Woolford, M.W. & J.H. Williamson, 1982. The electrical conductivity of milk as diagnostic of subclinical mastitis. In: Proceedings of the Conference on Dairy Production from Pasture. Ruakura Animal Research Station, Hamilton, New Zealand.

Measuring milk conductivity and temperature during milking

J. Vegricht, P. Ambroz & A. Machalek

Research Institute of Agricultural Engineering, K Šancím 50, 163 07 Prague 6 - Řepy, Czechoslovakia

Summary

Many experiments have demonstrated relationships not only between milk electrical conductivity and mammary inflammation but also between dairy cow body temperature and oestrus and/or illness. Hence it is advantageous to equip the milking machine with sensors to measure milk conductivity and temperature during milking.

This work is primarily directed toward studying the set of sensors that measure milk conductivity and temperature during milking, including the electronic modules for interfacing and transforming signals from sensors. The probe is built into the milking claw. A simple entry for clearing the accumulation wells is possible by shifting or removing the crucible from the probe body.

An experiment was carried out in the next phase, where milk conductivity and temperature were measured during milking of a selected group of cows. It was discovered that it was possible to replace common methods of detecting inflammation by using known methods of processing measured conductivity data with less than 3% error. A new processing method was defined from measured values. This method has all the advantages of the relative methods and uses data measured by one sensor only, allowing the error caused by the drift of the sensor to be eliminated. The milk temperature measurement was shown to be less significant, because many factors contribute to milk temperature changes.

Using the measured data for evaluating the health of selected cows is also part of this work. A learning system was developed for solving this problem.

Keywords: milking, conductivity, temperature, learning system.

Introduction

There is unambiguous correlation between milk conductivity and mammary inflammation, and criteria for the evaluation, and for the diagnostic efficiency of these criteria have been determined (e.g. Fernando, et al., 1982; Janal, 1986). Some results gained during the determination of criteria values led to the following factors being identified as having substantial influence on the milk conductivity: duration of the interval between milkings, number of lactation, stage of lactation, composition of feedstuffs, breed and fat content in milk.

Practical methods have been developed to be used to measure of conductivity in real time by means of sensor inserted in the short milk tube or collector, after checking the mutual relation between conductivity and mastitis. These systems do not complicate the operation of milking apparatus because they do not interfere with the operating process of milking. They enable the milk conductivity to be measured during each milking.

Body temperature is also an important factor used for diagnosing the health status and abnormalities of milking cows. Together with disease, oestrus is the most important factor influencing body temperature. It is difficult to incorporate the daily measurement of body temperature of cows into the system of automated data collection. It is more suitable to use an indirect method, i.e. to measure the milk temperature during milking, on the assumption that milk temperature is directly related to body temperature. The measured temperature is related to the average of preceding measurements during the evaluation of milk temperature values. Twice the standard deviation from the average temperature, measured in five preceding days is considered to be a significantly higher temperature (Maatje et al., 1987).

When evaluating measured values it is most important to find the relationship between the value of the measured variable and the occurrence of a disease or abnormality of the dairy cow (conductivity and mammary inflammation, body temperature and oestrus etc.). The evaluation is influenced by a number of other factors, and the threshold criteria values obtained differ from each other.

For daily farm management it is necessary to evaluate the health status of milking cows as a whole, from all the factors measured simultaneously and with all the mutual interrelationships i.e. to create a feature classifier fitted with several inputs and one output, where the generated signal is interpreted as a classification.

Results and discussion

The probe

Figure 1 shows the technical implementation of the MVT (Mereni Vodivisti a Teploty = Conductivity and Temperature Measurement) probe. Constructional solutions and modifications have been carried out on the probe on the basis of the results of laboratory measurements. For these measurements the sensors of conductivity and milk temperature must work in the real environment of the milking apparatus under conditions similar to the milking process.

The laboratory milking simulator was designed to allow individual changes in the rate of flow, ranging from 0.05 to 2.0 litres per minute in each of the quarters. The sampling period was set at 0.1 sec, taking account of the need for a response following within the pulsation cycle.

The exact information about dynamic properties of the probe provides the transient characteristic. Within the laboratory measurements the results of the MVT probe were compared with the CHECK GATE probe (produced by Eisai, Japan). Over the whole range of measured rates of flow, the MVT probe attained better dynamic properties than the CHECK GATE probe (Machalek et al., 1990).

The graphs of all transient characteristics of the temperature sensor differ from the expected transient characteristic of the first order. Within the graphs measured under conditions similar to the milking process, the fall in temperature occurred during the passage of tested solution through the teat cup liner.

Measurement during milking

Measurements were obtained during milking using a measuring unit in a mobile milking device placed on a truck in the tie-barn of Krasna Hora farm. The mobile milking device was equipped with a flow meter and an electronic unit allowing milking control, identification and data transfer. Thirteen milking cows were measured at the same stage of lactation (Czech red-white breed).

The result of the NK test (method of mastitis detection based on the chemical reaction of milk sample with the reagent) was taken as a reference value for the diagnosis of animal diseases. It is evident that the NK test is not an objective method for evaluating inflammation and will always contain a systematic error. The result is rather a comparison between a common detection method and evaluation by means of conductivity of milk.

The following methods were compared. Each has its specific way of data collection and processing:

1. absolute conductivity at the beginning of milking (AVZD), measured by digital dipping indicator AZD-514, which measures the absolute value of conductivity with 2.5% accuracy;
2. relative conductivity at the beginning of milking (RVZD), measured by dipping indicator AZD-514;
3. absolute conductivity during milking (AVPD), calculated from the average of maximum values measured by MVT probe during milking;
4. relative conductivity during milking (RVPD), calculated from the average of maximum values measured by MVT probe during milking.

Measurements during milking were carried out daily and made it possible to improve methods 3 and 4 by averaging values from the last three measurements. This improves the precision of evaluation (Datta, et al., 1984).

The results of evaluating of measured conductivity values by means of methods described in literature are shown in Table 1. It is evident that all the methods agree well with the evaluation of inflammation carried out by the NK test, and the total error is less than 5%.

Table 1. The results of evaluation of measured conductivity values.

Method	Threshold	Number of values	Classification (%) TN	TP	FP	FN	Total error (%)	Coefficient (%) detection	list
AVZD	0.65	1	91.4	3.9	3.2	1.6	4.8	71.4	55.6
RVZD	1.15	1	88.7	5.9	4.0	1.1	5.1	83.3	57.7
AVPD	0.76	1	90.2	5.1	3.9	0.8	4.7	86.7	56.5
RVPD	1.24	1	89.1	6.6	3.5	0.8	4.3	89.5	65.4
AVPD	0.76	3	91.4	4.7	2.3	0.8	3.1	85.7	66.7
RVPD	1.24	3	92.2	5.1	1.9	0.8	2.7	86.7	72.2

AVZD = absolute conductivity at the beginning of milking
RVZD = relative conductivity at the beginning of milking
AVPD = absolute conductivity during milking
RVPD = relative conductivity during milking
TN = true negative classification
TP = true positive classification
FP = false positive classification
FN = false negative classification. Values are in relation to total number of quarters

Total error = FP + FN

$$\text{Detection coefficient} = \frac{\text{number of TP}}{\text{number of TP} + \text{number of FN}} \times 100$$

determines effectiveness of inflammation detection.

$$\text{List coefficient} = \frac{\text{number of TP}}{\text{number of TP} + \text{number of FP}} \times 100$$

determines effectiveness of list of problem cows.

The worst results generally give the list coefficient, which indicates that in the best case (RVPD, number of values 3) almost one-third of all healthy quarters are in the list. This is in accordance with the fact that the thresholds of absolute and relative conductivity determined with an attempt to minimize error with respect to the results of the NK test are much higher compared with the values described in literature. This allows us to assume that the NK test is a subjective method which discovers the advanced stage of inflammation with great reliability. All the data were recorded within the complete milking operation and enabled the dependence of conductivity on time to be determined in individual quarters of a dairy cow. Figure 2 shows an example of a graph for a cow with inflammation in the right rear quarter. The considerable deformation of the graph of conductivity in the infected quarter is evident. These results agree with previously published graphs (Datta et al., 1984; Maatje et al., 1983).

The analysis of the single quarter graphs led to efforts to provide a criterion for detecting mammary inflammation direct from this graph, by means of conductivity measurement. The criteria value PMH was determined:

$$PMH = \frac{M(1,m)}{M(k-m,m)} \qquad (1)$$

where

PMH . . . . ratio of ordered maximum values,

$$M(i,m) = \frac{Cond(i) + Cond(i+1) + \ldots + Cond(i+m)}{m} \quad [S/m] \ldots \text{ m values average}$$

of decreasingly ordered series of conductivity values according to magnitude,
M(1,m) . . . . m values average of maximum conductivity values (for $i=1$)
Cond(i) [S/m] . . . . member of decreasingly ordered series of measured conductivity values according to magnitude,
$i = 1,2, \ldots . k$, k, m . . . . natural numbers.

The criterion suggested in this way has all the advantages of relative methods and eliminates the disadvantages connected with mutual comparison of values, measured in the quarters, i.e. unequal diagnostic efficiency in each of the quarters and error resulting from different changes of electrode parameters in time (fat and sediments and microscopic changes on the surface of electrode) (Ambroz & Machalek, 1991).

Table 2 shows the evaluation of measured values by means of PMH criterion for two thresholds. The first threshold has been rated with regard to minimum total error, and the second one with regard to minimum number of incorrect negative determinations. From the measured values it is impossible to ascertain how the criterion determines the advanced stage of inflammation. The criterion value approaches the value for the evaluation of relative conductivity.

Table 2. The results of evaluation by PMH method.

Method	Threshold	Number of values	Classification (%)				Total error (%)	Coefficient (%)	
			TN	TP	FP	FN		detection	list
PMH	1.22	1	82.1	6.6	10.5	0.8	11.3	89.2	38.6
PMH	1.22	3	90.6	5.1	3.5	0.8	4.3	86.4	59.3
PMH	1.23	1	87.4	6.3	5.5	0.8	6.3	88.7	53.4
PMH	1.23	3	92.0	4.7	2.0	1.1	3.1	81.0	70.1

The evaluation of the milk temperature measurements was less conclusive because of the dynamic properties of the sensor and the relatively short duration of the experiment. Many factors can significantly increase milk temperature and it is difficult to recognize them from the procurable information. The probable causes of the significant increase in the milk temperature were separated into three groups:

1. Oestrus produceable in only two cows, both had three oestrus cycles during the experiment. Increased temperature recorded in 5 out of 6 cases of oestrus occurrence.
2. Inflammation displayed considerable variation of temperature values in the case of one cow (milk temperature increased significantly occurred five times during the measurement).
3. Stress or faulty diet. There was a significant increase in milk temperature on the 14th day in all the cows; temperature changed within 1-3 days and then stabilized. The precise cause of this increase is unknown.

Learning system

The classifier enables the cow's health status to be checked every day, and provides the basic selection of problem cows on the basis of daily measurement and evaluation of all procurable information. To ensure that topical data are available for operators and farm managers the health status must be evaluated adequately.

The data input in the system are measured (conductivity, temperature, yield etc.) and from the herd information system (stage of lactation, information about treatment etc.). These data (features) must in many cases be rendered into usable form before being used as the input feature vector of the classifier.

The learning classifier works in two phases. The first is a classification in which it assigns objects (cows) to the output classes (healthy cow, cow with inflammation, cow in oestrus etc.). The second phase is learning, in which the teacher information (information about correct class for corresponding vector) is added to the input data.

The resulting proposal is based on the principle of three independent classifiers, while the class is indicated by the positive value of output of the conformable classifier (dichotomy). If not one single classifier indicates a health problem, the cow is assigned to the class of healthy cows (without abnormality). Learning of individual classifiers is provided by constant increments combined with the algorithm of fastest approach.

The total number of data evaluated during the experiment was 1170 (feature vectors). These data were used as input for the classifier and were augmented by the information on conformable classification according to the result of examination and treatment. 59 representative vectors were selected from the total number and used as training samples for the proposed classifier. All 1170 vectors were classified by this classifier.

The total number of incorrectly classified cows was 15, i.e. total error 1.28% and no cow with abnormality was classified as healthy. Thirteen healthy cows were classified as abnormal (1.11%) and 2 cows were classified incorrectly in the frame of abnormality (0.17%).

References

Ambroz, P. & A. Machalek , 1991. Mereni merne elektricke vodivosti a teploty mleka v prubehu dojeni. Zemedelska technika, 10.

Datta, A.K., H.B. Puckett, S.L. Spahr & E.D. Rodda, 1984. Real time acquisition and analysis of milk conductivity data. Transactions of the ASAE 27:1204-1210.

Fernando, R.S., R.B. Rindsig & S.L. Spahr, 1982. Electrical conductivity of milk for detecting of mastitis. Journal of Dairy Science 65:659-664.

Janal, R., 1986. Mereni konduktivity mleka a jeji vyuziti v praxi. VSZ Prague.

Maatje, K., W. Rossing, G.J. Garssen & H.G. Pluygers. 1983. Automation of electrical conductivity measurements during milking. In: Proceedings of the Symposium Automation in Dairying, IMAG, Wageningen, The Netherlands, p. 89-101.

Maatje, K., F. Wiersma & W. Rossing, 1987. Measuring milk temperature during milking and the activity of the dairy cow for detecting sick cows and cows in oestrus. In: Proceedings of the Symposium Automation in Dairying, IMAG, Wageningen, The Netherlands, p. 176-184.

Machalek, A., P. Ambroz & L. Galler, 1990. Zdokonalovani linek dojeni a zpracovani mleka. Research report number, Z - 2227, VUZT Prague.

Investigations on the suitability of different milk parameters for the early detection of mastitis, and implications for automated monitoring

D. Schlünsen* & R. Bauer**

* *Federal Research Centre for Agriculture (FAL), Institute for Production Engineering, Bundesallee 50, D-3300 Braunschweig-Völkenrode, Germany*

** *Technical University of Munich, Institute of Agricultural Engineering, Freising-Weihenstephan, Germany*

Summary

The effects of an artificial infection with *Strep. uberis* on the secretion performance of udder quarters were examined in experiments on cows in early and late lactation. The results have implications for the automated monitoring of udder health.
Keywords: animal health monitoring, mastitis, milk yield, milk components, milk conductivity.

Introduction

In many parts of the control of industrial processes, automation is accompanied by the monitoring of the working process and product quality. Transferred to the conditions in dairying it is obvious that monitoring and controlling are particulary important for its biological processes. Once robot milking completes automation in dairy husbandry, the requirements for animal health control from the viewpoint of animal welfare, and the demands for product quality control from the point of view of economics and consumer, requirements will be closely linked. Computerized monitoring of animal health aims to detect deviations from the normal physiology and changes in animal behaviour at a very early stage, to avoid disorders or reduce their effects. Ultimately, this means controlling the quality of the product or influencing it.

At the Institute of Production Engineering experiments were done to find suitable parameters for describing the normal state of health and for the early detection of deviations that can be monitored by electronic devices. The research reported below focused only on monitoring udder health.

Experimental procedure

Animals from the FAL research herd were used in the experiments. The experiments were subdivided into two groups:

- experiment 1 comprised 9 cows in late lactation (on average 7071 kg milk, 3.76% fat, 3.35% protein, 275 days in milk).
- experiment 2 comprised 6 cows in early lactation (on average 7927 kg milk, 3.84% fat, 3.32% protein, 67 days in milk).

In both groups *Strep. uberis* (4× 106 CfU) was used for the artificial infection. After the morning milking it was applied to each cow, into the udder quarter which had the highest somatic cell count value in the preliminary test. The secretion rate of the corresponding, non-infected quarter was used as a control value. This ensured that interfering effects such as nutrition or lactation state were eliminated. The milk from the single quarters was milked with a special quarter-milker and weighed. Samples to determine the milk composition were taken from the main milk of the quarters. Daily average values were calculated as weighted average of the milk composition in the morning and evening milk. The electrical conductivity of the milk in every single quarter (foremilk) and in the composite milk was measured off-line with a hand-held conductivity meter. The result of the manifestation of the artificial infection was given by the determination of the SCC and a bacteriological test. A multivariate analysis of variance was used for the statistical analysis.

Results and discussion

Milk yield

The comparison of the milk yield of healthy and treated udder quarters showed that the infected udder quarters had a reduction in yield of 7 to 8 percent of the average of the control quarters during the whole test period (Figure 1). This difference increased for two days post infectionem. No evidence of a compensation for a reduced yield in infected quarters by a higher secretion rate in one or more non-infected quarters was found in experiment 1. In the second experiment the yield of the control quarters was higher at the time when the yield of the infected quarters was lowest, however the differences were not statistically significant.

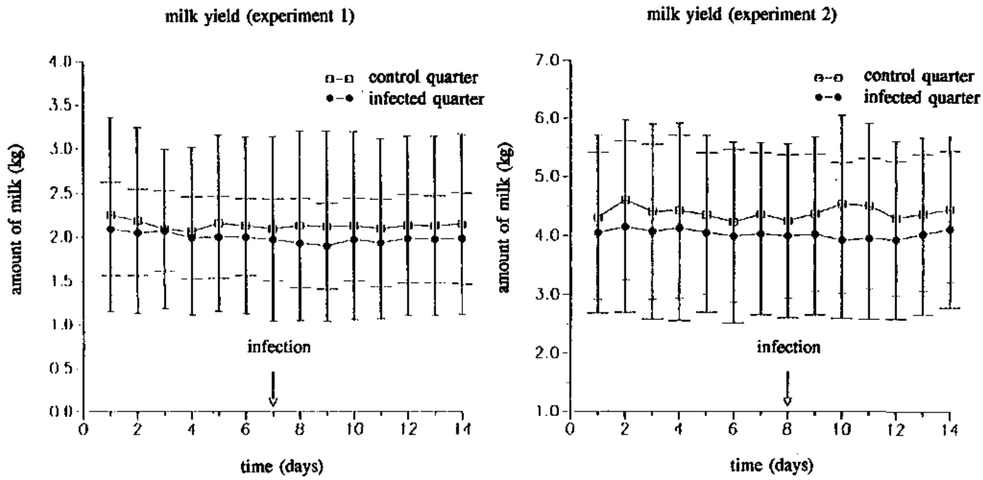


Figure 1. Mean values and standard deviation of the milk yield of the infected and the control quarters.

As stated above, the changes in the amount of milk from the chosen udder quarters could not be confirmed within the composite milk. From these results we conclude that the present milk yield recording of the bucket milk is not of great diagnostic value for the differentiated early detection of subclinical mastitis, taking into account that normal diurnal deviations in milk yield can reach +/- 2 kg without any visible causal interactions. On the other hand, with the automated milk yield recording it is possible to obtain indications for other diseases (for example ketosis) by comparing present data with the database on individual milk yield (Schlünsen, 1987).

Milk composition

In these trials it was shown that the milk fat content has the greatest variability of all the milk components (Figure 2).

The trend in the fat content in the course of both experiments could not give a clear indication of deviations in fat secretion from the infected quarters. Nevertheless, it was obvious that two days after the pathogenic suspension had been injected the parallelism in the course of the graph, especially in experiment 2, was interrupted. Even if these changes are seen in conjunction with the infection, and a deviation of 0.33 to 0.43 percent in the fat component is considered as normal, it has to be stated that the milk fat content is not a suitable detection parameter for the main objective of this investigation. Furthermore, in the near future no measuring method will be available for a low-cost, on-farm determination of the milk fat (or for the protein content of the milk).

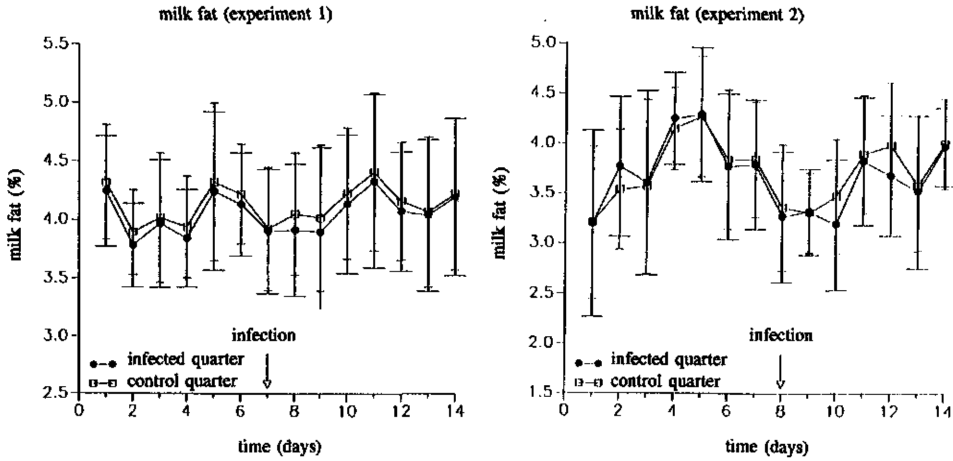


Figure 2. Mean values and standard deviation of the milk fat of the infected and the control quarters.

In contrast to the control values the average content of lactose declined to 0.32 percent (experiment 1) and 0.22 percent (experiment 2) in the infected quarters (Figure 3). The statistical comparison shows significant differences in the trend of the second and third degree for experiment 2 in the cubic component of the trend. This decline of the lactose content, which has often been reported (Jennes, 1985; Kitchen, 1981; Renner, 1974; Sissoko et al., 1984), was not found in the composite milk either.

Although in some states of Germany the lactose concentration is taken as a part of a monthly yield control and used as an indicator of udder health, these regular measurements, especially when they are taken from the bucket milk, can only give limited information for day-to-day herd management and for the early detection of secretion disturbances in particular.

Although the diagnostic value of the lactose content is widely acknowledged the use of this parameter is limited by constraints to the present measuring techniques. Similar to the determination of the fat content it has to be assumed that in the near future no reliable measurement procedure will be developed for the on-farm determination of the lactose content. Biosensors, which are already used in human medical care, are mainly applicable for the detection of monosaccharides. It is being doubt they would be sufficiently robust to withstand the conditions the measuring equipment in dairy farming is subjected to.

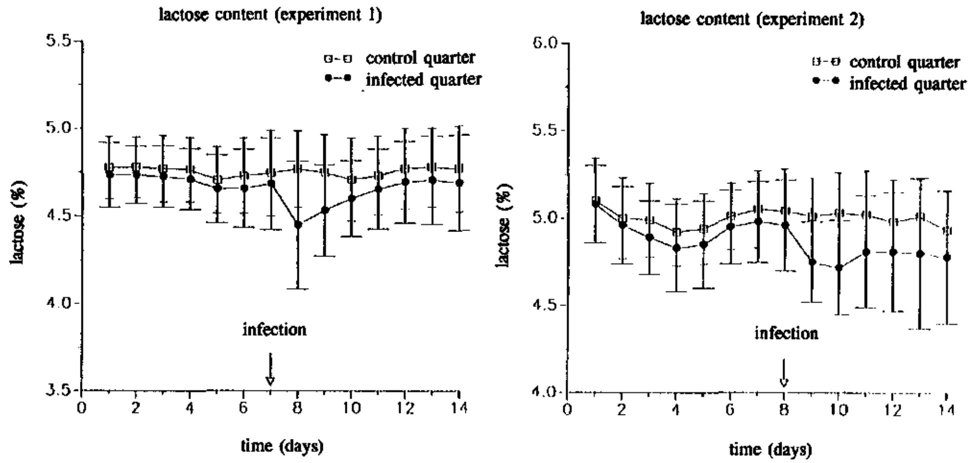


Figure 3. Mean values and standard deviation of the lactose content in the milk of the infected and the control quarters.

In our study the electrical conductivity of the milk also proved to be a very sensitive parameter to detect diseases in the udder (Figure 4). The conductivity of the milk from the infected quarters increased distinctly in both our experiments. The increase (+0.57 mS/cm) was greater in the cows in early lactation. The analysis of the trend showed non-random differences in the course of the values. Simultaneously with the increase of the values for the conductivity in the first experiment, the standard deviation increased by more than 35 percent, whereas in the second experiment only a limited variance around the mean values was observed. Two days post infectionem the conductivity values rose only slightly in the milk of the group of late lactating cows, whereas the cows in early lactation still reacted with an increase of the conductivity and stayed above the average value during the whole experimental period.

In the composite milk there were no signs of a change in conductivity. The close relation between the lactose concentration and the electrical conductivity is verified by the coefficient of correlation of $r = -0.73$ (experiment 2) to $r = -0.90$ (experiment 1). In contrast to this there was only a coefficient of $r = 0.20$ to $r = 0.48$ for the correlation with the SCC. This outcome corresponds to other published results (Maatje et al., 1983) and confirm the suitability of a quarter-specific measurement of the conductivity as a method to detect changes in the milk caused by infection.

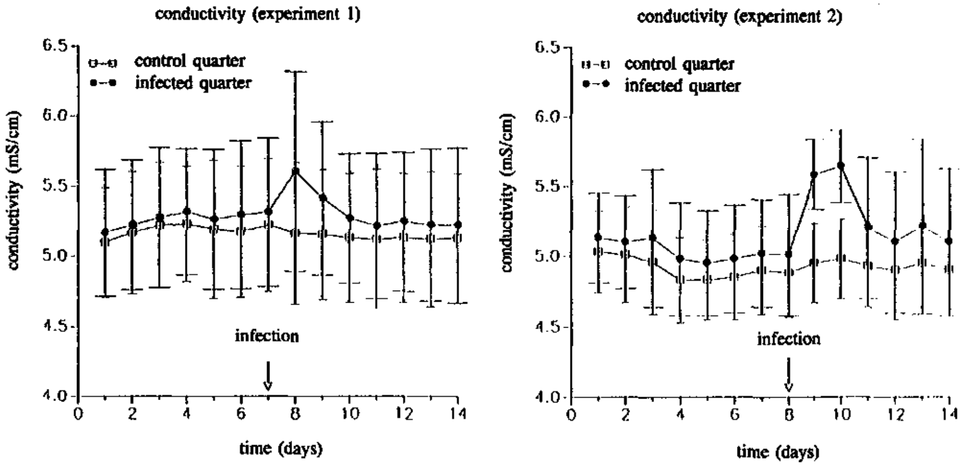


Figure 4. Mean values and standard deviation of the electrical conductivity of the milk of the infected and the control quarters.

Specially designed techniques are available for the measuring. These systems use conductive and inductive principles (Figure 5). Our experience with conductive systems suggest that continuous accuracy and stability of the measured values, so they refer to the conditions of daily use on the farm, cannot be achieved because particles are deposited on the electrode. It is not clear to what extent this problem has been taken into account in present commercially available sensors, or what degree of stability these sensors can offer.

The inductive measuring system avoids these shortcomings. Similar to conventional measurements using electrodes, trapped air or bubbles cause measuring errors. Therefore the milk has to be allowed to come to rest by stopping the flow briefly near the coil.

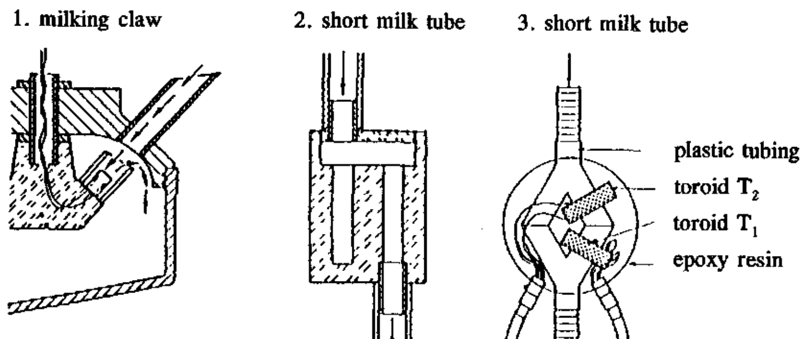


Figure 5. Sensors for milk conductivity measurement.
1: after Rossing, 1987; 2: after Schlünsen et al., 1989; 3: after Lake, 1987.

Conclusions

From the results of extensive investigations in animal health monitoring it has to be assumed that there are many specific parameters on which the early detection of certain diseases can be based. The interpretation of deviations of these parameters requires a database per individual cow or per udder quarter, to enable these possible changes to be detected as real deviations. Furthermore, it is necessary to take interfering effects and interactions of these parameters into account and combine them.

This implies that apart from the automation of the data acquisition by on-line recording systems, sophisticated algorithms (knowledge based systems) are required. However, they should allow a comprehensive data handling and processing and at the same time focus the information on the most significant events in animals or herd health status.

References

Jennes, R.C., 1985. Biochemical and nutritional aspects of milk and colostrum. In: B.L. Larson: Lactation. The Iowa State University Press, Ames, Iowa, p. 164-197.

Kitchen, B.J., 1981. Review of the progress of Dairy Science: Bovine Mastitis: milk compositional changes and related diagnostic tests. Journal on Dairy Research 48:167-188.

Lake, J.R., 1987. A low maintenance milk conductivity sensor for detecting mastitis. Proceedings of the third Symposium Automation in Dairying, IMAG, Wageningen, The Netherlands, p. 129-137.

Maatje, K., W. Rossing, G.J. Carsson & H.G. Pluygers, 1983. Automation of electrical conductivity measurements during milking. Proceedings of the Symposium Automation in Dairying, IMAG, Wageningen, The Netherlands, p. 89-100.

Renner, E., 1974. Beziehungen zwischen dem Lactosegehalt der Milch und Secretionsstörungen beim Rind. Tierzucht 26:18-20.

Rossing, W., E. Benders, P.H. Hogewerf, H. Hopster & K. Maatje, 1987. Practical experiences with real-time measurements of electrical conductivity for detecting mastitis. Proceedings of the third Symposium Automation in Dairying, IMAG, Wageningen, The Netherlands, p. 138-146.

Schlünsen, D., 1987. Automatic detection of metabolic disorders by computer aided systems. Proceedings of the third Symposium Automation in Dairying, IMAG, Wageningen, The Netherland, p. 376-383.

Schlünsen, D., H. Schön, R. Artmann, W. Paul & H. Speckmann, 1989. Eignung der automatischen Milchtemperaturerfassung zur Gesundheitsüberwachung und Brunstkontrolle in der Milchviehhaltung. Landbauforschung Völkenrode 31(4):241-250.

Sissoko, S., H.U. Wiesner, K. Nogai & M. Schütz, 1984. Der Lactosegehalt in Hern und Milch des Rindes bei subklinischer ß-Streptococcen-Mastitis. Deutsche Tieärztlichen Wochenschrift 91(4):151-154.

Experiments to influence the content of somatic cells in bulk milk by separating the milk from quarters with high electrical conductivity in fore-milk

M. Graupner, G. Wehowsky, F. Tröger & K. Barth

Leipzig University, Faculty of Agricultural Sciences, Engineering Department, Johannisallee 19a, D-O-7010 Leipzig, Germany

Summary

In 7 experiments (each involving 40 cows) and on the basis of the correlation between the electrical conductivity of the quarter fore-milk on the one hand and the cell content on the other hand we tried to reduce the cell content in bulk milk by separating the quarter milk when predetermined conductivity thresholds were exceeded. The thresholds we used for the separating of quarter milk were 5, 6, 7, 8, 9 and 10 mS/cm at a temperature of 25 °C. As the conductivity threshold for separating quarter milk from the marketable bulk milk decreased the cell content of the bulk fell. The correlation between conductivity threshold and the cell content of the bulk milk after the separation was 0.98 averaged for all experiments. Data are given on percentage of milk separated. Separation was also possible after alveolar milk ejection (letdown) by using measured values of conductivity. The feasibility of automating this system and integrating it into udder health control is discussed.
Keywords: conductivity, milk quality, cell content, udder health.

Introduction

The specific electrical conductivity of milk largely depends on the ion content of the milk. Other factors such as fat content and udder diseases also influence the ion content of the milk considerably. They lead to changes of the osmotically active milk substances and cause the content of chloride and sodium ions to rise and the content of potassium ions and of lactose to fall (Mielke 1975). This is why it has long been attempted to use the electrical conductivity of milk to diagnose diseases in udder quarters. The availability of values measured as electrical signals and the possibility of continuous and automatic measuring during milking are essential for this. An increased cell content or positive bacteriological findings are regarded as criteria for the existence of udder diseases, therefor many studies have compared electrical conductivity with these parameters. Table 1 shows a selection of published results proving the correlation between conductivity and cell content.

The published correlation coefficients are mainly between 0.4 and 0.6. Differences of > 0.2 might be attributable to linear and logarithmic consideration of cell quantities. Another reason for the relatively large variations between the individual experiments could be the strong influence of the release of alveolar milk ejection (let-down) on conductivity in fore-milk (Fernando et al., 1985; Mielke et al., 1974). If conductivity is measured more than 1 min after the udder is first touched, the conductivity values decrease considerably, especially those of subclinically diseased quarters (Graupner et al., 1989).

Table 1. Correlation coefficient R between conductivity and cell content published by various authors.

Author	R	Remarks
Chamings et al. (1984)	0.39	
Fernando et al. (1985)	0.21	
Grega et al. (1985)	0.48 . . . 0.62	with > 500 000 Cells/ml
Hamann (1986)	0.32 . . . 0.63	depending on the conducivity threshold values used
Maatje et al. (1983)	0.56	
Mielke et al. (1983)	0.48	
Okigbo et al. (1984)	0.3 . . . 0.82	
Graupner & Barth (1992)	0.6	lg of the cell content
Total	0.21 . . . 0.82	

Materials and method

On the basis of these established correlations attempts have seen made to use electrical conductivity as a criterion for udder health control. The most important problem in this respect remains the reliability of the measured conductivity values (frequency of false positive and false negative measured values compared to cell content and bacteriology). Criteria other than conductivity should be used to assess udder health. Amount of quarter milk is a favourable parameter for an evaluation of udder quarter health, though it is still relatively complicated to measure (Graupner et al., 1990).

If the conductivity in the individual udder quarters is measured during milking these values can also be used for other purposes. In conventional milking it is assumed that deviant milk is identified and the appropriate amount of milk is removed. Subclinical diseases cannot be diagnosed by this method. Deviant milk is characterized by a sharply increased content of cells and changed composition. If mixed with bulk milk the cell content of bulk milk collected from the herd is increased considerably, and hence permitted limits are frequently exceeded. As a rule, no therapy is applied to diseased quarters that produce this milk, as they are usually not identified. In addition to changes of the milk composition these cases of subclinical mastitis result in considerable yield losses (Graupner et al., 1989). Therefore, the subclinically diseased quarters produce relatively less milk and this milk has a high cell content. For this reason, we tested the possibilities of reducing the cell content of bulk milk by separating the milk of these quarters during milking.

We carried out 7 experiments with a herd of about 40 cows in monthly intervals. The amount of quarter milk was determined and a proportional milk sample was taken by milking the udder quarters individually. The conductivity of foremilk was measured before milking. After that in the laboratory the quarter milk samples were mixed according to the determined conductivity thresholds, in order to produce bulk milk samples. If the relevant conductivity threshold was exceeded, the milk from that quarter was discarded. Cell content and the amount of bulk milk and of separated milk were determined.

Results and discussion

Figure 1 summarizes the cell contents found (average for the 7 experiments).

The mean cell content of the herd bulk milk of 597 000 cells/ml was very high, indicating bad udder health in the herd. As the conductivity threshold for the separating of milk decreased, so did the cell content of the bulk milk produced. The cell content of the separated milk increased correspondingly. The threshold for milk quality used in Germany and the standard applied when milk with 500 000 cells/ml is delivered would not be exceeded if a threshold of 8 mS/cm for the separation of mastitis milk were fixed for this herd. The separated quarter milk had a cell content of 3 206 000 cells/ml. To evaluate this method it is important to know how much milk is produced when the various conductivity thresholds are applied (Figure 2).

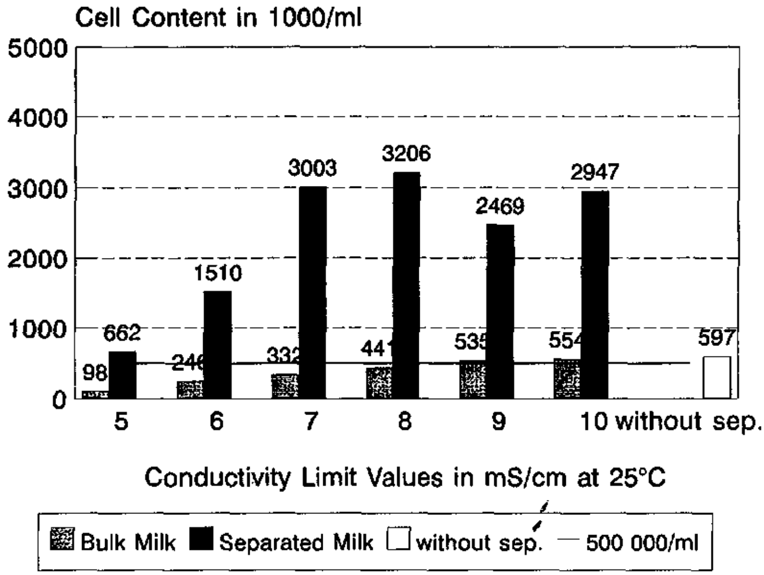


Figure 1. Cell content changes of bulk milk and separated milk with different conductivity thresholds for quarter milk separation (prior to let-down).

When the conductivity threshold 8 mS/cm was applied 4.4% of the milk was separated. This meant that the cell content in bulk milk could be reduced by about 150 000 cells/ml, with a milk loss of about 5%. Other relations will be obtained under other conditions, especially under a changed primary cell content in bulk milk. More detailed investigations in large herds, however, proved that significant changes in the results are unlikely.

Using an automatic sluice to separate of the quarter milk when an adjustable conductivity threshold is exceeded enables this procedure to be used during milking without having to rely on the milker. Such a system for safeguarding the quality of bulk milk by separating the amounts milked from subclinically and clinically diseased quarters has to be seen in connection with the development of udder health control systems that work on the basis of conductivity measurements, and it completes these systems. If it is incorporated into computer-aided herd management as well as into milking control, the system enables milk to be automatically separated in cases of known udder diseases and milk produced from treated udders to be reliably separated, or fore-milk to be drained. This reduces the risk of mixing inhibitors and fore-milk with the bulk milk.

There is a very high statistical correlation between the cell content in bulk milk achieved after separation of mastitis milk and the conductivity thresholds used. Table 2 shows the correlation coefficients for our 7 experiments.

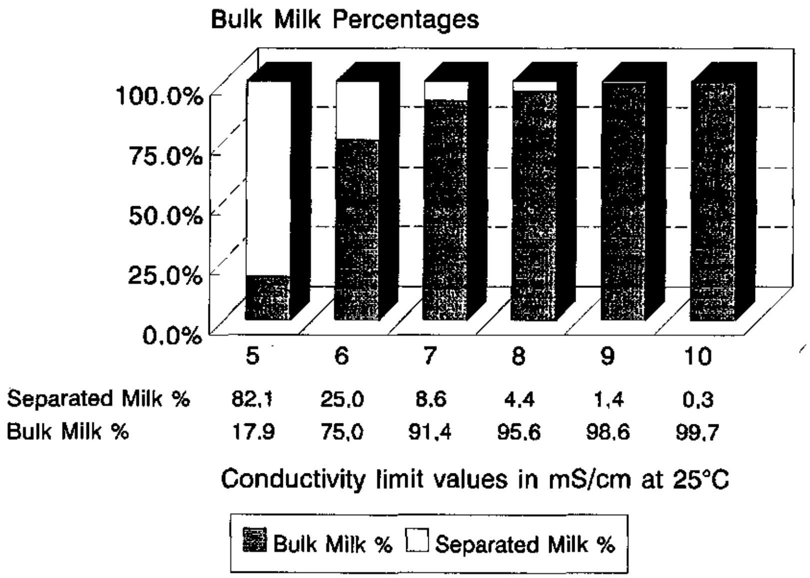


Figure 2. Percentages of milk produced by separation of quarter milk if different conductivity thresholds were exceeded.

Table 2. Correlation coefficient R between conductivity limit values and cell content achieved in bulk milk in 7 experiments.

Experiment	1	2	3	4	5	6	7	Total
R	0.84	0.95	0.94	0.97	0.97	0.91	0.97	0.98

Selecting a suitable threshold corresponding to the health situation of a given herd enables milk with different cell content to be produced. The regression between the conductivity threshold used and the cell content achieved in bulk milk is shown in Figure 3.

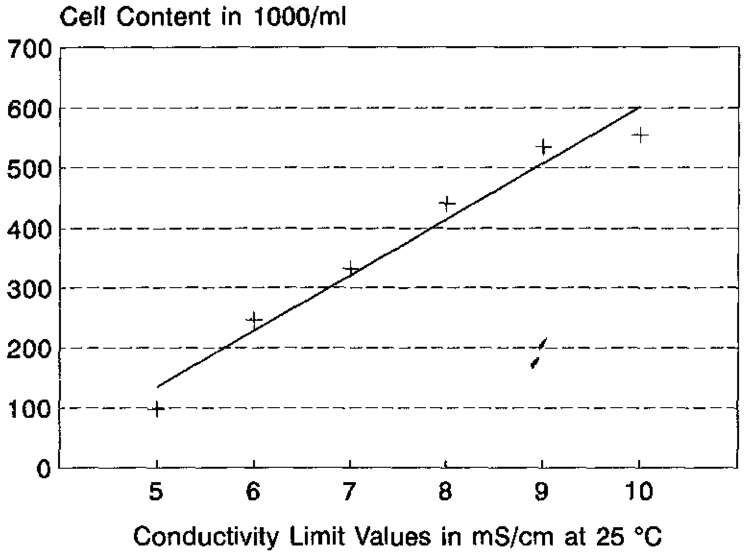


Figure 3. Regression of cell content in bulk milk versus the conductivity threshold applied for the separation of quarter milk.

The relation is so obvious that the cell content in the bulk milk produced can be predetermined by using a certain conductivity threshold. Ways of influencing the cell content in bulk milk increase as the cell content of the original herd bulk milk (without separation of mastitis milk) rises. This means there are more options to influence the cell content in bulk milk in herds with udder health problems than in healthy herds. Using an appropriate threshold control sluiceway milk separation enables milk to be separated from all quarters if the conductivity threshold of one quarter is exceeded. This would be required to comply with German legislation on milk.

Tests have proved that this can be done. Changes occur, especially when there is a considerable increase in the amount of milk to be separated. The threshold of 500 000 cells/ml, for instance, was not exceeded in our herd after quarter milk separation or after the separation of the total amount of milk produced by a given cow when a conductivity threshold of 8 mS/cm was applied for the separation of mastitis milk. The proportions of milk that had to be removed in the case of quarter milk separation and of the separation of the whole milk, respectively, were 4.4% and 16.7%.

The results described were obtained on the basis of conductivity measurements in fore-milk before alveolar milk ejection was released. As cisternal milk is "contaminated" by cleaning or otherwise handling the udder or due to prestimulation, we also investigated the possibility of milk separation on the basis of conductivity values after let-down. The results are shown in Figure 4.

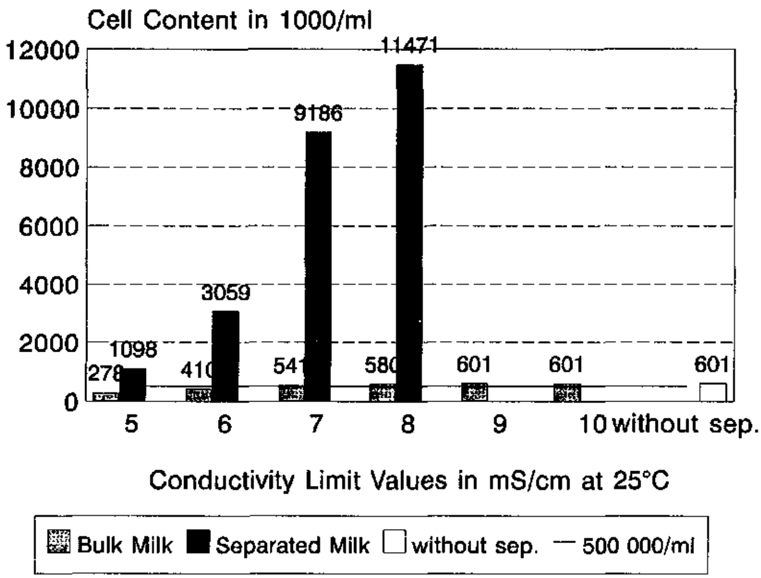


Figure 4. Changes of cell content in bulk milk and separated milk as a result of the quarter milk had been separated after a certain conductivity threshold had been exceeded (after let-down).

Since no conductivity values > 9 mS/cm occurred after milk let-down the variability of the separation decreases. The threshold to be applied had to be reduced by about 2 mS/cm to obtain comparable results. In principle, a separation carried out on the basis of conductivity measurements after milk let-down was effective, too.

References

Chamings, R.J., G. Murray & J.M. Booth, 1984. Use of conductivity meter for the detection of subclinical mastitis. Veterinary Record 114(10):243-245.

Fernando, R.S., S.L. Spahr & E.H. Jaster, 1985. Comparison of electrical conductivity of milk with other indirect methods for detection of subclinical mastitis. Journal of Dairy Science 68:449-456.

Graupner, M., G. Wehowsky, H.J. Rudovsky & R. Horn, 1989. Über den Einfluß von Alveolarmilchejektionen auf die elektrische Leitfähigkeit der Viertelanfangsmilch bei gesunden und an Mastitis erkrankten Kühen. Monatshefte für Veterinarmedizin 44:783-787.

Graupner, M., G. Wehowsky & H.J. Rudovsky, 1990. Verlaufsuntersuchungen von Viertelmilchmenge und elektrischer Milchleitfähigkeit bei gesunden und kranken Euterviertein. In: Aktuelle Fragen des maschinellen Melkens, Intern. Kolloquium der Sektion Tierproduktion/Veterinarmedizin, Wissenschaftsbereich Maschinentechnik, KMU Leipzig, Eisenach, Germany, Teil 2, p. 204-213.

Graupner, M. & K. Barth, 1992. Zur Beeinflussung der elektrischen Leitfähigkeit durch Alveolarmilchejektion. In: Stimulation und Melken, Intern. Kolloquium, Agrarwissenschaftliche Fakultät, Wissenschaftsbereich Maschinentechnik, Universität Leipzig, Grimma, Grimma, 5.-7.5.

Grega, T. & J. Szarek, 1985. Über die Beziehung zwischen Zellgehalt, Leitfähigkeit und pH-Wert der Milch. Przeglad Mleczarski 2:14-15.

Hamann, J., 1986. Vergleichende Untersuchungen von Zellgehalt und Leitfähigkeit in Viertelanfangsgemelksproben. Milchwissenschaft 41(1):8-11.

Maatje, K., W. Rossing, G.J. Garssen & H.G. Pluygers, 1983. Automation of electrical conductivity measurements during milking. In: Proceedings of the Symposium Automation in dairying. IMAG, Wageningen, The Netherlands, p. 89-100.

Mielke, H. & W. Fischer, 1974. Methode und Gerätetechnische Lösung für die Mastitisschnelldiagnose zum MM-System (Entwicklung und Erprobung einer ökonomisch begründeten automatisierten EDV-gerechten Lösung für die laufende Eutergesundheitskontrolle). Forschungsteilabschlußbericht, Karl Marx Universität, Sektion der Tierproduktion und Veterinarmedizin, Leipzig, Germany.

Mielke, H., 1975. Das Verhalten der osmotisch aktiven Substanzen in der Milch gesunder und kranker Euterviertel als biologische Grundlage automatisierbarer Eutergesundheits- und Milchqualitätskontrollsysteme bei der industriemäßigen Milchproduktion. Monatshefte für Veterinarmedizin 38(9):334-338.

Mielke, H. & J. Schulz, 1983. Verhalten und korrelative Beziehungen der elektrischen Leitfähigkeit und anderer diagnostischer Kriterien der subklinischen Mastitis in Abhängigkeit vom Laktationsstadium der Kühe. Archiv Experiment. Monatshefte für Veterinarmedizin 37(4):629-640.

Okigbo, L.M., M.A. Sheliah, G.H. Richardson, C.A. Ernstrom, R.J. Brown & E.L. Tippetts, 1984. Portable conductivity meter for detecting abnormal milk. Journal of Dairy Science. 67(7):1510-1516.

Automatic milking: milk quality

D. Westhoff & C.J. Liu

University of Maryland, Department of Animal Sciences, College Park, Animal Science Centre, Maryland 20742-2311, U.S.A.

The Maryland Agricultural Experiment Station

Summary

Prototype automated milking systems are available for testing and refinement. They differ from conventional milking equipment and practices, particularly in the way the teats are cleaned prior to milking. Since these devices are intended to be "robotic" or fully automated they must also be self cleaning. The udder/teat cleaning brush represents a unique change. This study presents preliminary microbiological evaluation of an automated milking system.
Keywords: automatic milking, microbiology, milk quality, cleaning brush.

Introduction

Several prototype "robotic" automated milkers are available. They have received, and they will continue to receive, significant public attention. Data generated from these prototypes probably will not be long standing. Rather this data is transitory and serves as an indicator of changes and refinements needed.

Despite the forward march of technology, one thing that has not really changed is the milk itself. Microbiologists are acutely aware of the intrinsic factors of substrates that affect their microbiology and milk is an excellent substrate for microorganisms. The microbiological quality of raw milk has significant ramifications to human health and disease. It also serves as a basis for quality payments, and/or compliance with stringent regulatory guidelines and standards. The specific factors (of conventional milking) influencing the microbiological quality of raw milk have been extensively investigated (IDF, 1980).

The consuming public perceives unintentional additives, intentional additives and pesticides to be the major public health concerns in our food supply. Despite the fact that statistical data and food safety professionals insist that the major risk to the consuming public is the presence of foodborne bacterial pathogens. The incidence of foodborne outbreaks attributed to bacterial sources has increased steadily in recent years. Milk and dairy products have historically been shown to harbor classical foodborne pathogens such as *Salmonella, Bacillus cereus, Staphylococcus aureus, Campylobacter jejuni, Clostridium perfringens* and *Yersinia enterocolitica.* The last ten years have seen the dairy industry respond dramatically to newer concerns such as *Listeria monocytogenes* and *Escherichia coli* 0157:H7.

Since milking conditions in animals differ, the initial microbiological quality of milk can vary. However, regardless of the existing conditions and the milking equipment used, the microbial quality of raw milk can be directly related to three main sources:

- microorganisms entering milk from within the udder;
- microorganisms entering milk from contamination on the teats and the udder;
- microorganisms entering milk from contamination by the specific milking and storage equipment used.

The use of automated or robotic milk harvesting equipment will directly alter the latter two sources of contamination. The way the automated equipment cleans the udder and the teats will affect the level of contamination entering milk from those sources. Similarly, the design differs significantly from conventional milking equipment and therefore the actual milking apparatus and assembly may serve as a source of contamination.

Of particular interest is the method by which an automated system might clean the udder and teats. This system could actually retain microorganisms and serve as a source of contamination to the next animal to be milked. Biofilm formation is possible and several pathogens are notorious for their ability to resist cleaning and sanitizing when a biofilm is formed (Lewin, 1984; Ho, 1986; Anwar et al., 1990; Krysinski et al., 1992; Frank & Koffi, 1990).

Obviously, automated milking and automated washing of cows is different from conventional practices. Therefore, one cannot predict the kinds of contamination and possible buildup of microorganisms that might occur in an automated system. The purpose of this study, therefore, was to begin to investigate the microbiological quality of milk harvested by an automatic milking device. This information is critical to the long-term development of the automated process and to satisfy regulatory concerns that will be generated based on raw milk quality and actual milk collection procedures.

Methodology

The work described here made use of an automated milking system (AMS) manufactured by Gascoigne-Melotte, The Netherlands. It is located in a new facility constructed at one of the Maryland Agricultural Experiment Station experimental farms in Clarksville, Maryland.

Samples of raw milk, the surface of the teat cups, and the udder/teat washing brush, were examined. Table 1 outlines the analysis performed on each of the specific samples. Additionally, quarter milk samples were analyzed prior to cows being trained on the AMS. Whenever possible sampling techniques outlined in Standard Methods for Examination of Dairy Products (SMEDP) were followed (American Public Health Association, 1985).

Table 1. Sampling sites and specific analysis performed.

		Sampling site		
Analysis		Udder/teat brush	Teat cup	Raw milk
Aerobic plate count	32°C	X	X	X
	22°C	X	X	X
	7°C	X	X	X
Anaerobic plate count	32°C	X	X	X
	22°C	X	X	X
	7°C	X	X	X
Coliform count		X	X	X
Sporeformers (80°C,10 min)		X	X	X
Total Gram negatives		X	X	X
Staphylococcus aureus		X	X	X
Milk composition				X
Somatic cell count				X
Sediment test				X
Freezing point				X

The inner surfaces of the teat cups were swabbed using sterile, disposable cotton swabs, predipped in buffered rinse solution (40 ml) with excess solution removed. The entire inner surface of the cups was swabbed with the same swab which was rinsed between cups in the buffered rinse solution. The sample was placed on ice and returned to the laboratory for plating the same day. Dilutions were prepared and the number of bacteria per teat cup reported.

The udder/teat brush was sampled using a sterile sponge technique (SMEDP). Cellulose sponges were cut into 5 cm^3 (5×1×1 cm), wrapped individually in Kraft paper and autoclaved at 121°C for 20 min. Sponges were pre-moistened in 10 ml sterile 0.1% peptone water using rubber gloves and sterilized crucible tongs.

The sponges were placed and held in the brush fibres, with movement back and forth as it "cycled" one time during normal operation. The exposed sponge was then placed in a sterile bag containing 50 ml of buffered rinse solution and placed on ice for transport to the laboratory. The sponge was vigorously massaged in the bag and dilutions made, followed by appropriate plating. The number of microorganisms per unit surface area was calculated.

Milk samples from the weigh jar and the bulk tank were obtained with sterile syringes via TRU-TEST sampling ports. Milk collected was transferred to sterile vials, placed on ice, and transported to the laboratory. Dilutions were prepared, followed by appropriate plating and the number of microorganisms per ml reported.

Microbial analysis

Standard plate counts were determined at 7°C (7d), 22°C (4d), and 32°C (2d) and followed methodology outlined in SMEDP. Plates were incubated aerobically and anaerobically (BBL, gas-pak jars). Coliforms and fecal coliforms were determined using the 3-tube MPN procedure as described in the FDA Bacteriological Analytical Manual (AOAC, 1984). The number of *Staphylococcus aureus* and coagulase positive *S. aureus* were determined as described in AOAC (1984). Total sporeformers were determined by plating of samples following heating to 80°C for 10 min. Dilutions were plated in Standard Methods Agar (BBL) plus 0.1% soluble starch. Plates were incubated aerobically and anaerobically at 32°C for 2d and then counted according to SMEDP. A gram negative count was determined by plating samples on McConkey agar at 32°C for 2d.

Microbial identification

Plates from the highest dilution assayed were used to select colonies/isolates using a random numbers table. All isolates, following streaking for purity, were identified to species using a MIDI System (Microbial ID, Inc., Newark, DE) and conventional taxonomy employed.

Results

Microbial enumeration

Data reported was obtained between 2/1/92 and 6/1/92. The AMS was run periodically during this time with a maximum of three cows. Our samples were always obtained before and after the last cow milked. Table 2 summarizes microbiological data obtained on 10 different sampling dates. Raw milk aerobic plate counts (APC) at 32°C ranged from a log number of 2.56 to 3.01 during the study with a mean log count of 2.74. Coliform numbers in the raw milk and at all the sampling sites did not exceed 10/ml. The number of sporeformers (aerobic) in the raw milk and at each of the sampling sites never exceeded 90/ml and most of the time were not detected.

Table 2. Bacterial counts expressed as log numbers from samples obtained from an automated milking system.

Aerobic plate count		Raw milk	Udder/teat brush Before milking	After milking	After cleaning cycle	Teat cup Before milking	After milking	After cleaning cycle
7°C	mean	3.17	3.35	3.30	3.28	3.14	3.14	<1.0
	max	4.01	4.03	3.91	3.97	3.79	3.95	1.90
	min	2.51	2.62	2.58	2.41	1.69	2.01	<1.0
22°C	mean	3.00	3.28	3.31	3.31	3.59	3.61	<1.0
	max	3.51	4.13	4.85	4.90	4.65	4.95	1.86
	min	1.88	2.59	2.46	2.56	2.82	2.82	<1.0
32°C	mean	2.74	3.48	3.54	3.43	3.76	3.75	<1.0
	max	3.01	3.94	4.61	3.99	4.99	4.88	1.93
	min	2.56	2.98	2.76	2.68	2.92	2.88	<1.0
Gram negative count								
	mean	2.70	2.13	2.00	1.95	2.24	2.19	<1.0
	max	3.15	3.94	3.81	3.87	3.86	3.81	<1.0
	min	2.11	<1.0	<1.0	<1.0	1.65	1.58	<1.0

Anaerobic plate counts (32°C) in the raw milk ranged from a log number of < 1.0 to 3.35. However, we normally did not have detectable levels at the various sampling sites. The AMS is capable of harvesting milk of acceptable quality.

We did observe a difference in the self cleaning capabilities between teat cup cleaning and udder/teat brush cleaning. For example, the APC at 32°C was reduced from a mean log number of 3.75 after milking to <1.0 during the cleaning cycle, indicating a reduction approximately three log cycles or a 99.9% removal of microorganisms. Conversely, the mean log counts on the udder/teat brush were unaffected. These observations have led to further investigations with the udder/teat brush and its cleaning cycle.

Microbial identification

To determine the types of bacteria being counted and isolated from the AMS sampling sites, colonies from plates were numbered and then selected or "picked" by consulting a random numbers table. Table 3 presents some of the bacteria isolated from the various sampling sites. Our experience to date suggests that a closer examination of the udder/teat brush and its cleaning cycle is necessary. Biofilm development studies on the brush are currently underway. Overall, however, the AMS as currently configured is potentially capable of meeting milk bacterial quality guidelines for coliforms and aerobic plate counts.

Table 3. Speciation of bacteria isolated and identified from samples obtained from the automatic milking system.

Sample source[1]	Bacteria identified[2]
Brush - before milking	*Aeromonas sobria*
	Aerococcus viridans
	Pseudomonas fluorescens B
	Pseudomonas marginalis
	Acinetobacter johnsonii
	Pseudomonas vesicularis
Brush - after milking	*Acinetobacter calcoaceticus*
	Moraxella phenylpyruvica
	Arthrobacter aurescens
	Acinetobacter haemolyticus
Brush - after self-cleaning	*Pseudomonas vesicularis*
	Acinetobacter radioresistans
	Micrococcus kristinae
	Acinetobacter johnsonii
	Acinetobacter calcoaceticus
	Acinetobacter johnsonii
	Acinetobacter haemolyticus
Teat cup - before milking	*Aerococcus viridans*
	Bacillus sphaericus
	Enterococcus casseliflavus
	Enterococcus durans
Teat cup - after milking	*Brevibacterium divaricatum*
	Enterococcus faecium
	Bacillus sphaericus
	Bacillus megaterium
	Escherichia coli
	Pseudomonas marginalis
	Acinetobacter junii

[1] The original site or sample that the microbial analysis was performed on.
[2] Bacteria not listed in order or by frequency.

Acknowledgement

Scientific Article No. A6349, Contribution No. 8533 of the Maryland Agricultural Experiment Station, University of Maryland, College Park. We also appreciate the help and assistance of Tom Moreland of the Clarksville Farm of the Central Maryland Research and Education Center.

References

American Public Health Association, 1985. Standard methods for the examination of dairy products. 15th edition. American Public Health Association, Washington DC, USA.

Anwar, H., M.K. Das Gupta & W. Costerton, 1990. Testing the susceptibility of bacteria in biofilms to antibacterial agents. Antimicrobial Agents and Chemotherapy 34:2043-2046.

Association of Official Analytical Chemists, 1984. Bacteriological Analytical Manual. 6th edition FDA, Arlington, Va, USA.

Frank, J.F. & R.A. Koffi, 1990. Surface-adherent growth of *Listeria monocytogenes* is associated with increased resistance to surface sanitizers. Journal of Food Protection 53:550-554.

Ho, C.S., 1986. An understanding of the forces in the adhesion of microorganisms to surfaces. Process Biochemistry (Oct):148-152.

IDF, 1980. International Dairy Federation. Factors influencing the bacteriological quality of raw milk. Doc. No. 120, IDF, Brussels.

Krysinski, E.P., L.J. Brown & T.J. Marchisello, 1992. Effect of cleaners and sanitizers on *Listeria monocytogenes* attached to product contact surfaces. Journal of Food Protection. 55:246-251.

Lewin, R., 1984. Microbial adhesion is a sticky problem. Science 224:375-377.

Teat cleaning and stimulation

E. Schuiling

Research and Advisory Station for Cattle, Sheep and Horse Husbandry, Runderweg 6, 8219 PK Lelystad, The Netherlands

Summary

Three experiments were done on two types of automatic teat cleaning devices. The first device tested sprays water in the teat cup liners for a short time with a high pulsation rate. Swab samples taken from the teats showed that using the device was better than no cleaning at all but worse than manual cleaning. In the second experiment a rotating brush was used to clean the udder and the teats. The removal of dirt from the teats was estimated from the amount of an indicator found in the collected milk. This indicator (lithium) was mixed into sterilized manure, which was applied to the teats before cleaning. According to the amount of indicator recovered, 69% of the manure was removed. It is concluded that both systems are better than no cleaning, but neither system is able to remove all the visible dirt. In the third experiment the rotating brush was tested for its stimulating properties. It promoted milk ejection (let-down). There was no significant difference between how many trajects (3, 6 or 9) the brush made along the udder.
Keywords: automatic milking, udder cleaning, pre-milking preparation, milk ejection.

Introduction

Before milking, the cow has to be prepared: the udder and the teats have to be cleaned, milk ejection (let-down) has to be stimulated and the udder health has to be checked (Pankey, 1989). Different countries have different ways of cleaning. Cleaning with water with or without additives has to be followed by drying the teats (Galton et al., 1982; Galton et al., 1986; Pankey, 1989), because otherwise dirt and bacteria will flow with the water from the udder and the upper parts of the teat to the teat tip. This needlessly pollutes the milk with dirt and bacteria. A dry cleaning can avoid this problem, but can only be done if the udders are reasonably clean. Automatic milking systems cannot (yet) distinguish between clean and dirty udders. So all the udders must be given the same treatment. This implies that cleaning has to be carried out in such a way that even the dirtiest udder is cleaned well.

Clearly, introducing an automatic milking system should not adversely affect milk quality. Milk quality starts with clean teats and udders; Therefore we investigated two automatic cleaning devices: a spraying unit built into the teat cup and a rotating brush.

A good stimulation of milk ejection is needed for optimal milk production (Worstorff et al., 1987; Hamann & Dodd, 1992). Normally, rubbing the udder and the teats with a towel will achieve this stimulation before the cluster is attached. But the milking machine can also stimulate after the cluster has been attached, by using a high pulsation rate at the start of milking (Worstorff et al., 1987). An automatic milking system could try to stimulate the udder by massaging (e.g. a rotating brush), or with a high pulsation rate (as the spraying unit does), or both. At first sight, brushing the udder seems to be unpleasant for the cow, therefore the effect of the brush on let-down was investigated.

Experiments

Experiment 1. Cleaning with water in the teat cup

The experiment was carried out on the experimental farm "De Vijf Roeden" of IMAG-DLO. The automatic cleaning device, as designed for the AMS (Bottema, 1992), was installed in one of the front cow stalls of the 2×4 herringbone parlour. The front stall on the other side of the parlour was used as a reference.

The cleaning device sprayed water in four places on the head of each liner for 15 sec. During this time a high pulsation rate was used. The idea is that the water and the movement of the liner together clean the teats. The water and the first milk were collected in a special jar by means of a valve. After a certain time the valve was reset and the milk flowed into the normal milk jar.

The automatic cleaning device was compared with manual cleaning and with no cleaning while the hygienic conditions in the cowshed were very good. Afterwards the automatic cleaning was compared with no cleaning while the hygienic conditions were moderate and with no cleaning after deliberately applying sterilised manure to the teats. Swabs were taken from the teat surface of one teat before and after cleaning and bacteriological samples were taken from the long milk tube at three times: just after the start of milking, about halfway through and at the end of the milking. A milk filter was placed in the tube between milk jar and milkline to collect the dirt.

Under good hygienic conditions there was no significant difference in milk quality (total bacterial count, number of coliforms and number of aerobic spore formers) between automatic cleaning and manual cleaning or between automatic cleaning and no cleaning. Only the swabs taken after cleaning showed a significant difference (manual cleaning was better than automatic cleaning, and automatic cleaning was better than no cleaning). With moderate hygienic conditions and deliberately applying manure to the teats no significant difference in the bacterial count of the swabs was found between automatic cleaning and no cleaning. The total bacterial count in the milk samples, however, showed that automatic cleaning was better than no cleaning. The examination of the milk filters showed that manual cleaning gave the best results, and that automatic cleaning was better than no cleaning.

Experiment 2. Cleaning by brush

To clean the udder and teats a rotating brush is used, which moves from the rear to the front of the udder and back again (six trajects in total) (Van der Linde & Lubberink, 1992). In the first traject water is added to the brush. In this experiment a half brush was used. So only one side of the udder was cleaned and it was possible to compare the right side with the left side of the udder.

As mentioned in experiment 1 it is very difficult to detect the effect of cleaning. In our experiment we used an indicator (lithium), which was mixed into the sterilized manure (2.7% lithium). Normally lithium is not present in manure and insignificant in milk (0.03 mg/l). 1,2,4 or 8 hours before milking, some manure (about 2 g/teat) was applied to the teats with a small paint brush. The amount of manure was calculated by weighing the amount of manure in the tray before and after applying the manure. The amount of lithium in the milk of each quarter was expressed in per mln. of the amount of lithium applied to the teat. Eight cows were used in this experiment, divided into groups, allowed different times for the manure to dry on the teats.

The cows were milked twice daily. The cows were milked with a quarter-milker, which collects the milk of each quarter separately. The type of quarter-milker used has no claw and the short milk tube is long and ends directly in the jar. Because there is no air inlet, teat washing is very likely.

The effect of cleaning was measured as the amount of lithium in the milk of each udder half. The results showed a significant difference ($p<0.001$) in the amount of lithium in the milk between the cleaned udder half (5.25 per mln.) and the uncleaned one (16.9 per mln.). The effect of cleaning was not significantly influenced by machine time or drying time. With shorter drying times, however, there was slightly more lithium in the milk. There are two possible causes: more dried manure was lost from the teats with longer drying times, and the ease of rinsing off manure when it is has not yet dried out totally.

Experiment 3. Mechanical stimulation

Manual stimulation is usually done by rubbing the udder with a dry or wet towel and by taking some squirts of milk. The rotating brush which is used (see experiment 2) may also encourage stimulation and thus milk let-down.

In this experiment eight cows milked twice a day at 12-hour intervals were used. The cows were divided into four groups, each of which contained a relatively slow milking cow and a relatively fast one. The intensity of the cleaning (number of trajects of the brush across the udder) in the experiment was 0, 3, 6 or 9. The same intensity was used on a group of cows for 14 days (experimental period). In the 14-days period before and after the experiment an intensity of 6 trajects of the brush across the udder was used (standard).

The effect on the stimulation was measured as the time needed to collect the first kg of milk and as the mean milk flow rate. These data were collected using an electronic milk meter (Gascoigne Melotte MR 2000). The results are given in Tables 1 and 2.

Table 1. Mean milk flow rate (MFR) in the experimental period, expressed as a percentage of the MFR in the pre-experimental period.
(100% = overall mean in pre-experimental period).

Intensity	0	3	6	9
MFR		85	100	9994

Table 2. Time needed to collect the first kg of milk (TF1) in the experimental period, expressed as a percentage of the TF1 in the pre-experimental period.
(100% = overall mean in pre-experimental period).

Intensity	0	3	6	9
TF1	149	96	106	108

Only not brushing had a significant influence on the mean flow rate and the time needed to collect the first kg of milk. The number of trajects of the brush across the udder produced no significant differences.

Discussion and conclusions

Both methods were better than no cleaning. In the first experiment with the cleaning system inside the liner, it was clear that manual cleaning gave the best results. In the second experiment no comparison with manual cleaning was done. From the recovery of the indicator in the milk it can be concluded that about 69% of the manure was removed by the automatic cleaning. With both methods contamination on teats was still visible after cleaning. A good manual cleaning normally does not stop before all the visible dirt is removed. Summarizing, it can be concluded that udders are cleaner when they are treated manually, but the automatic cleaning devices did remove dirt, so they are better than no cleaning.

Under good hygienic conditions in the cow house, udders will be clean when the cow enters the parlour. In this case it is not necessary to clean the udders. Furthermore, cleaning with water will wash dirt and bacteria off the teat and transport them to the teat tip and to the liner. Under these circumstances no cleaning might be better. In some countries, however, it is legally required to clean before milking.

From the results of experiment three it can be concluded that using the rotating brush had a positive effect on milk let-down. The number of trajects of the rotating brush was not important.

References

Bottema, J., 1992. Automatic milking: reality. In: A.H. Ipema, A.C. Lippus, J.H.M. Metz & W. Rossing (Eds.): Proceedings of the International Symposium on Prospects for Automatic Milking, EAAP publication No. 65, Pudoc Scientific Publishers, Wageningen, The Netherlands, p. 63-71.

Galton, D.M., R.W. Adkinson, C.V. Thomas & T.W. Smith, 1982. Effects of premilking udder preparation on environmental bacterial contamination of milk. Journal of Dairy Science 65:1540-1543.

Galton, D.M., L.G. Petersson & W.G. Merrill, 1986. Effects of premilking udder preparation practices on bacterial counts in milk and on teats. Journal of Dairy Science 69:260-266.

Hamann, J. & F.H. Dodd, 1992. Milking routines. In: Machine milking and lactation, Insight Books, Berkshire, England, p. 69-96.

Pankey, J.W., 1989. Premilking udder hygiene. Journal of Dairy Science 72:1308-1312.

Van der Linde, R. & J. Lubberink, 1992. Robotic milking systems (RMS): design and performance. In: A.H. Ipema, A.C. Lippus, J.H.M. Metz & W. Rossing (Eds.): Proceedings of the International Symposium on Prospects for Automatic Milking, EAAP publication No. 65, Pudoc Scientific Publishers, Wageningen, The Netherlands, p. 55-62

Worstorff, H., G. Karch, A. Prediger & D. Schams, 1987. Integrating mechanical stimulation to machine milking. Proceedings of the third Symposium Automation in dairying, IMAG, Wageningen, The Netherlands, p. 207-215.

Effects of milking intervals on the demand for cleaning the milking system in robotized stations

D. Ordolff & D. Bölling

Federal Dairy Research Centre, P.O. Box 6069, D-2300 Kiel 14, Germany

Summary

Automatic milking systems may be designed to work around the clock, milking cows in incoherent sequences with unpredictable intervals between milkings. An experimental milking installation was used to investigate the interaction of the time since a milking and the bacterial contamination of the milking installation when milk residues were left in place without rinsing or cleaning. In the experiment, the clean installation was first contaminated with fresh milk and then, after various time intervals rinsed with 2 litres of UHT milk. In a 2nd experiment it was rinsed with a mixture of 2 litres of UHT milk and 0.5 litres fresh milk. Samples were taken at the outlet of the installation and the bacterial count was evaluated. Up to 60 minutes after milking the bacterial count of this milk did not exceed the initial value, but there was a significant increase after 120 minutes. It was concluded that the removal of milk residues by rinsing or full cleaning and disinfection may be delayed by up to 60 minutes.

Introduction

At present, the milking of cows requires human operation every day of the year. It can be expected, however, that the introduction of robotic milking will liberate the dairy farmer from this routine work and will give more freedom to animals too. It is predicted that at least on certain types of robotized farms, fixed milking times will be replaced by irregular timing of milking operations according to voluntary visits of cows to milking stations. Because fewer milking units will be required than in systems with two fixed milking times per day, and because these will operate virtually round the clock, the design of technical equipment related to milking and milk storage will have to be modified. Milk flow at every hour of the day with long and unpredictable intervals between two milking episodes and with milk residues remaining in the installation, may also affect the cleaning and disinfection of equipment in robotized systems.

We therefore investigated how the intervals between two milking operations affected the bacterial count of bulk milk, if no rinsing or cleaning occurred in between.

Literature

Although milk originally is sterile (Cousins & McKinnon, 1979) it is accepted that in practical conditions no sterile milk can be produced (Bockelmann, 1982), since there are several opportunities for bacterial contamination en route from the alveoli to the bulk tank. One major source for contamination is the milking installation (Heeschen et al., 1981) which may add 10^4 to 10^5 microbes/ml to the milk. Therefore, cleaning and disinfection are essential for maintaining low bacterial counts in milk, although it is impossible to remove all microbes from the installation (Cousins & McKinnon, 1979). One common scheme is circulation cleaning (Gehring, 1990) which is based on four steps:

1. pre-rinse with clear water of 20 - 25 °C;
2. clean and disinfect with certified chemical agents for at least 15 minutes at a temperature of more than 40 °C;
3. rinse with clear water;
4. air dry.

Another procedure is based on the application of acidified, boiling water. The quantity used depends on the surface area of the milking installation: at the point furthest from the inlet a temperature of 77 °C must be maintained for at least two minutes.

Rinsing the milking installation with 10 l of clear water per milking unit was reported by Runnalls (1988) to be sufficient to remove almost 100% of milk left in the milking installation. Ipema et al. (1987) presented the results of an experiment to simulate fully automatic milking, with milking operations occurring round the clock. The installation was cleaned twice daily, additionally it was rinsed four times with 10 l of warm water. An identical bacterial count of 154 000/ml was found in the milk of the experimental and the reference group.

There are several reports on experiments related to voluntary milking of cows (Rossing et al., 1985; Ordolff, 1989), all referring to frequencies of 4 to 5.4 milking operations per cow and per day. More recent experiments tend to have milked cows less frequently, e.g. Kremer et al. (1992). In connection with the reduced activity of the animals during some periods of the day (Ordolff, 1989) machine idle times of up to 90 minutes between two milkings have been observed in these cases.

Material and methods

An experimental milking installation was used to simulate milking operations according to the scheme described for automatic stations offering free access to cows. To simulate milking a stock of 30 l of milk, kept under vacuum, was passed through a heat exchanger, a milking unit, and a proportional milk meter into a terminal unit. The flow of liquid was controlled by different vacuum levels in the container that stored the milk and in the milking installation. Samples were taken from the milk meter. The heat exchanger was used to control the temperature of water and cleaning solutions. It was possible to have liquid pumped from the terminal unit to a container under atmospheric pressure and to reintroduce it into the stock included in the vacuum system.

Table 1. Technical data on the experimental installation.

Vacuum level milking installation:	50 kPa
Vacuum level milk container:	28 kPa
Liquid flow:	4.3 l/m
Cleaning and disinfection:	
Pre-rinse	20 l waterat 20 °C
cleaning	40 l solutionat 60 °C
postrinse	40 l waterat 20 °C
Chemicals	0.7% Calgonit DA
Surface area of the installation	2 m^2
Ambient temperature	20 - 24 °C

To start an experiment, the installation was rinsed with 15 l of fresh milk from the herd of the experimental farm to create an initial, natural contamination. Within the next three to four hours milking operations were simulated by rinsing the installation with 2 l of UHT milk in the first set of experiments and with a mixture of 2 l UHT milk and of 0.5 l bulk milk, to achieve the contamination of milk found in practice by Von Bockelmann (1982), in further experiments.

The intervals between two rinses were 15, 30, 60 or 120 minutes. Milk residues were not removed from the installation between two rinses. Each experiment was terminated by a conventional circulation cleaning procedure. The installation was left in this condition until the next day. Samples were taken from the milk meter immediately after each rinse. Modified plate counts using the "petrifilm" method (3M Health Care, Medical Surgical Division, St. Paul MN, USA) were used to determine the total bacterial count of the rinsing liquid.

Results and discussion

The average bacterial count of milk used for initial contamination of the experimental milking unit was 108 000/ml, with a standard deviation of 58 000/ml. In all experiments, bacterial contamination in samples of the same milk, obtained after passing through the experimental unit, was considerably higher (Table 2 - Table 4). This was probably due to growth of microbes left in the equipment since the last cleaning.

The bacterial counts of samples taken after rinsing with UHT milk within 60 min from contamination were found to be decreasing rapidly. Later on they remained very stable (Table 2). Washing out the microbes with the practically sterile UHT milk, as described by Wiesner (1985), was obviously more efficient at higher levels of contamination.

Table 2. Bacterial counts after rinsing with UHT milk.

No. of rinse	Time [min]	Repetitions n	Bacterial count [10^3/ml] in samples Average	sd
Start	0	4	1472	841
1	30	4	865	1038
2	45	4	298	468
3	60	4	169	237
4	90	4	146	201
5	120	4	117	203
6	180	4	353	624

When UHT milk was replaced by a mixture of 4 parts of UHT milk and 1 part of fresh milk for rinsing, no major fluctuations of bacterial counts in samples were found until the end of the experiment. It can be concluded that the intensity of microbial growth and the amount of microbes. That entered the installation with the moderately contaminated rinsing mixture did not result in increased microbial contamination of the milking installation, if intervals between two consecutive rinses did not exceed 60 min (Table 3).

Table 3. Bacterial counts after rinsing with UHT milk + fresh milk.

No. of rinse	Time [min]	Repetitions n	Bacterial count [10^3/ml)] in samples Average	sd
Start	0	10	202	167
1	30	10	355	406
2	45	10	214	188
3	75	10	258	332
4	135	10	191	172
5	195	10	203	153
6	225	10	173	128

Not much variation of bacterial counts was to be found with rinsing intervals of 120 min (Table 4). The trend, however, seemed to be towards higher counts instead of lower counts, as the intervals between rinses became shorter. This may indicate the beginning of a phase of more rapid bacterial growth, since the installation remained untouched long enough to enable microbes to adapt to the environment. The intervals may also have been long enough to allow microbes to multiply in accordance with the temperature in the installation.

Table 4. Bacterial counts after rinsing with UHT milk + fresh milk and intervals of 120 min between rinses.

Number of rinse	Time [min]	Repetitions n	Bacterial count [10^3/ml] in samples Average	sd
Start	0	9	244	134
1	120	9	450	402
2	240	10	308	199

The operation of robotized milking installations, as reported by Ipema et al. (1987) and other authors, may be based on voluntary visits of cows. Due to variations of cow activity the intervals between two milking events in a milking station may be important, especially when several milking stations are available. Our results suggest that up to intervals of 60 min between milkings it does not seem to be necessary to rinse the equipment with fresh water immediately after each milking to remove milk residues. Doing so may raise the water content of the milk and its freezing point. This was noticed by Ipema et al. (1987) with four daily rinses only. When systems to control cow movements in fully automatic dairy barns become available they can probably be used to obtain a balanced utilization of multiple milking stalls. So the risk of idle times exceeding the limit for the safe operation of single milking stations without rinsing or cleaning can be reduced.

Conclusions

Based on the results reported it can be concluded that milk residues left in milking equipment after milking for up to 60 minutes do not increase bacterial contamination of milk obtained in the next milking. If milking intervals exceed this limit, however, then rinsing with fresh water or cleaning may be necessary to maintain good milk quality. To reduce the necessity of these operations, which may cause elevated water content in milk, technical aids may be used to balance the frequency of operation of multiple milking stalls by control of cow movements.

References

Cousins, C.M. & C.H. McKinnon, 1979. Cleaning and Disinfection in Milk Production. In: C.C. Thiel & F.H. Dodd (ed.): Machine Milking, Technical Bulletin 1, National Institute for Research in Dairying, Reading, UK.

Gehring, M., 1990. Reinigung und Desinfektion von Melkanlagen. Landtechnik 45:444-453.

Heeschen, W.H., G. Suhren & A. Tolle, 1981. Bakteriologisch-Biochemische Kriterien der Milch und ihre Beziehungen zu Frische, Haltbarkeit und Qualität. Deutsche Milchwirtschaft 41:532-538.

Ipema A.H., E. Benders & W. Rossing, 1987. Effects of More Frequent Daily Milking on Production and Health of Dairy Cattle. In: Proceedings of the third Symposium on Automation in Dairying, IMAG, Wageningen, The Netherlands, p. 283-293.

Kremer, J. & D. Ordolff, 1992. Experiences with continuous robot milking with regard to milking yield, milk composition and behaviour of cows. In: A.H. Ipema, A.C. Lippus, J.H.M. Metz & W. Rossing (Eds.): Proceedings of the International Symposium on Prospects for Automatic Milking, EAAP publication No. 65, Pudoc Scientific Publishers, Wageningen, The Netherlands, p. 253-260.

Ordolff, D., 1989. Voraussetzungen und Grundlagen automatischer Milchgewinnung. Habilitationsschrift Universität Hohenheim, Forschungsbericht Agrartechnik der Max-Eyth-Gesellschaft 191.

Rossing, W., A.H. Ipema & P.F. Veltman, 1985. The feasibility of milking in a feeding box. IMAG, Wageningen, Research Report 85-2.

Runnalls, R.J., 1988. Influence of the Pre-rinse on the Efficiency of Circulation Cleaning Milking Machines. Journal of the Society of Dairy Technology 41:14-16.

Von Bockelmann, I., 1982. Cleaning of Milking Equipment and Quality Payment of Milk. Kieler Milchwirtschaftliche Forschungsberichte 34:36-39.

Wiesner, H.-U., 1985. Qualitätssicherung der Anlieferungsmilch durch R+D-Programme. Die Milchpraxis 23:1820.

Cleaning frequency of automatic milking equipment

J.G.P. Verheij

Research and Advisory Station for Cattle, Sheep and Horse Husbandry, Runderweg 6, 8219 PK Lelystad, The Netherlands

Summary

Freshly drawn milk was transferred through a 'model' pipeline circuit, and the increase in microbes was measured. Results indicate that a 12-hour cleaning interval is insufficient to prevent high microbial counts. Similar results emerged from a larger and more practical experiment in a normal milking parlour. It is concluded that 12-hour cleaning intervals in an automatic milking system would only be possible if additional precautions are taken, such as instant cooling.
Keywords: automatic milking, milk quality, equipment, cleaning.

Introduction

The process of cleaning milking equipment usually consists of pre-rinse, alkali or acid main cleaning, disinfection and after-rinse. Cleaning is done after each milking, e.g. twice daily. When milkings are spread throughout the day by an automated system, other practices are needed.

Assuming the udders are healthy, the microbial load of the milk will largely depend upon bacterial growth in the equipment. If the equipment has been designed appropriately, each milking will, to a large extent, flush away residues from the previous one. This flushing will never be perfect, and some bacteria may remain adhering to the walls. Nevertheless, microbial growth may be considerably retarded, because fresh milk has bacteriostatic properties, called the lactoperoxidase system (Bjorck, 1991). Therefore, if the interior of the equipment is rinsed 5-10 times per hour with fresh milk, microbial growth may be limited.

No data on aspects of the cleaning of automatic milking systems are available in the literature.

Materials and methods

Two experimental designs were used in this research. In a model experiment a relatively small pipeline system, intended to be a realistic imitation of an automatic system, was set up on an experimental farm. Every half hour a cow was milked in a bucket with great hygienic care and 5l fresh milk was drawn through the pipeline system. Microbiological samples were taken from the milk before and after it passed through this pipeline, and analysed for total plate count (SPC), thermodurics, coli, lactobacilli and psychrotrophic bacteria.

The other experiment was done on an experimental farm where matched groups of 13 cows were milked 2, 3 or 4 times daily. This experiment (Ipema, 1991) was designed to investigate various aspects of frequent milking (feeding, milk, cow behaviour, health and fertility). The milking pipeline was cleaned normally, twice daily (for 40 weeks) or only once a day (for only 8 weeks, because of poor results). One day per week the milk was hygienically and proportionally sampled just after the milk pump. The sample cup was replaced every hour and analysed for SPC, thermodurics and psychrotrophic bacteria.

Results

In the model experiment during some test runs the original quality of the milk varied by up to >100 000 SPC in some milkings. The temperature in the milking parlour was maintained at 20 °C. The increase in the SPC after passage through the pipeline in the first experiment was limited to less than one log unit in two test runs that lasted for 12 and 18 hours. The results are presented in Figure 1.

Figure 1 is considered to be a representative example. In a further test run where milking was continued for 18 hours and the original SPC was good (generally below 10 000), the increase rose from 0.8 towards 2.0 log units, after an initial decrease in the first 4 hours from 1.2 towards 0.8. Apparently an infection had been present in the equipment and had been partly flushed away in the first hours. This test run was repeated after thoroughly cleaning the pipeline. The log increase of SPC in the next test run stayed below 0.6, without showing an upward trend during the whole test run.

The other parameters showed no clear picture, except for the psychrotrophic bacteria, which showed a considerable increase during 18 hours, in one case from 0.2 towards 1.0 log units and in another run from 0.5 to 2.5 log units.

In the second experiment, the 24 hourly milk samples of the herd (cows being milked at various intervals) generally showed an increase in microbial counts. The number of thermoduric bacteria rose significantly only when cleaning was done once per day, but SPC and psychrotrophics then increased by almost two log units. In a 12-hour cleaning interval the latter organisms increased up to 0.9 log units, as summarized in Table 1.

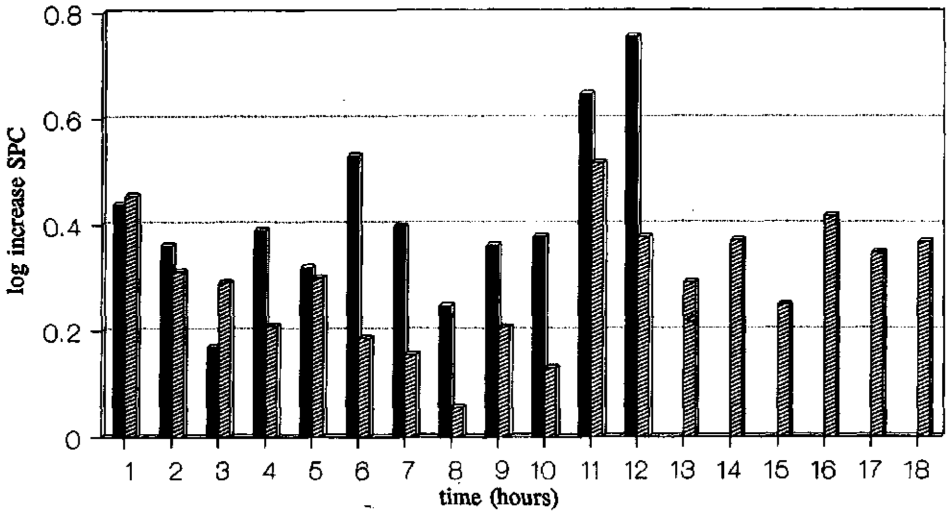


Figure 1. Bacterial growth in a pipeline circuit during continuous milking for 12 (■) and 18 (///) hours (source: Schuiling, 1989).

Table 1. Average numbers of bacteria in milk during the first three hours after cleaning and during the last three hours prior to the next cleaning for two cleaning intervals.

Cleaning interval (hours)	SPC		Thermodurics		Psychrotrophics	
	begin	end	begin	end	begin	end
24	3.49	5.21	2.18	2.65	2.89	4.60
12	3.44	4.28	2.38	2.42	2.76	3.64
		1)		2) 3)		1)

1) statistically significant difference (P<0.001); 2) statistically significant difference (P<0.01); 3) no statistically significant difference.

Temperature effects

All experiments were done with fresh warm milk. An automatic milking system may incorporate direct cooling before milk transfer to the milk tank. This will probably improve the results.

Another factor will be the temperature in the milking parlour. In the second experiment a small effect of the ambient temperature was observed (variation from 3 to 25 °C) for the 12-hour cleaning interval. In the period of 24-hour intervals the temperature hardly varied.

Discussion

Under the experimental conditions cleaning intervals of 24 and 12 hours appeared insufficient for maintaining good microbial milk quality. Total plate count and psychrotrophic counts increased unacceptably. More frequent cleaning would be necessary, e.g. every 8 hours.

The sanitary design of the milk transfer equipment used in automatic milking ought to be optimized. In addition, instant cooling of milk immediately after extraction may be desirable. Under such circumstances it may be possible to extend the cleaning intervals towards 12 hours.

Intermediate short water rinses of the whole system or only the cluster might also solve the microbial problem, but this would introduce disadvantages: risk of adding water to milk, loss of capacity (time) and increased water consumption.

The above observations relate to continuous milking for many hours. If an automated milking system were to milk in three daily shifts separated by several hours of rest, cleaning would probably have to be repeated after each shift.

References

Bjorck, L. 1991. Significance of the indigenous antimicrobial agents of milk to the dairy industry. IDF-Bulletin 264, IDF, Brussels, Belgium.

Ipema, A.H., 1991. Onderzoek naar de optimale melkfrequentie. IMAG-DLO, Wageningen, The Netherlands, Nota 91-56.

Schuiling, H.J., 1989. Voortgang onderzoek automatisch melksysteem, Landbouwmechanisatie 40(11):85.

Composition of milk in relation to its processing in dairy industry

P. Zoon

Netherlands Institute for Dairy Research (NIZO), P.O. Box 20, 6710 BA Ede, The Netherlands

Summary

The variability of milk, especially the variability in milk protein content, and its consequences for the manufacturing of some dairy products will be discussed. Specifically I will give attention to: the variability and the determination of protein in milk; the profitability of the separation of milk with high and low protein content at the farm compared to selection of farms delivering milk with relatively low and high protein content; standardization of protein content of milk at the dairy production plants. From an economic point of view, milk with a low protein content can best be used for the production of liquid milk and milk with a high protein content for the production of cheese. The separation at the farm of milk with relatively low and high protein content is thought to be less profitable for the dairy industry than standardization on protein content, if this is permitted in future.
Keywords: milk, variability, dairy industry, selection, standardization.

Introduction

Recent developments, such as automation in milking and the in-line or on-line determination of product properties, have raised the question whether it would be desirable to collect the milk of the individual cows on the farm in different batches depending on the gross composition of the milk. To answer this question the following aspects have to be evaluated:

- the variability of milk composition and its technical and economic consequences for the production of different dairy foods;
- the technical possibilities and economic desirability of separating milk streams before they are delivered at the dairy production plants;
- possible alternatives to this method.

Variability of milk and its consequences for the dairy industry

It is well known that the composition and properties of milk are variable. The main factors for the natural variation are genetic factors, stage of lactation, and feed. An example of the variation in the main components of milk is given in Table 1. This Table is meant to illustrate trends only and has no general validity.

Table 1. Mean Coefficient of Variation (CV) of milk of 10 Friesian cows from one herd throughout a lactation period (10 months). Source: Walstra & Jenness, 1984.

Milk component	CV (%) within cows	CV (%) among cows
Fat	14.5	6.2
Protein	10.6	6.5
Lactose	4.5	4.6

Fat and protein content are usually positively correlated. Fat and lactose content are usually negatively correlated as are protein and lactose content.

Variability in the composition has consequences for the dairy industry. In the Netherlands the five main groups of dairy products are: cheese; milk powder; liquid milk and milk products; condensed milk; and butter.

The protein content, especially the casein content, of milk is positively correlated with the cheese yield. Lactose is mainly lost in the whey and the fat content of raw milk is too high for the production of Gouda cheese (48+) so standardization on fat is applied. From the milk protein only the casein (about 80% of the protein) passes into the cheese, whereas most of the whey protein (about 20% of the protein) is lost in the whey. The ratio of casein to total protein is mainly dependent on genetic factors. The ratio is rather constant for any one cow.

The yield of milk powder and condensed milk is determined by the dry matter content. For most products the milk is standardized for fat and the solids-non-fat mainly affects the product yield. Milk with high protein content is sometimes more difficult to process and the resulting milk powders have functional properties, for example viscosity after recombining, which are possibly outside limits which can be tolerated in food-processing equipment.

The protein content does not influence the yield of liquid milk and milk products. In the Netherlands milk must contain at least 3.5% fat, whereas the average fat content of milk is 4.38%. The protein content is not defined explicitly, but the milk must have a fat-free dry matter content of at least 8.5%. The content of lactose, minerals and organic acids is about 5.6%, so the protein content should be at least 2.9%, being much less than the mean protein content of Dutch milk (3.45%). However, at present it is not permitted to standardize the milk on protein content.

From this evaluation it follows that milk with a relatively high protein content can best be used for cheese production. Milk with low protein content can best be used for the production of liquid milk and milk products or in some cases for milk powder production. In the Netherlands about 10^9 kg of milk is sold as pasteurized milk. If milk is used with a 0.5% (abs) lower protein content, about 5 million kg of protein becomes available, with which about 12 million kg of 48+ cheese can be produced. With a correction for the extra amount of milk fat needed the profit will be about NLG 60 million.

Separation of milk with relatively high and low protein content

Selection of farmers

In some areas of the Netherlands milk with a relatively high protein content is transported to cheese factories and milk with a relatively low protein content to a neighbouring liquid milk production plant. This does not affect the production volume of liquid milk, but more cheese can be produced per litre of milk. In this way more products can be produced within the limits of the milk quota. However, not only does the profit through higher yields increase, but so do the costs for transport and logistics. It depends on the local situation, e.g. number of farms per area; the number of cows per farm; variability of protein content; and the distance between farm and dairy plant, whether the profits outweigh the costs. In the Netherlands, with its high milk density, it is profitable to collect milk separately in certain areas, but the companies regularly calculate the break-even point, because the profits are rather small.

Selection of individual cows

The question arose (Mandersloot et al., 1991) whether it would be favourable to separate the milk from individual cows into two portions of milk with different composition at the farm. The most important parameter is the protein content of the milk and in particular the casein content. In order to separate milk with different protein content the protein content of the milk must be known. The protein content might be determined with an in-line or on-line method at the farm. At present this can only be performed with NIR (near-infra-red) analysis. However, the available apparatus (Milkoscan MSC 134, Milk Monitoring Systems, Foss Electric) is too expensive (about NLG 240 000) for use on a farm. Cheaper instruments (about NLG 20 000) are those relating total concentration of components to density or refractive index. A disadvantage of these methods is that they do not specifically measure protein and therefore the data are not unambiguous. For instance, milk with 3.2% protein, 4.7% lactose and 4.0% fat has the same density as milk with 3.6% protein, 4.4% lactose and 4.4%

fat. Cheap sensors able to detect protein concentration will probably not be available within a few years, but could be developed.

Another option is for milk samples of the individual cows to be sent to a laboratory for routine analyses of protein. Based on the protein content of the milk the cows are divided into two or more groups.

The variability in protein content of milk from different cows at one farm is generally much higher than the variability in protein content of bulk tank milk from different farms. The standard deviation of the protein content of average bulk tank milk is about 0.11% (abs) (Scholl, 1992). If the bulk tank milk is divided into equal volumes of low protein milk and high protein milk, the difference in protein between those milks will be about 0.15% (abs). Based on the figures of three groups of cows from one farm, Mandersloot et al. (1991) found that when milk of individual cows was divided into (40%) high protein milk and (60%) low protein milk, the difference in protein content between both batches was about 0.5% (abs). The difference in the protein content of the bulk milk arriving at the dairy plant will be somewhat lower, e.g. due to the variation in protein content of the milk between farms. The high protein will possibly contain about 0.2% more protein than average bulk milk.

Again with the profits of the higher yield extra costs arise due to the investment in a selection mechanism, second tank and higher analysis and transport costs. The extra costs are estimated to be at least NLG 4 000 per farmer per year, which corresponds with about 800 kg of protein or with 200 000 litres of milk with an increased protein content of 0.2% protein.

Alternative: protein standardization at the dairy plant

At present, definitions of milk in the legislation allow the adjustment of the content of milkfat to the desired level in many dairy products, such as liquid milk, milk powders and cheese, but do not permit the adjustment of protein content of milk. However, the mean protein content in milk of the EC countries varied in 1989 from 2.97 to 3.39% (Agra Europe Special Report No.55, 1990 Dairy Review). To avoid unfair competition in the common European market it is desirable that protein standardization be allowed soon.

For countries with a high protein content in the milk, protein standardization is the most profitable way to maximize dairy product yield. At present, ultrafiltration is the most suitable technology. Ultrafiltration is a membrane separation process. Water and small molecules, such as salts and lactose, can pass the semipermeable membrane nearly quantitatively (permeate). The larger molecules and dispersed particles such as casein, whey protein and fat globules are retained by the membrane and are thus concentrated in the retentate. The permeate can be used to lower the protein content of the milk used for liquid milk production to e.g. 2.95%. The retentate, in which the proteins, i.e. casein and whey proteins, are concentrated, can best be used for cheese production. During ultrafiltration, casein as well as whey proteins are concentrated. For a liquid milk factory producing about 45 million litres of milk the removal of 0.5% (abs) protein from the liquid milk to be used in cheese manufacture leads to a profit of about NLG 2.5 million. The costs for UF apparatus are roughly estimated as NLG 30 000 per year. Other costs are e.g. extra tanks at the factory and transport costs.

The cheese yield could be further increased if the casein only could be concentrated. At this moment it is possible to separate casein and whey proteins to a certain extent in a membrane separation with microfiltration. Microfiltration is a process comparable to ultrafiltration, but the pores of a microfiltration membrane are larger than those of an ultrafiltration membrane. The ratio of casein permeation depends on the pore size of the membrane. The liquid milk standardized on protein with microfiltration permeate will contain more whey protein and less casein than milk standardized with ultrafiltration permeate. The nutritive value of whey proteins is higher than that of casein, so the use of microfiltration permeate instead of ultrafiltration permeate will not impair the nutritive value of liquid milk. With a decrease in the casein content the calcium and phosphate content of the milk will also decrease, which is negative from a nutritive point of view.

By using membrane filtration the protein content of the liquid milk can be much better controlled than when low protein and high protein milk are collected separately. I expect that for the near future it will bring a small profit to select farms or areas on protein content in the milk in areas with high milk density and that in future the dairy industry will standardize milk on protein content by making use of membrane filtration.

Conclusion

The composition and properties of milk are variable. From an economic point of view, milk with a relatively high protein content can best be used for cheese production. milk with low protein content can best be used for the production of liquid milk and milk products or in some cases for milk powder production. I expect that for the near future it will bring small profit to select farms or areas on protein content in the milk in areas with high milk density. the separation of milk into low protein and high protein milk at the farm will probably lead to a larger difference in protein content than selection of farms or areas, but the investments are also much higher. I expect that in the future the dairy industry will be allowed to standardize milk on protein content e.g. by making use of ultrafiltration. This will be more profitable than selection of cows, farms or areas on protein content of the milk.

References

Walstra, P. & R. Jenness, 1984. Dairy chemistry and physics. John Wiley & Sons, New York, USA, pp. 157.

Mandersloot, F., J.P.C. Verheij, C.J. Jagtenberg & E.A.A. Smolders, 1991. Milking in two tanks: high and low protein content. Praktijkonderzoek Proefstation voor de Rundveehouderij, Schapenhouderij en Paardenhouderij 4(1):41-44 (in Dutch).

Scholl, D.T., 1992. An epidemiological study of dairy farm management and farm bulk tank milk protein concentration. Ph.D thesis, Utrecht University, The Netherlands.

Near-infrared spectroscopy for evaluating milk quality

R.N. Tsenkova*, K.I. Yordanov* & Y. Shinde**

* *Technical University-Rousse, Rousse, Bulgaria*

** *Obihiro University of Agriculture and Veterinary Medicine, Inada-cho, Nishi 2-13, Obihiro-shi, Hokkaido 080, Japan*

Summary

Many milk quality control organizations are currently considering the automation of milk control processes on farms to improve milk quality and the services to milk producers. So far, mid-infrared and near-infrared (NIR) (1100-2500 nm) spectral analysis have been used to analyse milk components in whole milk. The analysis is done to liquid milk by transmittance (absorbance) and includes sample preparation, e.g.: adding a preservative to samples, warming them up to about 40 °C, then homogenizing or drying the samples.

To avoid bias we chose to work on quarter foremilk samples from all udder quarters. In addition, morning and evening bucket milk samples from the individual cow were obtained from milk yield meters. Absorbance spectra of 680-1230 nm (NIR) were recorded using a 6250 Pacific Scientific spectrophotometer. The spectral data were subjected to multiple linear regression.

The results obtained show:

1. A high correlation coefficient for each constituent of milk (fat, protein, SNF, lactose, somatic cell count) for every cow, between NIR and laboratory measurements.
2. A 95% accuracy of mastitis diagnosis using NIR absorbance at only four wavelengths, when compared with somatic cell count. For the same samples, the accuracy of mastitis diagnosis by electro-conductivity is 88%. The NIR method is therefore more accurate.
3. The lower wavelength range (680-1230 nm) extends the range of optical sensors and fibre optics, therefore the NIR method may provide feedback and automatic adjustment of treatment for every cow.

Keywords: Near infrared analysis, milk, mastitis, quality control, composition measurement.

Introduction

The modern management of dairy farms involves automated systems for the control of the entire production process (Rossing & Ipema, 1989). On-line control of milk is already used to determine temperature and electrical conductivity for mastitis detection and also milk quantity (Rossing et al., 1989; Rossing & Ipema, 1989).

The next step in this concept could be to apply the use of near-infrared (NIR) principles and equipment for on-line milk control (suitable for automation) in order to establish the composition of milk and the physiological status of the cow.

Near-infrared spectroscopy is a non-destructive method, which has recently developed as a rapid and simple method for determining the composition of various types of food and feed (Williams, 1990). This method has been applied to measure the contents of various constituents in dairy products (De Boever et al., 1990; Sato et al., 1987; Williams, 1990), but so far NIR analysis has used homogenized milk samples, which are inconvenient for on-line measurement.

In previous papers (Kyrilin & Tsenkova, 1980; Tsenkova, 1988; Tsenkova et al., 1990) the NIR method was examined in comparison with conventional methods for mastitis diagnosis and it was found to be very reliable for mastitis diagnosis, using unhomogenized milk samples.

This paper reports on research to examine the feasibility of the NIR range for on-line milk quality control.

Material and methods

Milk samples and spectra

In this study quarter and individual (bucket) milk of 25 Holstein cows was analysed for 5 months, from September 1991 to February 1992. From these cows a total of 360 unhomogenized milk samples, obtained at Obihiro University Farm was analysed by Pacific Scientific Spectrophotometer - NIR System, model 6250. Prior to analysis each sample was warmed to 40 °C in a water bath. The NIR transmittance spectra (T) were collected in terms of optical density -OD, i.e. OD=log(1/T) with a wavelength range of 680 to 1235 nm and 700 data points per sample. Absorbance data - log(1/T) were stored in the linked computer. For NIR data, a quartz cuvette with walls 1mm thick and containing a milk sample of 4mm thick was used. Spectra were obtained as the average of 50 scans. The other duplicate samples were sent to the Tokachi Research Center of Obihiro (Japan) for milk component analysis.Each sample (50 ml) was thoroughly mixed before division into subsamples for the various analyses. Two experiments were carried out.

Experiment 1

A total of 200 individual morning and afternoon milk samples from the entire udder were taken from twenty cows that were monitored continuously for 5 months. These samples were obtained monthly from each cow milk-yield meter after milking was finished.

Experiment 2

A total of 160 quarter foremilk samples was collected from each teat of five mastitis cows. This entailed sampling each cow before the morning milking for four consecutive days. Five cows with the highest level of SCC after the regular monthly checking in December were selected for this particular experiment.

Chemical analysis

The duplicate milk samples sent to Tokachi Research Center were analysed for milk constituents by Milko-scan and Foss-somatic (N. Foss-Electric A/S Hillerød DK3400 - Denmark). The samples were analysed for: fat (F), protein (P), lactose (L), solids non fat (SNF) and somatic cell count (SCC). Log(SCC) was used for calibration work. In addition, electro conductivity (EC) was determined for foremilk samples by digital mastitis detector (DMD) or "milk checker".

Data treatment

The scattering induced by the particles in milk showed a distinct individual pattern for each cow. On-line measurement of milk components does not allow for the analysis of homogenized milk. To avoid the influence of these factors in our two experiments, we analysed the spectral data of each cow separately. The data on each cow was stored in its respective file. The file names correspond to the cow number.For comparison, some mixed data files containing spectral data from different cows were treated in parallel. In the first experiment 20 files from 20 cows and one mixed file composed of individual milk spectral data from all 20 monitored cows, taken after morning milking in September were analysed. In the second experiment 5 files from 5 cows and 4 mixed files that contained data from different cows were analyzed. Each of the mixed files contained spectral data of milk samples from the same udder quarter of four different cows, obtained during the 4 consecutive days in which the experiment was carried out. The files were referred to as: FLMIX (front-left mixed); FRMIX (front-right mixed); RLMIX (rear-left mixed); RRMIX (rear-right mixed). The same number of spectra in the files were compared and analysed in each experiment.

Preliminary calculations showed that a better sample component analysis could be obtained by using the second derivative of the log(1/T) absorbance curve rather than log(1/T). All data were therefore analysed quantitatively by using the second derivative transformation.

To evaluate the feasibility of the use of NIR spectroscopy for quantitative analysis of the main milk components, multiple linear regression analysis was carried out on each of the sets of reference data on the duplicate readings of the five means (four from Milko-scan and one from Foss-somatic). The criteria used for evaluation were a high multiple correlation coefficient (R) and a low standard error (SE).

For qualitative analysis, to detect mastitis, a new function (F1) was created, using raw absorbance near NIR spectral data at four wavelengths, which contain significant information for mastitis diagnosis: $F1 = F(\log(1/T\lambda_i)$, $i=1...4$, λ_i — (680-1235 nm)

Results and discussion

Original NIR spectra of individual morning milk samples of mastitis cow 664 and healthy cow 698 (Figure 1; Table 1) showed that the spectra from the same cow are similar. However, the groups of spectra from different cows are different. Differences in the shape of the curves are most apparent between 750 to 970 nm (lactose, protein and water absorption band),also, between 1018 to 1188 nm (protein and fat absorption band), (Williams & Norris, 1987). Mastitis causes an unbalance in milk composition, i.e. changes in all milk components (Barbano, 1989). These changes occur as corresponding multiplicities in the whole near NIR milk spectra.

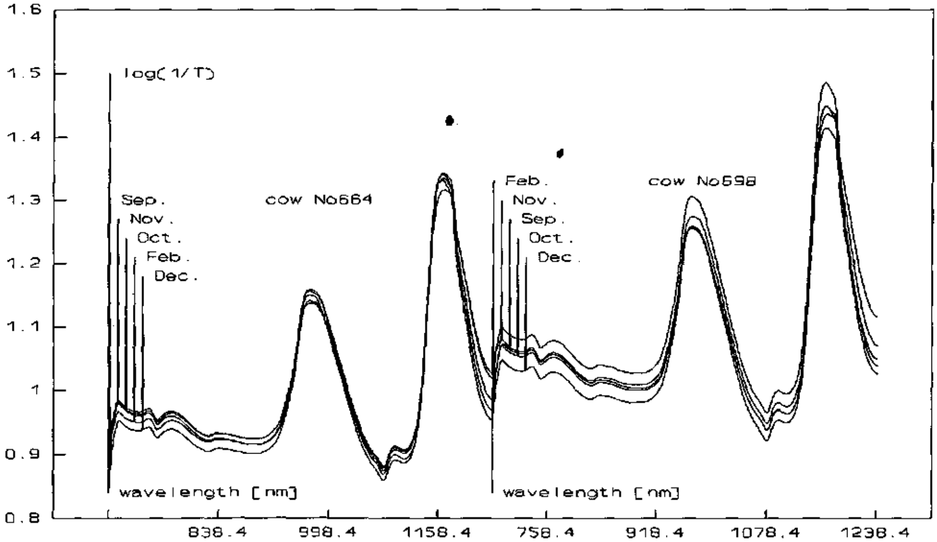


Figure 1. Raw spectra of individual milk samples of mastitis cow 664 and healthy cow 698 - morning milking.

Table 1. SCC for every sample (× 1000).

Cow No.	Somatic cell count per month				
	Sept.	Oct.	Nov.	Dec.	Feb.
664	913	171	408	574	1225
698	9	6	21	10	16

The results of the regression analysis obtained for respective constituents when 20 cows were used showed high correlation for individual cow data, even though the spectra for these files were taken once a month after morning and evening milking for five consecutive months. Table 2 represents a sample of data obtained from five cows and data from the mixed file. The last file with spectral data (IMIX) had a notably lower correlation coefficient and higher standard error, compared with other groups. Variation between spectra of individual cow milk samples seems to depend on individual variation rather than on composition.

Table 2. Individual milk - correlation coefficient and standard error.

Data file	Constituents									
	Fat		Protein		Lactose		S N F		log(SCC)	
	R	SE	R	SE	R	SE	R	SE	R	SE
I498	0.99	0.05	0.98	0.05	0.96	0.04	0.99	0.02	0.98	0.29
I558	0.99	0.08	0.99	0.02	0.97	0.07	0.95	0.08	0.99	0.03
I567	0.99	0.24	0.99	0.03	0.97	0.08	0.99	0.03	0.98	0.18
I610	0.99	0.19	0.99	0.03	0.95	0.07	0.96	0.09	0.98	0.24
I631	0.99	0.16	0.99	0.03	0.99	0.02	0.98	0.05	0.88	0.05
IMIX	0.86	0.55	0.78	0.15	0.73	0.12	0.77	0.15	0.59	0.47

R = correlation coefficient; SE = standard error.

The correlation coefficients for quarter milk spectral data of each cow also showed a high correlation with all quarter milk constituents analysed (Table 3). When the treated file contained spectral data from different cows, the positive correlation coefficients were low even though the samples were taken from the same udder quarters. For further investigation on the calibration and selection of wavelengths for regression equations to measure milk components using near NIR, official analytical reference methods should be used (Gerber, macro - Kjeldahl, etc.).

Table 3. Quarter milk - correlation coefficient and standard error.

Data file	Constituents									
	Fat		Protein		Lactose		S N F		log(SCC)	
	R	SE	R	SE	R	SE	R	SE	R	SE
Q660	0.99	0.05	0.91	0.15	0.98	0.14	0.94	0.20	0.98	0.23
Q686	0.97	0.16	0.85	0.32	0.90	0.33	0.91	0.11	0.94	0.42
Q697	0.99	0.09	0.98	0.08	0.93	0.32	0.88	0.30	0.94	0.37
Q701	0.95	0.16	0.97	0.25	0.97	0.45	0.91	0.32	0.87	0.58
Q741	0.98	0.09	0.89	0.05	0.92	0.17	0.95	0.13	0.96	0.28
FLMIX	0.76	0.32	0.92	0.14	0.88	0.12	0.90	0.25	0.72	0.42
RLMIX	0.84	0.36	0.78	0.51	0.82	0.98	0.83	0.55	0.68	0.76
FRMIX	0.83	0.29	0.94	0.12	0.93	0.09	0.98	0.10	0.80	0.40
RRMIX	0.80	0.70	0.77	0.56	0.83	0.55	0.92	0.21	0.85	0.81

R = correlation coefficient; SE = standard error.

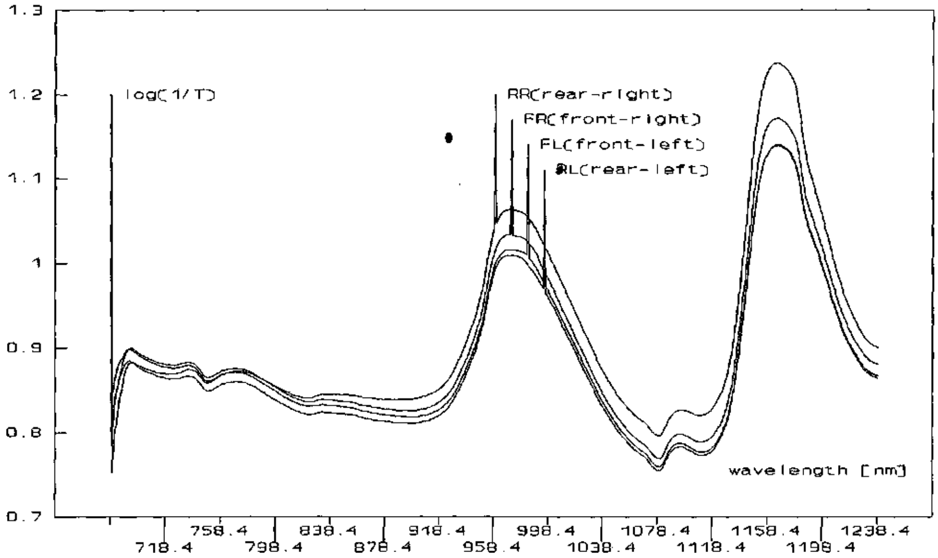


Figure 2. Raw spectra of quarter milk samples of mastitis cow 660 (the mastitis quarter is RR with SCC > 500 000).

Original NIR spectra of quarter milk samples of mastitis cow 660 (Figure 2) showed different spectral curves of healthy and mastitis quarters in the same range of wavelengths as was found for individual milk (Figure 1). Corresponding graphs of F1 and log(SCC) (Figure 3) for all quarter milk samples from cow 660 showed that we can use the F1 or NIR method instead of the somatic cell count. This allows mastitis diagnosis to be done on the farm, using on-line optical sensors for milk control. The accuracy of NIR diagnosis when compared with somatic cell count was 95%. For the same data,the accuracy of electro-conductivity was 88%.

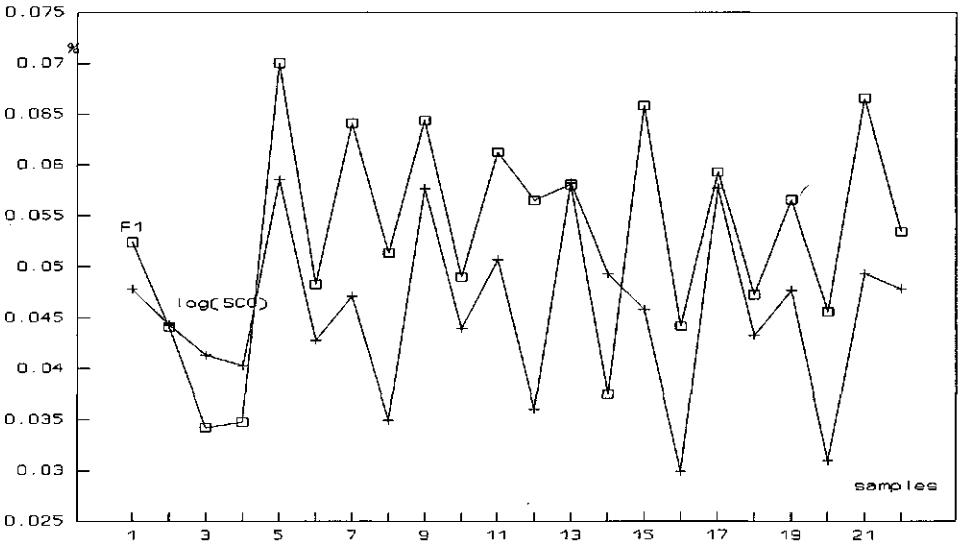


Figure 3. Cow 660 - corresponding graphs for log(SCC) and F1.

Conclusions

The NIR spectroscopy is better applied for milk component analysis when spectra of individual (bucket) or foremilk samples of each cow are used. A comparison of the NIR method and the standard method (somatic cells count) for mastitis diagnosis revealed that these methods gave similar results. The advantages of NIR method over other mastitis test methods are its repeatability and simplicity. On the basis of NIR range (680 to 1235 nm), different prototypes for milk quality control are available, depending on the purpose and the place of intended use. Having NIR on-line information for milk and feed quality and composition (Williams & Norris, 1987; Williams, 1990), it could be possible to organize feedback and to adjust cow treatment and herd management accordingly. In other words, the use of NIR spectroscopy could be a further step towards full dairy automation.

Acknowledgments

The authors wish to thank the staff of the Obihiro University Farm and Tokachi Research Center for their help and for the laboratory analysis of the milk samples, the Kubota company of Japan for provision of the equipment.

References

Barbano, D., 1989. Impact of mastitis on dairy product quality and yield: research update. In: Proceedings of the 28th Annual Meeting of the National Mastitis Council, INC, Tampa, Florida, USA, p. 44-48.

De Boever, J.L., G. Huyghebaert, Ch. Boucque & G. de Groote, 1990. Prediction of fat and protein content in individual cow milk by NIRS - preliminary results. In: Proceedings of the 3rd International NIRS Conference, Brussels, Belgium, p. 279.

Kyrilin, N.I. & R.N. Tsenkova, 1980. A study on the optical characteristics of milk, aiming at effective diagnosis of subclinical mastitis. In: Proceedings of the national symposium Physics-Agriculture, St. Zagora, Bulgaria.

Rossing, W., K. Maatje, E. Benders, P.H. Hogewerf & W. Buist, 1989. Automatic mastitis detection in the milking parlour. In: Proceedings of the 28th Annual Meeting of the National Mastitis Council, INC, Tampa, Florida, USA, p. 58-67.

Rossing, W. & A.H. Ipema, 1989. From cow identification to fully automatic milking. In: Proceedings of the 28th Annual Meeting of the National Mastitis Council, INC, Tampa, Florida, USA, p. 68-80.

Sato, T., M. Yoshino, S. Furukawa, Y. Someya, N. Yano, J. Uozumi & M. Iwamoto, 1987. Analysis of Milk Constituents by the Near Infra-red Spectrophotometric method. Japanese Journal of Zootechnical Science 56(8):698-706.

Tsenkova, R.,1988. A comparative analysis of some applications of infra-red spectroscopy for determining of milk quality during milking. In: Proceedings of the 6th World Conference on Animal Production, Helsinki, Finland.

Tsenkova, R., E. Statev, R. Georgieva & D. Topuzanov, 1990. A device for differential diagnosis of subclinical mastitis in cows. Selskostopanska Tehnika 27(7):68-73.

Williams, P.C. & K. Norris, 1987. Near-infrared technology in the agricultural and food industries. American Association of Cereal Chemistry, Inc., St. Paul, MN, USA

Williams, P.C., 1990. Application of Near-Infrared Reflectance and transmittance spectroscopy in agriculture. In: Proceedings of the 3rd International NIRS Conference, Brussels, Belgium, p. 463-473.

Fresh raw milk composition analysis by NIR spectroscopy

Z. Schmilovitch, E. Maltz & M. Austerweil

Institute of Agricultural Engineering, Agricultural Research Organization, The Volcani Center, P.O. Box 6, Bet Dagan 50250, Israel

Summary

Milk testing using the current periodic routine is off-line by nature, expensive, time and labour consuming, and low in frequency. Near Infra-red (NIR) spectroscopy has been established as a method for analysing the ingredients in dairy products. NIR systems are non-destructive and remote and real-time analyzers satisfy the challenging requirements of dairy farming. Results of this study indicate the feasibility of using this technology for fresh milk composition analysis. Fat and Total Soluble Solids (TSS) content, were analysed using a near-infra-red scanner spectrometer in reflectance mode. The wave range was 1200 nm to 2400 nm. One hundred and ten samples were tested. Fifty samples, chosen randomly from the set were used for calibration. Predictions were made for the rest of the set. Prediction results provided correlation factors of 0.90 and 0.83 and SEP of 0.233f and 0.274 for fat and TSS, respectively.
Keywords: milk, near-infra-red, fat, tss.

Introduction

Milk composition plays a major role in dairy farming. It provides vital input for both strategic and managerial decisions. Today, however, the lack of frequent, reliable data from each cow in the herd prevents efficient utilization of milk composition for daily managerial decisions on the farm (Maltz et al., 1991; Maltz et al., 1992). Milk testing by means of the current periodic routine is off line, destructive, expensive, time and labour consuming and of low frequency. The procedure, by nature, is error-prone (Ng-Kwai-Hang et al., 1988; Barbano & Clark, 1989; Smith & Barbano, 1990) and provides delayed information. Thus, its utility for managerial decisions is limited. As milk composition and milk yield are the most important variable affecting the selection of bulls and genetic improvement, Automatic Milking Systems (AMS) could benefit considerable from the implementation of individual feeding and milking regimes. Hence the future utility of AMS depends on the development of more efficient and reliable milk testing methods. Efficient individual feeding strategy is based on an energy balance calculation. Energy intake is invested in body weight or milk (Maltz et al., 1991; Maltz et al., 1992). Data on fat and TSS are sufficient for the determination of milk energy output estimates.

NIR technology is being widely implemented throughout the food industry. It is a non-destructive method used successfully for analysing the ingredients of organic products (Williams & Norris, 1987). NIR systems are applied in on-line procedures both in laboratories and production processes. Near-infra-red spectroscopy analysis is based on the ability of the ingredients to absorb radiation at certain wavelengths in the NIR spectrum and the overtones of the same effect in the IR spectrum. A broad range of the IR analyzer is used for the routine lab analysis of milk composition (Sjauna & Andersson, 1985; International IDF Standard, 1988; Ginn & Packard, 1989a, 1989b). NIR systems are used in the dairy products industry for the analysis of water content in milk powder, fat and proteins in cheese, and other constituents (Frankhuizen et al., 1983; Frankhuizen & Veen, 1985; Fuhrmann, 1987; Martel et al., 1989; Downey et al., 1989). The feasibility of performing raw milk analysis by NIR spectroscopy has been demonstrated in several works (Black, 1984; Robert et al., 1987; Sato et al., 1987). Fiber optics and a multiplexer head enable the remote and multi-channel operation of NIR systems (Birth, 1967; Anonymous, 1989). NIR analyzers are PC-integrated for data acquisition, storage and analysis (Williams & Norris, 1987).

In the light of the characteristics described above, NIR technology has the potential of becoming the preferred method for on-line, real-time, multi-channel milk composition analysis in the milking parlour, enabling frequent milk composition data to be provided on each cow. Along with other on-line, real-time data on the individual cow (e.g. milk yield, body weight, concentrates, and ration composition), milk composition can be incorporated into a management system for decision making on each cow in the herd.

The objective of this study was to evaluate the feasibility of analysing fresh, raw, and non-homogenized cow milk by means of the NIR system.

Materials and methods

In this study, a commercial near-infra-red scanner spectrometer (Quantum 1200, manufactured by LTI Inc.) was used in a reflectance mode with a grating suitable for a range of 1200-2400 nm. A cell with a 2 mm path length was used, utilizing an original LTI compartment with a special sample holder. One hundred and ten samples were tested.

Milk samples were obtained for scanning by milking lactating cows a few minutes before scanning. The samples were stored in a water tank with a controlled temperature, in order to prevent the effects of temperature change on the milk before scanning. A portion of each sample was sent for laboratory testing following routine procedure customary in the dairy industry. The samples were analysed for fat and TSS content. The tested samples varied with herd and milking time. Fifty samples, chosen randomly from the set, were used for calibration. Predictions were made for the rest of the set.

In this study, spectroscopic analysis was based on Spectra Matrix and LightCal Plus software (by LTI Inc.). Data were processed for several options, such as first derivative, second derivative, Log(1/R), and its derivatives as well. LightCal Plus (1990) software, the PLS (Partial Least Squares Regression), and PCR (Principal Component Regression) methods were applied to the data for each mathematical process carried out.

Results

The best results, in terms of standard error of prediction, were obtained by combining the first derivative treatment and the PLS method. Five to seven factors of the PLS method were sufficient. Examples of the calibration results of this combination are presented in Figures 1 and 2. Calibration procedure provided the standard error of calibrations (SEC) of 0.149 and 0.167 for fat and TSS content, respectively. Examples of validation results from this combination are presented in Figures 3 and 4. Prediction results provided correlation factors of 0.90 and 0.83 and Standard Error of Prediction (SEP) of 0.233 and 0.274 for fat and TSS content, respectively.

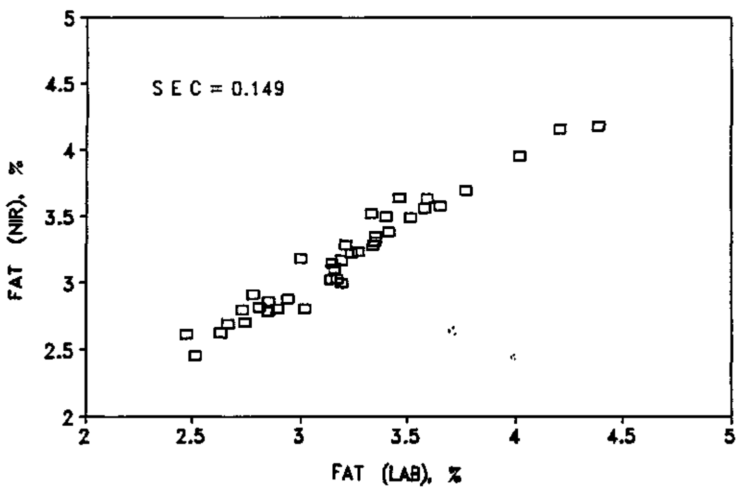


Figure 1. Comparison of fat in raw fresh milk calibrated by NIR model vs. laboratory results.

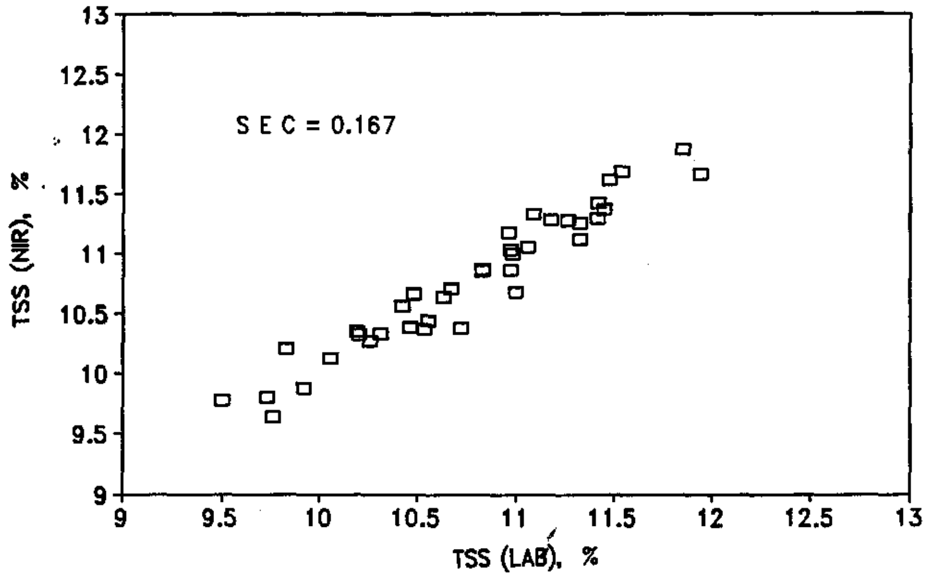


Figure 2. Comparison of TSS in raw fresh milk calibrated by NIR model vs. laboratory results.

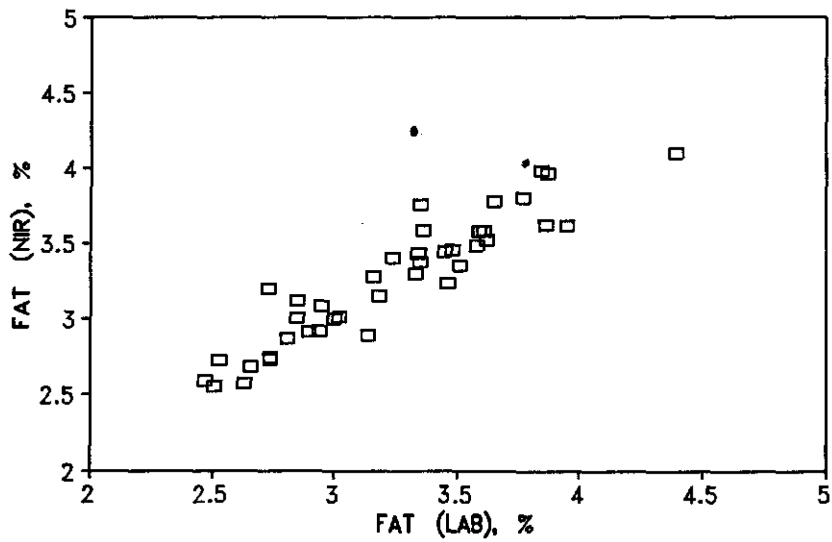


Figure 3. Comparison of fat in raw fresh milk predicted by NIR model vs. laboratory results.

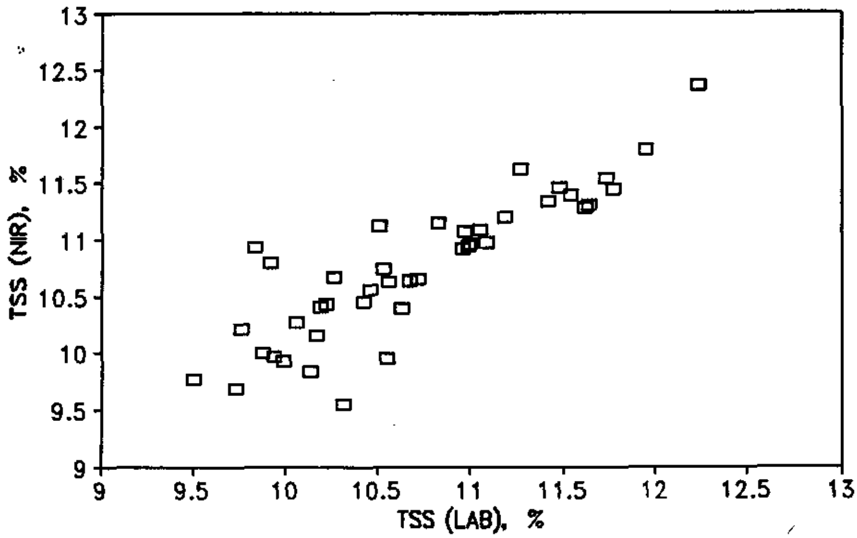


Figure 4. Comparison of TSS in raw fresh milk predicted by NIR model vs. laboratory results.

Discussion and conclusions

Near-infra-red spectroscopy seems to be a suitable method for the analysis of fresh raw milk composition. The preferred spectral treatment is a combination of first derivative and PLS. Quantum 1200 represents a commercial system that might be capable of dealing with milking parlour demands. In future, evaluation of the system should be expanded in the direction of combining the system with the milking unit. Furthermore, the utilization of fiber optics and a multiplexer head for multi-channel operation should be considered for the milking parlour.

References

Anonymous, 1989. LT catalog - Accessories for the Quantum 1200. L.T. Industries Inc., Rockville, Maryland, USA.

Barbano, D.M. & J.L. Clark, 1989. Infra-red milk analysis challenges for the future. Journal of Dairy Science 72(6):1627-1636.

Birth, G.S., 1967. A fiber optic reflectance attachment. Agricultural Engineering 48:448-449.

Black, R.G., 1984. Analysis of raw milk by NIR. In: D. Miskelly, D.P. Law & T. Clucas (Eds.): Proceedings of an International Symposium on Near Infra-red Reflectance Spectroscopy. Victoria, Australia, p. 105-113.

Downey, G., D. Bertrand, P. Robert & P.M. Kelly, 1989. NIR reflectance a new use in the dairy industry. Farm and Food Research 20(4):18-20.

Frankhuizen, R., E.A.M. Boers & H. Oortwijn, 1983. Determination of the composition of dried skim milk by Near Infra-red Reflectance Spectroscopy (NIR). Zuivelzicht 75(9):210-213.

Frankhuizen, R. & N.G. van der Veen, 1985. Determination of major and minor constituents in milk powders and cheese by near infra-red reflectance spectroscopy. Netherlands Milk and Dairy Journal 39(4):191-207.

Fuhrmann, J., 1987. Use of Near infra red (NIR) reflection spectroscopy in dairy industry. Lebensmittelindusrie 34(4):171, 34(5):223.

Ginn, R.E. & V.S. Packard, 1989a. A study of control of infra-red instruments used in analysis of various components of raw milk. Dairy and Food Sanitation 9(1):8-12.

Ginn, R.E. & V.S. Packard, 1989b. A study of the accuracy of infra red milk component analysis in DHIA laboratories. Dairy, Food and Environmental Sanitation, 9(2):61-63.

International IDF Standard, 1988. Whole milk. Determination of milkfat, protein and lactose content. Guide for the operation of mid infra-red instruments, no. 141.

Maltz, E., O. Kroll, S.L. Spahr, S. Devir, A. Genizi & R. Sagi, 1991. Milk yield, parity, and cow potential as variables for computerized concentrate supplantation strategy. Journal of Dairy Science 74(7):2277-2289.

Maltz, E., S. Devir, O. Kroll, B. Zur, S.L. Spahr & R.D. Shanks, 1992. Comparative responses of lactating cows to total mixed rations or computerized individual concentrates feeding. Journal of Dairy Science 75(6):1598-1603.

Martel, R., P. Paquin, R. Roberge & A. Talbot, 1989. Water determination in condensed milk using Fourier transform near-infra-red spectroscopy. Journal of Dairy Science 72(1):116.

Ng-Kwai-Hang, K.F., J.E. Moxley & F.R. van de Voort, 1988. Factors affecting differences in milk fat test obtained by Babcock, Rose Gottlieb, and infra-red methods and in protein test from infra-red milk analysis. Journal of Dairy Science 71(2):290-298.

Robert, P., D. Bertrand & M.F. Devaux, 1987. Multivariate analysis applied to near-infra-red spectra of milk. Analytical Chemistry 59(17):2187-2191.

Sato, T., M. Yoshino, S. Furukawa, Y. Someya, N. Yano, J. Uozumi & M. Iwamoto. 1987. Analysis of milk constituents by the near infra-red spectrophotometric method. Japanese Journal of Zootechnical Science 58(8):698-706.

Sjauna, L.O. & I. Andersson, 1985. Laboratory experiments with a new infra-red (IR) milk analyzer, the MilkoScan 605. Acta Agriculturae Scandinavica 35(4):345-352.

Smith, E.B. & D.M. Barbano. 1990. Evaluation of uncorrected signal linearity on infra-red milk analyzers. Journal of Dairy Science 73(1):91.

Williams P. & K. Norris (Eds.), 1987. Near-infra-red Technology in the Agricultural and Food Industries. American Association of Cereal Chemists, Inc. St. Paul, MN, USA.

3. Milking frequency

The effects of frequent milking on udder physiology and health

J.E. Hillerton & A. Winter

AFRC Institute for Animal Health, Compton, Newbury, Berkshire, RG16 0NN, United Kingdom

Summary

The general results of a series of detailed experiments milking heifers and cows 2 or 4 times daily are presented. Under experimental conditions, in split-udder design trials, a yield increase of >11% resulted. The control of production appears to be similar to that described in the goat. There was an immediate effect from removal of a feed-back inhibitor, with cellular differentiation and evidence in the longer-term of cellular proliferation.

In a comparative trial it was found that the frequency of milking and bovine growth hormone operate differently in stimulating extra production; their effects were additive. This shows that with four times daily milking the metabolic capacity of the mammary gland is not reached.

The cow adapts rapidly to more frequent milking and produces wholesome milk with improved composition. It is likely that some forms of mastitis could be reduced with more frequent milking to improve animal health and milk bacterial quality. It is concluded that more frequent milking may offer opportunities to improve dairy cow welfare.

Keywords: milk yield, mastitis, BST, mammary differentiation, feedback inhibition.

Introduction

There has been a persistent drive over at least the last 4 or 5 decades to improve dairy production and efficiency by maximising output. This has involved significant advances in nutrition, animal breeding, milking systems and a continual flirtation with milking more than twice daily. There is generally a significant benefit to yield from more frequent milking regimes than twice daily (more frequent milking is used here to describe more than twice daily milking) but the efficiency of such production systems depends largely on the variable costs incurred, especially the extra labour needed to milk. The success of more frequent milking routines and their usual adoption is therefore in dairy industries where there is ample cheap labour. One of the many attractions of automated milking systems is the opportunity to milk frequently for a relatively small increase in variable costs.

Frequent milking regimes are not new. They were often the basis of town dairy systems in the last century, and before, where the aim was not so much to produce more milk but to produce milk of a quality to be drinkable under conditions of limited suitable storage. The benefits of more frequent milking on milk quality, and udder health, are not a new consideration either.

However, there has been relatively little investigation into the basic biological responses of the mammary gland of the modern dairy cow to such routines and these have been largely confined to production studies. The lack of easy availability of automated systems has meant, so far, that there has been limited opportunity for medium to long-term studies of the physiological responses of cows. It has been necessary to conduct experimental studies using existing milking systems where cows have been milked more frequently. This has allowed a significant number of variables to be controlled to experimental advantage although efficient experimentation has required fixed milking intervals. Results from some of these studies are presented in the context of automated milking systems and the implications of such milking regimes for the welfare of the dairy cow.

Responses to an increase in milking frequency

An increase in milking frequency invariably results in an increase in milk yield. This has been measured under many experimental and field circumstances but usually for three times (3×) daily milking where 5-25% more milk can be obtained. The precise increase has depended on the length of the trial, short or for a whole lactation, the age of the animals involved, when the trial was conducted, and the parity of the animals. It is often quoted that heifers respond better (15-25% increase in yield) compared with multiparous cows (10-15% increase). However, averaging over a number of trials (Lush & Shrode, 1950; Amos et al., 1985; DePeters et al., 1985; Allen et al., 1986; Gisi et al., 1986; Barnes et al., 1990) from different places and using animals of different genetic potential, largely because when and where the trial was conducted, shows that this is misleading and that over a lactation there is a similar additional weight of milk collected, approximating 1100 kg/lactation/animal, irrespective of parity. The mechanisms involved in stimulating this extra yield and the control of its synthesis and secretion are poorly understood, including the potential for more yield with more frequent than 3× daily milking. The best evidence comes from extrapolation from studies on goats at the Hannah Research Institute. Similar experiments have now been conducted on cows.

There are a number of stages in the response of the udder to an increased frequency of milking. The initial increase in yield occurs quickly, within 2-6 milkings (12-48 hours) and an initial response of producing some 10% more milk occurs. Figure 1, from Hillerton et al. (1990), shows the response. A statistically significant increase in yield of over 12% was found in a split-udder trial using 4 heifers and 4 cows at approximately 150 days post-parturition, when the milking frequency of 2 quarters was increased from 2× to 4× daily whilst the other two continued to be milked every 12 hours. The response within 36 hours is consistent with the effect described for goats. A similar response has been shown by Ipema et al.(1991) over 18 days of 6× daily milking of cows. It has been shown in the goat that control of milk production is autocrine (Peaker & Wilde, 1987) with short-term feed-back inhibition by a milk whey protein. Accumulation of milk in the alveoli suppresses cellular activity.

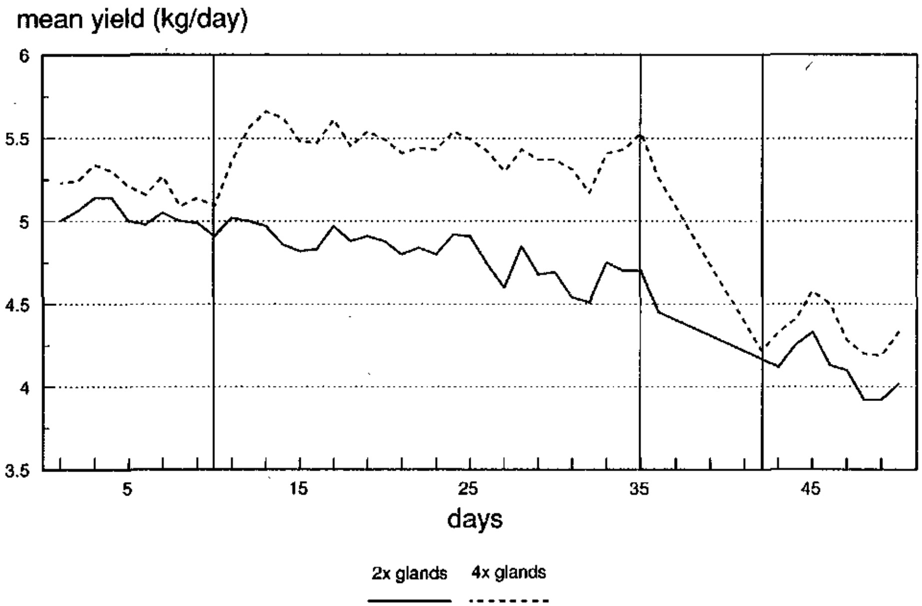


Figure 1. Daily milk yields for control glands (2× - solid lines) and test glands (4×- dashed lines) of cows milked four times daily in two glands. Each point is the mean of 8 animals, averaging 2 glands per animal. Vertical lines indicate periods; pre-treatment, frequent milking, biopsy, post-treatment.

No significant changes in the chemical composition of milk have been reported in the transitory phase to more frequent milking. Fat, protein and lactose are secreted actively and water follows passively to produce an isotonic secretion. A persistent effect of more frequent milking is to stimulate cellular activity in the alveolar epithelium and enhance the amount of synthetic enzymes such as acetyl-CoA carboxylase, fatty acid synthetase and galactosyltransferase. Thus there is increased cellular differentiation as a medium-term response. It is possible that this increase in the metabolic capacity of the gland is not lost too quickly on return to 2× daily milking and so aids the persistency of lactation in more frequently milked quarters after the experimental period. There is an increasing difference in yield between 2× and 4× daily milked quarters (Figure 1) with time and the rate of decline of yield was halved from 2% per week to 1% in the 4× daily milked quarters (Hillerton et al., 1990). The enhanced cellular differentiation may be compensating for the continual involution of secretory tissue from peak yield onwards.

A longer term response has been reported for the goat. In a study where 3× daily milking continued for a whole lactation there was evidence of cellular proliferation - mammary growth (Henderson et al., 1985). This has been shown by a 34% increase in the mammary parenchyma, a 22% increase in the number of cells and significantly higher DNA turnover (Wilde et al., 1987).

There are a number of consequences of these medium to long-term effects on the mammary gland. On return to 2× daily milking there was an increased persistency of lactation or a carry-over of the effect of more frequent milking; the yield from 4× daily milked quarters stayed higher (Figure 1). Over the four weeks of 4× daily milking Hillerton et al. (1990) found that milk fat and protein contents increased in all quarters but there was a small but significantly greater increase, only for protein, in the 4× daily milked quarters. The 0.5% increase in milk fat content, from a fairly low level, was probably a nutritional effect. No extra concentrate was fed for the yield increase so the animals obtained any extra nutrients from ad-lib silage. An increase in the fibre:concentrate ratio usually increases milk fat content (Sutton, 1986). There is generally an increase in the amount or certainly frequency of forage feeding in more frequently milked cows (Winter et al., 1992), on return from the parlour most animals engaged in a bout of feeding of silage and concentrate if available except perhaps during the night. There is likely to be an effect of this more efficient feeding in milk yield and composition but this can not be quantified from the data available.

Measurements from explants of biopsy material from mammary tissue have shown a medium-term response, after the first few days, of increased enzymic activity with more frequent milking. This enhanced activity (by some 18% for treated glands) was found for key enzymes in milk synthesis but not for other enzymes measured. Despite this there was no difference in the rate of synthesis of casein, fat or lactose but this was confounded by the logistics of the biopsy technique (Hillerton et al., 1990). This suggests that the effect is not cellular hypertrophy but cellular differentiation similar to that described for the dairy goat (Wilde et al., 1987). At this level the response is local with the effect of improved nutrition giving a systemic response.

Table 1. Alveolar size and rate of DNA synthesis in mammary biopsy samples taken from cows milked 2× daily or after 4 weeks of 4× daily milking (mean ± standard error mean).

	Milking frequency 2×	Milking frequency 4×
Equivalent alveolar diameter (μm)	78.2 ± 4.8[a]	93.9 ± 4.4[b]
Mean cell no./alveolus	30.9 ± 1.8	32.2 ± 1.5
DNA synthesis rate (dpm/h/μg DNA)	536 ± 72[c]	827 ± 153[d]

[a,b] statistically significant difference ($p < 0.05$ paired t-test)
[c,d] statistically significant difference ($p < 0.05$ ANOVA).

Quantitative histology on the biopsy material suggested that there were more epithelial cells per alveolus in the glands milked 4× daily and there was a higher rate of DNA synthesis in 4× daily milked glands (Table 1). This is evidence of a local cellular proliferation similar to that induced by long-term 3× milking of goats (Wilde et al., 1987).

There is obviously a hierarchy of control systems,with different targets and temporal effects, influenced by the frequency of milking. These have been investigated further in a comparison of the effects of 4× daily milking and growth hormone, administered as recombinant bovine somatotropin, separately and in combination, on heifers approximately 150 days post-parturition.

This showed that, separately, 4× daily milking and growth hormone, as an injected 14 day preparation, gave similar increases in yield of 13-14% (Figure 2) and that in combination the effects were additive but that there was no evidence of synergism (Knight et al., 1992). This experiment also provided further evidence of the induction of cellular proliferation, most markedly in the combined treatment group, as epithelial cell number again increased (Figure 3). There was evidence of enhanced nuclear activity in the epithelial cells of the combined treatment glands shown by staining of nuclear histones.

Most of the response was again local with obviously separate mechanisms at the cellular level for frequency of milking and growth hormone. The effects could be separated temporally too (Figure 2). The response to growth hormone was up to 2 days slower than for 4× daily milking. Again there were suggestions that the treatments imposed gave better persistency of lactation as the difference in mean daily quarter yield between the pre-experimental period and the post- experimental period, some 8 weeks later varied from a reduction of 0.13 kg to a net gain of 0.26 kg in the combined treatment group. The much lower decline in yield (2-3%) than might be expected over this length of time (10-15%) for the control, 2× daily milked glands, again probably reflects improved feeding efficiency. The carry-over of increased yield by the combined treatment glands may reflect the cellular proliferation indicated.

Shinde (1985) considered a similar response to 50 days of 4× daily milking of cows must be due to cellular proliferation but did not attempt to measure it. The effect in cows has been induced in only 4 weeks compared with a significantly longer period needed in 3× daily milked goats (Henderson et al., 1985).

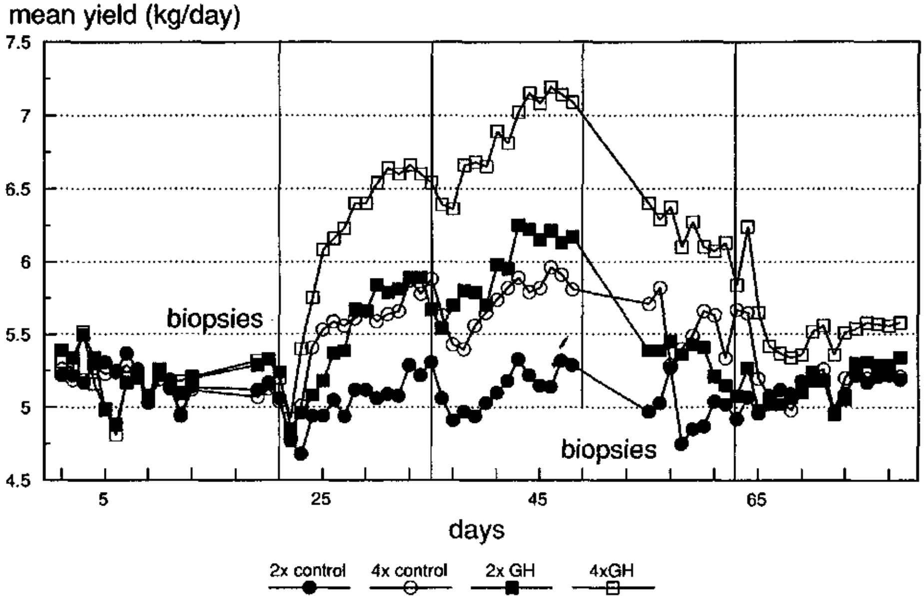


Figure 2. Daily milk yields for control and test glands for heifers treated with bovine growth hormone(GH) or untreated (C) and in which half of the udder was milked twice daily (2×) and the other half four-times daily (4×). Vertical lines indicate periods; pre-treatment control period, treatment periods 1 and 2 (both treatments applied), treatment period 3 (frequent milking only), post-treatment. Arrows indicate biopsies.

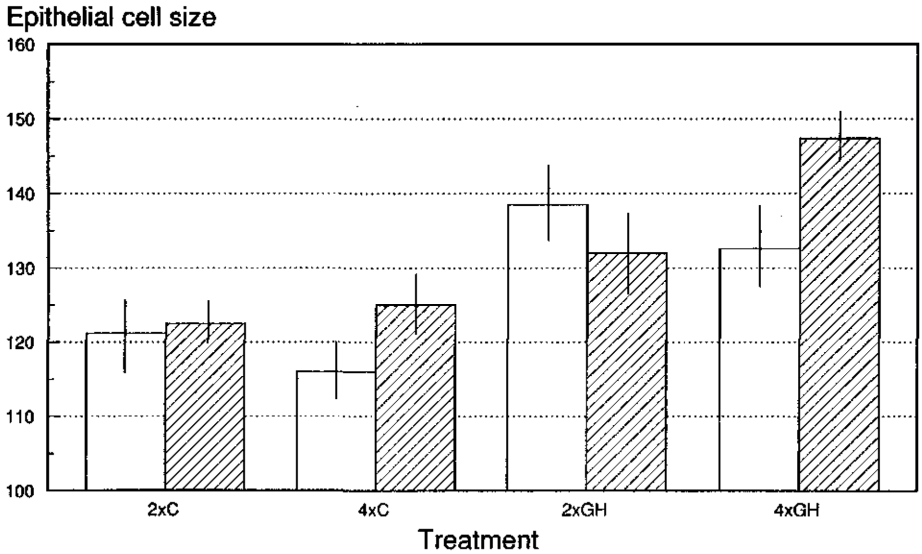


Figure 3. Mammary epithelial cell sizes (μm^2) in mammary tissue obtained by biopsy from cows prior to treatment (empty) or after 4 weeks treatment (hatched) with bovine growth hormone (GH) or untreated (C), and in which one biopsied gland per animal was milked twice daily (2×) or four times (4×) daily. Values are mean±sem for groups of six heifers.

Variability of response

The responses reported in most trials are averages and in the frequent milking experiments are for half udders only. There is evidence of wide variability in response within any group. The range of effect has included yield increases of up to 29% in 4× daily milked quarters and 12% in the within udder 2× daily milked quarters to no net effect or to 11% increase in yield in 4× daily milked quarters with compensatory reduction in yield of some 11% in the within udder 2× daily milked quarters. There is little evidence to explain why there is such variability which may be of particular importance when trying to arrive at the correct milking regime for each individual cow in an automated system.

In an experiment comparing 2× with 4× daily milking on a whole udder in heifers at different stages of lactation it has been possible to induce yield increases at 25, 150 and 250 days post-parturition. The heifers were most responsive early in lactation, giving a similar increase to cows, some 0.7 kg/quarter/day. The response at 150 and 250 days into lactation was much lower, 0.3 kg/quarter/day. Cows gave this low response only in late lactation. Shinde (1985) showed, in a between heifer study, a lower increase in yield in response to 4× daily milking started later in the lactation. The ability to respond in the short term may be related to the 'spare' capacity of the udder. Heifers have a greater persistency of yield and so can be considered to be producing nearer to capacity at any stage and hence respond less in absolute terms although better in percentage of yield. After peak the yield from cows declines at a much greater rate and the greater response in output is likely to be due to their overall greater potential to yield. In the first part of this experiment the 4× daily milked cows averaged 9.36 kg/quarter/day whilst heifers produced 6.36 kg/quarter/day.

The persistency of the 2× daily milked heifers was considerably better than the 4× daily milked heifers and the change to 4× milking at 250 days post-partum only increased the average yield to that sustained by the 2× daily milked group (3.97 kg/quarter/day for 4× versus 3.90 kg/quarter/day for the 2× group). None of the extra yield was sustained by the 4× daily milked group on return to 2× daily milking, yield declined by 0.5 kg/quarter/day whilst there was no change for the 2× daily milked group.

The 2× daily milked heifers had a high persistency of yield throughout the lactation. The more frequently milked animals, although increasing yield significantly in the experimental periods, seem to have had a consistently poorer persistency over the whole lactation. This experiment has shown that animals of different parity respond differently to changes in the frequency of milking at different stages of lactation but has given little indication of the effect over a whole lactation. As indicated previously the 305 day yields for heifers and cows have increased by a similar absolute amount in 3× daily milking field trials. As the persistency of lactation has been affected in the controlled frequent milking experiments, the yield at 305 days for targeted drying off is important. Is it feasible or desirable to dry off then, has sustained high yield from more frequent milking affected conception and will it be biologically necessary or economically feasible to extend the lactation? Thrice daily milking field trials generally show no effect on reproductive efficiency (Allen et al., 1986) although preliminary results from a 6× daily milking study suggested a considerable delay in return to oestrus (v.d.Dungen et al., 1991).

Udder health

When there is an increase in milking frequency there tends to be an increase in milk somatic cell count (SCC). This is transitory (Figure 4) and variable between animals (50-600% rises have been found). Within 4 days cell count declines to the 2× daily milking level or lower. It is difficult to find field data to support this as most studies on the effect of more frequent milking have used indirect measures such as the California Mastitis Test. Experimentally similar changes were reported by Waterman et al. (1983) for 3× daily milking. There seems to be cellular diapedesis in response to milk removal (Griffin et al., 1977), when this occurs more frequently more cells are removed per gland per day for no real reason. This may cause a depletion of mature blood neutrophils. An enhancement in phagocytosis activity can be demonstrated indicating immature cells in the blood. To reduce this depletion there appears to be a limitation to the rate or extent of diapedesis so that only the same number of cells are lost daily as previously.

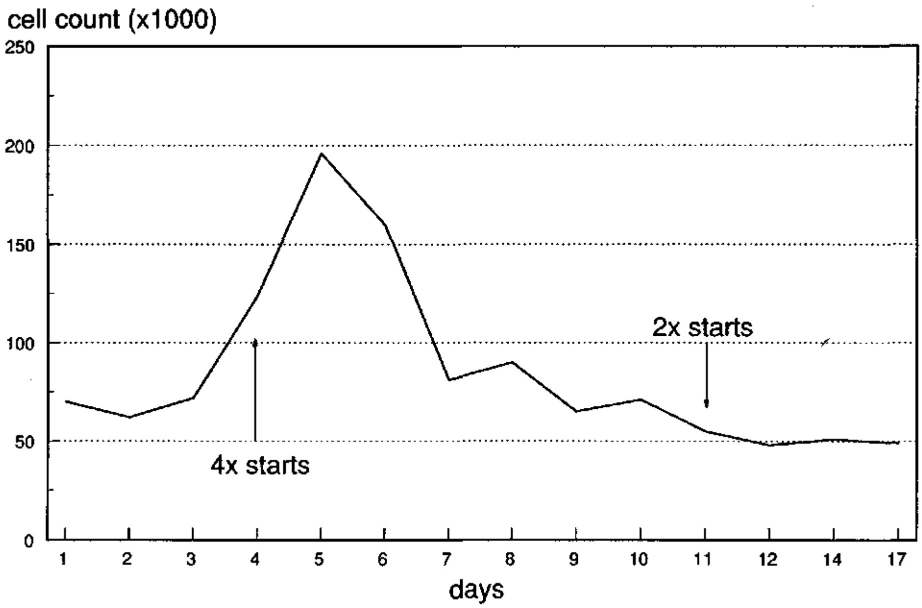


Figure 4. Mean daily milk cell count of each quarter of four uninfected cows milked every 12 hours then every 6 hours for 7 days returning to 12 milking for 7 days.

There are a number of implications of frequent milking for the rate of new infections. The increased activity and number of cells in milk in the transitory period may enhance the defences to invasion. More frequent milking may lead to more efficient removal of invading bacteria reducing the likelihood of establishment. On the contrary, more frequent milking may lead to more frequent invasion. There are many more possible changes differing between contagious mastitis pathogens and environmental pathogens and some predisposing to an increased likelihood of infection and others reducing the chances (Hillerton, 1991). The only evidence comes from a recent experiment (Hillerton, 1991) when 2.5×10^5 cfu *Streptococcus agalactiae* were introduced 3 mm into the teat duct using a Newbould inoculator. The rate of clinical mastitis in quarters milked 4× daily was significantly lower than in quarters milked 2× daily (Table 2). Also the rate of new infections was over 50% lower.

Table 2. The effect of 2× or 4× daily milking on the number of quarters becoming infected following inoculation of the teat duct with Streptococcus agalactiae.

Milking frequency	No. quarters exposed	No. clinical cases	No. bacteria positive[1]
2× daily	67	15[b]	9
4× daily	70	5[a]	5

[a,b] statistically significant difference ($p < 0.05$).
[1] number of quarters for which for-milk was bacteriologically positive in the absence of clinical signs of mastitis, in 2 of 3 samples.

Whilst more frequent milking could lead to more exposure with more frequent opening of the teat duct, more frequent milking might improve teat hygiene as there will be more frequent cleaning. Also, more frequent application of teat disinfectant will reduce teat bacterial colonisation and improve teat skin condition especially if the disinfectants include suitable emollients. In the various frequent milking experiments the cleanliness of teats being milked 4× versus 2× daily has been assessed and generally 4× milked teat are significantly cleaner with very occasional teats being visually dirty and needing to be washed. However preliminary calculations suggest that milk let-down is much slower in more frequently milked animals and hence udder preparation for adequate stimulation will remain vital.

It is possible that more frequent milking could lead to longer machine-on time per day. Ipema et al. (1991) showed that it doubled with 6× daily milking. This occurs because when yield/milking is reduced by more frequent milking flow rate is reduced. In one study a 48% reduction in yield was accompanied by a 56% reduction in quarter flow rate. This does not necessarily lead to more mastitis, indeed less mastitis occurs when the flow rate is lower, certainly between animals (Grindal et al., 1992). Over-milking does not lead to a greater incidence of mastitis (Natzke, 1978) but may lead to teat damage. This is usually found when the milking system is less than optimal (Peterson, 1964). Most probably there will be little effect on mastitis incidence as an automated system may allow customising of the milking system for the individual cow (perhaps even quarter), individual teat cup removal may be used, as in the system developed at the Silsoe Research Institute (Street, 1992), and good husbandry standards are to be expected when the herdsman is freed from teatcup attachment duties.

Conclusions

The cow has a considerable capacity to respond to more frequent milking by producing extra milk. The range of response found by different individuals indicates the variability between animals and the opportunity to optimise within a herd dedicated to a more frequent milking strategy, before the benefits of enhancing nutrition. It is obvious from the additive effects of growth hormone and more frequent milking stimulation that frequent milking alone has not, so far, taken the animal anywhere near its maximum capacity. Similarly the effects of the combined treatments show that nutrition, or the ability to take in extra forage and make much more milk from it, and increased metabolic efficiency are not limiting.

Practical use of automated milking systems may require the ability to vary the frequency of milking for the individual cow. It appears that cows may respond in a different way to heifers and show greater benefits from more frequent milking for longer into the lactation. Indeed they may benefit from a wholly different pattern of frequency of milking through the lactation from heifers. Whilst heifers can be very responsive to an increased frequency of milking their naturally high persistency of lactation suggests that the farmer will benefit much less from increasing their frequency of milking over much of the lactation. Stimulation of a higher peak yield may be sufficient. It is possible that the main benefit from and to heifers will be in a more even milking interval.

So far there is evidence that udder health will be improved by an increased frequency of milking given application of good husbandry. There is even the possibility of a reduction in the incidence of some forms of mastitis.

The experiments conducted so far suggest that more frequent milking could improve the productivity of the dairy cow and bring improved welfare.

References

Allen, D.B., E.J. DePeters & R.C. Laben, 1986. Three times a day milking: effects on milk production, reproductive efficiency, and udder health. Journal of Dairy Science 69:1441-1446.

Amos, H.E., T. Kiser & M. Lowenstein, 1985. Influence of milking frequency on productive and reproductive efficiency of dairy cows. Journal of Dairy Science 68:732-739.

Barnes, M.A., R.E. Pearson & A.J. Lukes-Wilson, 1990. Effects of milking frequency and selection for milk yield on productive efficiency of Holstein cows. Journal of Dairy Science 73:1603-1611.

DePeters, E.J., N.E. Smith & J. Acedo-Rico, 1985. Three or two times daily milking of older cows and first lactation cows for entire lactations. Journal of Dairy Science 69:123-132.

Gisi, D.D., E.J. DePeters & C.L. Pelissier, 1986. Three times daily milking of cows in California dairy herds. Journal of Dairy Science 69:863-868.

Griffin, T.K., F.H. Dodd, F.K. Neave, 1977. The concentration of somatic cells in milk secreted in milking intervals of 6 to 36 hr. Animal Production 24:128.

Grindal, R.J., A.W. Walton & J.E. Hillerton, 1991. Influence of milk flow rate and streak canal length on new intramammary infection in dairy cows. Journal of Dairy Research 58:383-388.

Henderson, A.J., D.R. Blatchford & M. Peaker, 1985. The effects of long-term thrice-daily milking on milk secretion in the goat: evidence for mammary growth. Quarterly Journal of Experimental Physiology 70:557-565.

Hillerton, J.E., C.H. Knight, A. Turvey, S.D. Wheatley & C.J. Wilde, 1990. Milk yield and mammary function in dairy cows milked four times daily. Journal of Dairy Research 57:285-294.

Hillerton, J.E., 1991. The effects of milking frequency on mastitis. In: Proceedings of the British Mastitis Conference, Stoneleigh, UK, p. 61-69.

Ipema, A.H., C.C. Ketelaar-de Lauwere & J. Metz-Stefanowska, 1991. The influence of six times per day milking on milk production, technology and cow behaviour. Report 91-20, IMAG-DLO, Wageningen, The Netherlands, p. 24.

Knight, C.H., J.E. Hillerton, M.A. Kerr, R.M. Teverson, A. Turvey & C.J. Wilde, 1992. Separate and additive stimulation of bovine milk yield by the local and systemic galactopoietic stimuli of frequent milking and growth hormone. Journal of Dairy Research 58:243-252.

Lush, J.L. & R.R. Shrode, 1950. Changes in milk production with age and milking frequency. Journal of Dairy Science 33:338-357.

Natzke, R.P., 1978. The relationship between overmilking and new infection. In: Proceedings of the Annual Meeting, National Mastitis Council 17:256-261.

Peaker, M. & C.J. Wilde, 1987. Milk secretion: autocrine control. NIPS 2:124-126.

Peterson, K.J., 1964. Mammary tissue injury resulting from improper machine milking. American Journal of Veterinary Research 25:1002-1009.

Shinde, Y., 1985. The effect of frequency of milking on milk production at various stages of lactation of the dairy cow. Bulletin Obihiro University 14:175-180.

Street, M.J., R.C. Hall, D.S. Spencer, A.L. Wilkin, T.T. Mottram & C.J. Allen, 1992. Design features of the Silsoe automatic milking system. In: A.H. Ipema, A.C. Lippus, J.H.M. Metz & W. Rossing (Eds.): Proceedings of the International Symposium on Prospects for Automatic Milking, EAAP publication No. 65, Pudoc Scientific Publishers, Wageningen, The Netherlands, p. 40-48.

Sutton, J.D. 1986. Milk composition In: W.H. Broster, R.H. Phipps & C.L. Johnson (Eds.): Principles and practice of feeding dairy cows. NIRD Technical Bulletin 8, p. 203-218.

v.d.Dungen, H.M., E. Smolders, C.C.F. Accord-Burleson & G. Bruin, 1991. Effect of frequent milking on fertility in dairy cattle. Journal of Reproduction & Fertility, Abstract Series No.8, Poster no. 48.

Waterman, D.F., R.J. Harmon, R.W. Hemken & B.E. Langlois, 1983. Milking frequency as related to udder health and milk production. Journal of Dairy Science 66:253-258.

Wilde, C.J., A.J. Henderson, C.H. Knight, D.R. Blatchford, A. Faulkner & R.G. Vernon, 1987. Effects of long-term thrice-daily milking on mammary enzyme activity, cell population and milk yield in the goat. Journal of Animal Science 64:533-539.

Winter, A., R.M. Teverson & J.E. Hillerton, 1992. The effect of increased milking frequency and automated milking systems on the behaviour of the dairy cow. In: A.H. Ipema, A.C. Lippus, J.H.M. Metz & W. Rossing (Eds.): Proceedings of the International Symposium on Prospects for Automatic Milking, EAAP publication No. 65, Pudoc Scientific Publishers, Wageningen, The Netherlands, p. 261-269.

Role of milking in the maintenance of lactation in dairy animals

Y. Shinde

Obihiro University of Agriculture and Veterinary Medicine, Inada-cho, 2-13 Nishi, Obihiro-shi, Hokkaido 080, Japan

Summary

Experiments were done on 34 lactating Holstein cows to determine the effect of milking removal on milk production. The milking treatments were applied using the half-udder technique. It appears that the removal of milk from the mammary gland increases the milk yield by promoting the activity of secretory cells and reducing the rate of involution during the lactation. A possible explanation of the results is that mammary blood flow is increased by milk removal form the udder.
Keywords: milking frequency, involution of mammary gland.

Introduction

Two hypotheses have been proposed to explain how mammary function and lactation in dairy animals are maintained by the milking process. The first states that milking stimulus results in the release of prolactin, adrenocorticotropic hormone and oxytocin from the pituitary gland, which is responsible for the maintenance of the mammary function and lactation. Many findings supporting this concept have been reported (Tucker, 1974). The other hypothesis is that the removal of the milk from the udder, which is the primary reason for milking, is indispensable for maintenance of the mammary function and lactation. There is much less experimental evidence to support this hypothesis.

In the past, only cows in high producing purebred herds were milked three times a day. The increasing cost of labour eliminated this practice in many of these herds. However, the increasing cost of land and facilities, increasing herd size, and automation of milking (reducing milking labour per cow) have renewed interest in milking three times a day (Allen et al. 1986; Poole, 1982). Therefore the present paper deals with experiments in which effects of milk removal on lactation in the cow were studies using the half-udder milking procedure. Part of this study has been reported elsewhere (Shinde, 1978, 1985).

Results and Discussion

Experiment 1

Four Holstein cows were used. Using an experimental method of half-udder comparison, the effects of frequency of milking on mammary function were assessed. In period I, both udder halves were milked for 5 days from the 5th day of lactation. In period II, however, during an experimental period which lasted 150 days, the left half of udder of each cow was milked three times a day and the right half was milked twice daily. Both halves were again milked twice daily for the following 30 days in period III. The daily milk yield of the left udder half (experimental udder half) compared to that of the right udder half (control udder half) increased progressively until the end of the experimental period (Table 1). Total milk yield of the experimental half was 52% more than that of the control half. In the post-experiment period, furthermore, the yield from the experimental half was 54% more than that from the control half. This difference in the milk yield between the experimental half and control half disappeared in the next lactation.

Table 1. Comparative milk yields of left and right half of udder in dairy cows in experiment 1 ([[left half/right half]/ right half] × 100).

No. of cows	Period I	Period II	Period III
4	0.1%	52.4%	54.2 %

Experiment 2

Of the 12 lactating Holstein cows used, 10 were in the first lactation and 2 were in second lactation. The lactation stage at the beginning of the experiment was the 6-7th day for group I, 98-117th day for group II, and 127-168th day for group III. Each group contained 4 animals. After both udder halves had been milked twice daily for 5 days in period I, the right udder half was milked twice and the left half milked three times daily for 50 days in period II. Period II was followed by a period during which both halves were milked normally twice daily for 10 days (period III). The milk yield of the udder halves in periods II and III was corrected by the differences in the yield between the udder halves for period I.

The difference in yields between udder halves appeared on the first day of period II; it increased very quickly over the next few days, and then gradually during the rest of the period II. The difference in yields was the highest in group I, which consisted of cows in the 6-7th day of lactation at the beginning of the experiment (Table 2). In this group the ratio of daily milk yield of the left half to that of the right udder half increased progressively until the end of period II. Total milk yield from the left half was 25.2% more than that from the right half. On the other hand, in cows in the 98-117th day of lactation (group II) daily milk yield from the left udder half increased more steeply than that from the right udder half throughout period II. However, the difference in milk yield between the two halves in group II was about half that obtained in group I (Table 2). Only 11.3% more milk was obtained in group III by milking three times a day, although the difference in the yield between the halves was statistically significant ($P<0.01$). There are significant differences in both milk yield and milk yield ration between groups I and II ($P<0.05$) (Table 2). Since the average daily milk yield during period I was not statistically significantly different among groups I, II and III, the difference in period II among groups can be ascribed to the difference in the lactation stage at which the experiments were carried out.

In period III the differences in milk yield and milk yield ratio declined markedly in each group. In animals in group III there was no significant difference between the two halves, whereas in animals in groups I and II, the left udder half produced more milk than the right udder half ($P<0.01$) (Table 2). Since the milk yield of the udder halves milked three times daily was always higher than the other udder halves in animals of groups I and II throughout the lactating period post-experiment, it is likely that the differences in milk yield between the two halves would relate to difference in the amount of mammary tissue.

In the present study the comparison of the effect of frequency of milking was made between two halves within a cow. Therefore the results of experiments 1 and 2 suggest that the increase in milk yield is definitely due to the removal of milk and not to the additional release of oxytocin or other hormones caused by the increased frequency of milking stimulation. In the present study, the effect of frequent milking appears more markedly in the early stage of lactation than in the late stage. It is reasonable to assume that frequent milking increases the milk yield by promoting the activity of secretory cells and reducing the rate of involution during the lactation period. Our results showed that more frequent milking influenced peak yield only slightly. However milking is three times a day did lengthen the time postpartum before cows started their downward trend in lactation. Pearson et al. (1979) reported that increased milk yield by frequent milking was primarily from prolonged peak yield and less subsequent decline. They also reported that milking three times a day had a positive carryover, while switching from three to two milkings decreased yield by 6 to 8% in the first week.

Table 2. Comparative mean milk yields ratio's of left and right half of udder (left/right) in dairy cows in experiment 2.

Group	Period II	Period III
I	1.24[c]	1.24[b]
II	1.15[b]	1.09[a]
III	1.11[a]	1.06[a]

[a,b,c] statistically significant difference in column ($P<0.05$).

Experiment 3

The effect of frequency of milking on milk production increased progressively during the experimental period (period II) in experiments 1 and 2. Therefore, experiment 3 was designed to elucidate the effect of milking frequency on milk production over a shorter period than in experiments 1 and 2. Experimental procedures were almost the same as in the previous experiments. Twelve Holstein heifers were in the 6th days of lactation, on average, at the start of the experiment, and their average milk yield during the 5 pre-experimental days was 14.7 kg (period I). During the experimental period (period II) which lasted for 20, 40 and 50 days in groups, I II, and III, respectively, the left half of the udder of each cows was milked three times a day and the right half was milked twice daily. Period II was followed by a further 10 days during which both halves were again milked twice daily (period III). The milk yields of the udder halves milked three times a day were corrected by the pretreatment differences in the yield between the udder halves. The udder halves milked twice a day. The differences in yields between halves were the least in group I and the most in group III (Table 3) and the difference was statistically significant ($P<0.01$). On the other hand, in period III in which both halves were milked twice daily, the difference in milk yield and milk yield ratio declined from high values in period II in groups I and II and were essentially the same in group III (Table 3). In the animals in group I, no significant difference was found between halves, but in groups II and III the milk yield of the left udder half was more than that of the right udder half ($P<0.01$). The results suggested that mammary tissue per se was not affected by such a short trial. Therefore, to retard involution of the mammary gland, it is necessary to continue milking three times daily from the day of parturition for at least 40 days in heifers.

Table 3. Comparative mean milk yields ratio's of left and right half of udder (left/right) in dairy cows in experiment 3.

Group	Period II	Period III
I	1.13[a]	1.04[a]
II	1.39[b]	1.26[b]
III	1.24[b]	1.24[b]

[a,b] statistically significant difference in column ($P<0.05$).

Experiment 4

The effects of frequent removal of milk resulting from frequent milking on the mammary gland could not be ascribed to hormonal factors, since these factors are common to both halves. A finding that the rate of milk secretion is constant during milking intervals of normal length (Elliot et al., 1960) suggest that relieving milk accumulation would not benefit milk secretion. A possible explanation of the increase in milk yield is that the smaller amount of residual milk and fat after the shorter intervals has a local effect on the secretory cells. It can be expected that when milking is twice daily the levels of residual milk and fat will be greater than when milking is thrice daily. But Elliot (1961) was unable to demonstrate that differences of this order in residual milk levels would influence milk yield sufficiently to account for the milking frequency effect. An alternative explanation (Mao & Caruolo, 1973) that milk removal causes in the mammary blood flow to increase deserves consideration. Therefore in experiment 4 an attempt was made to assess the velocity of blood flow in a milk vein of the cow. Six Holstein cows at various lactation stages were used. The blood flow was measured after milking intervals of 4-24h, using an ultrasonic method. The results suggest that milk accumulation inhibits mammary blood flow. At long milking intervals, mammary blood flow is markedly reduced. The decreased rate of milk secretion might also be explained by biochemical factors such as:

- smaller amounts of hormones reaching the mammary gland, or
- smaller amounts of milk precursors reaching the mammary gland.

Conclusion

The effect of frequency of milking on milk production increases progressively throughout the lactation period. Therefore it is reasonable to consider that frequent milking increases the milk yield by promoting the activity of secretory cells during early lactation and reducing the rate of involution after the peak of lactation.

References

Allen, D.B., E.J. DePeters & R.C. Laben, 1986. Three times a day milking: Effects on milk production, reproductive efficiency and udder health. Journal of Dairy Science 69:1441-1446.

Elliot, G.M., F.H. Dodd & P.J. Brumby, 1960. Variations in the rate if milk secretion in milking intervals of 2-24 hours. Journal of Dairy Research 27:293-308.

Elliot, G.M., 1961. The effect on milk yield of three times a day milking and of increasing the level of residual milk. Journal of Dairy Research 28:209-219.

Mao, W. & E.V. Caruolo, 1973. Effect of lactose content and milking interval on mammary blood flow. Journal of Dairy Science 56:729-732.

Pearson, R.E., L.A. Fulton, P.D. Thompson & J.W. Smith, 1979. Three times a day milking during the first half of lactation. Journal of Dairy Science 62:1941-1950.

Poole, D.A., 1982. The effects of milking cows three times daily. Animal Production 34:197-201.

Shinde, Y., 1978. Role of milking in initiation and maintenance of lactation in the dairy animals. In: A. Yokoyama, H. Mizuno & H. Nagasawa (Eds.): Physiology of mammary gland. Japan Scientific Societies Press, Tokyo, Japan, p. 347-360.

Shinde, Y., 1985. The effect of frequency of milking on milk production of various stages of lactation for dairy cow. Research Bulletin, Obihiro University 14:175-180.

Tucker, H.A., 1974. General endocrinological control of lactation. In: B.R. Larson & V.R. Smith (Eds.): Lactation. Academic Press, New York & London. Volume I, p. 296-317.

Milk production, and some related nutritional and reproductive variables, of dairy cows under two different milking regimes in early lactation

U. Bar-Peled*, A.R. Lehrer*, Y. Folman*, I. Bruckental*, J. Kali*, H. Gacitua*, E. Maltz**, H. Tagari*** & B. Robinzon***

* *Institute of Animal Science, Agricultural Research Organization, The Volcani Center, P.O. Box 6, Bet Dagan 50250, Israel*

** *Institute of Agricultural Engineering, Agricultural Research Organization, The Volcani Center, P.O. Box 6, Bet Dagan 50250, Israel*

*** *The Hebrew University of Jerusalem, Faculty of Agriculture, Rehovot, Israel*

Summary

Milk production and some related nutritional and reproductive variables of Israeli Friesian cows milked six times a day (treatment group, n=9) were determined, in comparison with cows milked three times a day (control group, n=10), during the first 6 weeks postpartum. During weeks 7-18 postpartum all cows were milked three times a day.

Mean results for the first 6 weeks postpartum, for control and treatment groups, respectively, were as follows (values with different superscripts differ significantly, at $p<0.05$): daily milk yield 35.3^a and 42.6^b kg per day; dry matter intake 16.8^a and 19.4^b kg per day; body weight loss 4.1^a and 5.6^b% on day 1-4 postpartum; body condition score 2.3^a and 1.9^b units (1 = thin, 5 = fat) at week 6 postpartum.

Milk yield and dry matter intake of the treatment group remained significantly higher despite the discontinuation of high milking frequency. Gain of body weight and body conditional score of the treatment cows was delayed by approximately 4 weeks relative to the control group. Number of pregnant cows by day 90 and 120 postpartum was smaller in the treatment than in the control group, due to both delayed postpartum resumption of ovarian cyclicity and lower conception rates.

It is concluded that frequent milking increases milk yield and the effect is carried over after reduction of milking frequency. The bearing of this carry-over effect on automatic milking should be investigated, and that of high milking frequency on reproductive performance should be investigated as well.

Keywords: milk production, milking frequency, early lactation, body weight, dry matter intake.

Introduction

Milk yield of dairy cows is positively related to milking frequency, but the quantitative relationship between the two variables is controversial (Hillerton et al., 1990; Wilde & Peaker, 1990). The envisaged application of automatic milking enables us to increase milking frequency beyond the present, labour-dependent frequency. However, the limited milking capacity of each automatic milking station requires optimization of milking frequency with regard to milk yield at different stages of lactation.

The main objective of this study was to determine the milk yield and related performance variables of high-yielding dairy cows, in response to six milkings per day during the first 6 weeks of lactation.

Animals, materials and methods

General

Nineteen Israeli Friesian cows in second lactation - at the dairy herd of Kibbutz Kefar Menahem - participated in this study, which covered the first 18 weeks postpartum. Calving took place during the period from mid February through the beginning of May 1992. The cows were randomly assigned to one of two groups with equal distribution of calving dates and postcalving body weight:

1. three milkings per day, at 04:00, 12:00 and 20:00 hours (control group, n=10);
2. six milkings per day, i.e., as the control group plus three additional milkings per day, at 07:00, 15:00 and 23:00 hours (treatment group, n=9).

The treatment period extended over the first 6 weeks postpartum. During weeks 7-18 postpartum all cows were milked three times a day. A third group underwent six udder emptyings per day by a combination of machine milking and suckling of two foster heifer calves; the results from this group are reported elsewhere (Bar-Peled et al., 1992).

Milk yield and composition

Daily milk yield of each cow was recorded for 18 weeks. Milk samples were taken once a week from each daily milking, for analysis of milk fat carried out by infrared spectroscopy (Milkoscan, 605/AB, Foss Electric, Copenhagen, Denmark).

Feeding, body weighing, and body condition scoring

Throughout the study, the cows were fed ad lib. a total mixed ration (Table 1). During the first 10 weeks postpartum the cows were penned and fed individually. Food offered and refusals were measured daily for each cow, and daily samples were taken for composition analysis carried out by the routine procedure of feed stuffs analysis. During weeks 11-18 postpartum the cows were penned and fed as a group.

Table 1. Total mixed ration composition.

Ingredient	% of DM
grain	44.00
soyabean	6.40
rape seed	3.40
corn gluten	3.40
cotton seeds	8.80
vetch hay	4.30
wheat silage	25.50
vitamin, minerals mix	4.20
Composition	
dry matter	51.80
crude protein	17.00
ADF	16.10
NDF	29.00
energy, Mcal NEL/kg DM	1.72

Postcalving body weight was calculated as the average body weight within 8 hours after calving and that on each of the first 3 days after calving. Cows were subsequently weighed and body condition was scored (body conditional score, on a scale of 1=very thin to 5=very fat) once weekly.

Reproduction

Plasma progesterone levels were determined in blood sampled three times a week between 08:00h and 09:00h. Postpartum time interval to resumption of luteal cyclicity was determined as the first of 3 consecutive days postpartum with progesterone levels >1.2 ng/ml plasma.

Observations for oestrus (standing heat) were carried out four times daily, for 40 minutes at 04:30h, 12:30h, twilight, and 20:30h. Artificial inseminations started at the first oestrus after day 59 postpartum. Pregnancy was determined, by rectal palpation, on day 45-50 after the last artificial insemination.

Results and discussion

Milk yield and composition

In the treatment period (first 6 weeks of lactation), frequent milking increased milk production (Figure 1). This could result from an increased number of secretory cells in response to higher milking frequency in early lactation (Wilde & Knight, 1989) and/or from frequent evacuation of the "interior inhibitor" (Wilde & Knight, 1989). In the last (6th) week of the treatment period, milk production of the treatment group was still rising, while that of the control group had already reached its peak (Figure 1). This indicates that the effect of treatment on milk production could have lasted for longer than 6 weeks.

Average milk fat percentage was higher in the treatment group (Table 2). This was probably a result of a higher proportion of residual milk at each milking.

Table 2. Milk fat (%, mean ±SE) of cows milked three times daily for 18 weeks (control) and of cows milked six times daily during the first 6 weeks of lactation (treatment).

Weeks postpartum	Treatment	Control
1-6	3.10 ± 0.29[a]	2.79 ± 0.32[b]
7-18	2.70 ± 0.12[b]	2.57 ± 0.12[b]

[a,b] statistically significant difference in row and column ($P<0.05$).

In the post-treatment period (7th - 18th week of lactation), milk production of the treatment group remained higher than that of the control group by an average of 5.1 kg per day (Figure 1), although both groups were milked three times daily. This carry-over effect supports the above suggestion that higher milking frequency during the first 6 weeks of lactation increased the number of secretory cells.

Average milk fat percentage tended to be higher in the treatment group, but did not attain statistical significance (Table 2).

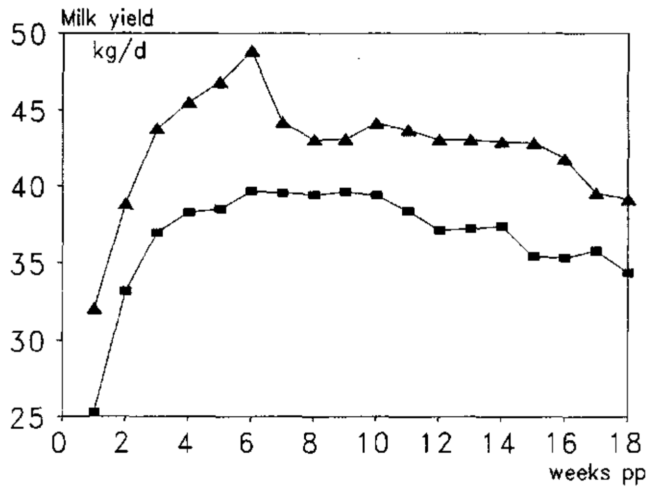


Figure 1. Average daily milk yields of cows milked six times a day during the first 6 weeks of lactation and three times a day thereafter (▲, n=9), and of cows milked three times a day throughout (■, n=10).

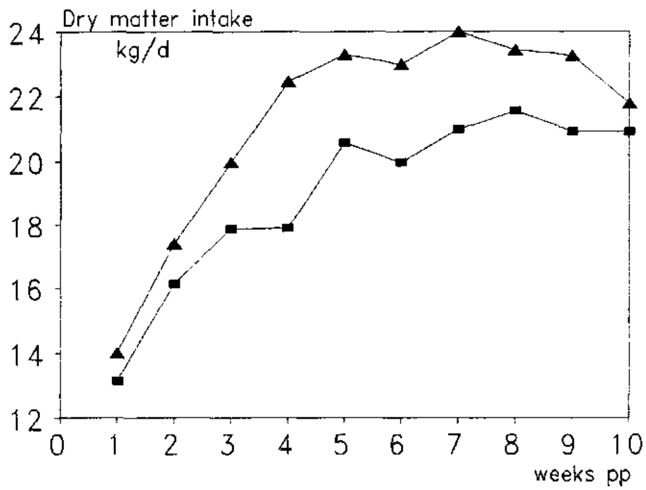


Figure 2. Average dry matter intake of cows milked six times daily during the first 6 weeks of lactation and three times daily thereafter (▲, n=9), and of cows milked three times daily throughout (■, n=10).

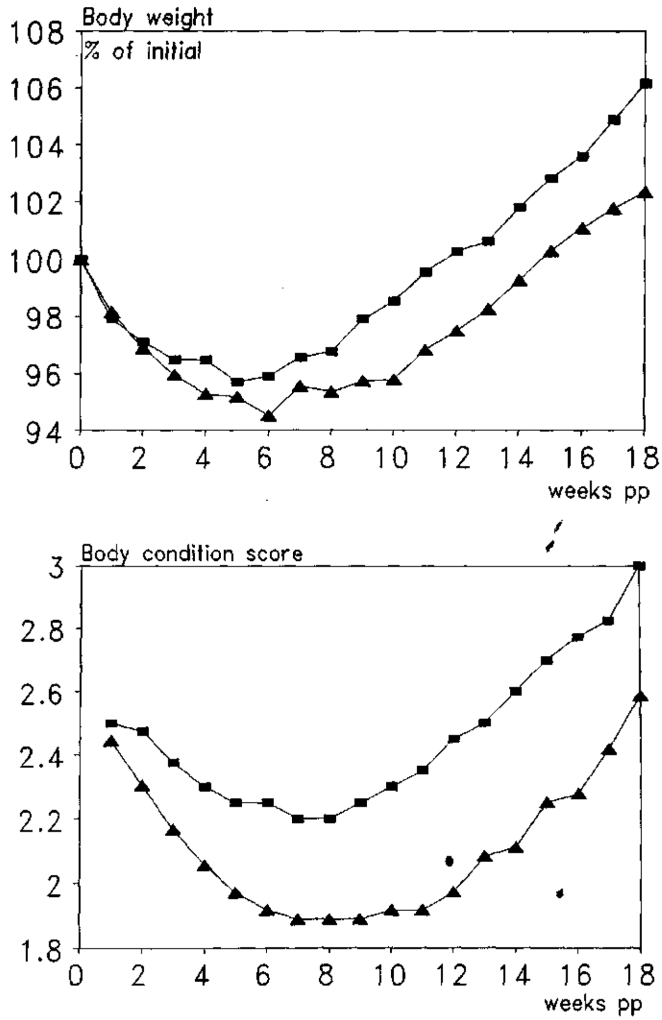


Figure 3. Average body weight (upper panel) and body condition score (lower panel) of cows milked six times daily during the first 6 weeks of lactation and three times daily thereafter (▲, n=9), and of cows milked three times daily throughout (■, n=10).

Dry matter intake, body weight, and body condition score

Average dry matter intake of the treatment cows was greater than that of control cows (Figure 2). However, the increased dry matter intake was smaller than the greater requirements for the additional milk and fat produced. Hence, a greater drain on body reserves, i.e., greater loss of body weight and body conditional score - was required (Figure 3). Both groups underwent loss of body weight and body conditional score during a 5-week period postpartum. In the control group, it was immediately followed by a gain in both variables. In contrast, in the treatment group onset of gain of body weight and body conditional score was preceded by a 4-5 week period of stability of body weight and body conditional score. This indicates that nutritional requirements for the higher milk yield of the treatment group were fully met by the dry matter intake during this period, and that the higher milk yield delayed the diversion of feed energy to the buildup of body energy reserves. The delayed onset of gain in body weight and body conditional score resulted in a similar delay in regaining peripartum values of these two variables in the treatment group.

Reproduction

The mean postpartum time interval to resumption of luteal cyclicity was significantly longer for the treatment (37 days) than for the control group (26 days).

The distribution of number of pregnant and non-pregnant cows by different post-partum time intervals is presented in Table 3. High milking frequency was associated with longer "open periods" due to both delayed postpartum resumption of ovarian cyclicity and lower conception rates.

Table 3. Number of pregnant cows at different postpartum time intervals, relative to number of milkings per day (Control = cows milked three times daily throughout; Treatment = cows milked six times daily during the first 6 weeks of lactation and three times daily thereafter).

Number of pregnant cows during:	Control	Treatment
Days postpartum		
< 90	4	1
91 - 120	3	1
121 - 150	1	1
> 150	-	2
not pregnant 2	4	
total	10	9

Conclusions and bearings in relation to automatic milking

1. Six versus three milkings per day increased milk production of high-yielding cows.
2. The above effect is carried over after reducing milking frequency to three milkings per day.
3. The additional energy requirements for the higher production are supplied partly by higher dry matter intake and partly by a drain on body reserves.
4. The lactation curve was still ascending at the end of the 6-week treatment period, suggesting that extending the high milking frequency period may result in a higher peak yield and perhaps a greater carry-over effect.
5. The response to high milking frequency and its carry-over effect point to the need to optimize milking frequency according to individual milk yields at different stages of lactation.
6. The larger number of cows with long postpartum intervals to conception in the treatment group points to the need to determine and quantify the bearings of high milking frequency on reproductive performance.

References

Bar-Peled, U., E. Maltz, R. Robinzon H. Tagari, Y. Folman, I. Bruckental, J. Kali, H. Gacitua & A.R. Lehrer, 1992. Milk production and some associated nutritional and reproductive variables, of high-yielding dairy cows, under different frequencies of udder emptying by machine-milking and suckling. In: The 43 Annual Meeting of the EAAF, Madrid, Spain.

Hillerton, E.J., C.H. Knight, A. Turvey, S.D. Wheatley & C.J. Wilde, 1990. Milk yield and mammary function in dairy cows milked four times daily. Journal of Dairy Research 57:285-294.

Wilde, C.J. & C.H. Knight, 1989. Metabolic adaptation in mammary gland during the declining phase of lactation. Journal of Dairy Research 72:1679-1692.

Wilde, C.J. & M. Peaker, 1990. Autocrine control in milk secretion. Journal of Agricultural Science 114:235-238.

Milking primiparous cows three times every two days in early lactation: milk secretion and nutritional status

B. Rémond, M. Petit & A. Ollier

INRA de Theix, 63122 Saint-Genès-Champanelle, France

Summary

Seven cows (group E) were milked 3 times each 2 days during the first 3 weeks of lactation and then twice a day for 21 weeks. Five control cows (group C) were milked twice a day throughout the trial. They were all primiparous. Milk yield was lower in group E than in group C by 2.9 kg/d over the trial and there was no recovery after the end of the treatment. Protein content in milk was higher during the first 10 weeks (+2.8 g/kg), largely because of the soluble proteins. Food intake was higher during the same period (+1.7 kg dry matter/d), liveweight loss was greatly reduced in early lactation (35 kg), and calculated energy balance was less negative or more positive (+2.2 Feed Units/day, on average).
Keywords: milking frequency, cow, milk, appetite, liveweight change, energy balance.

Introduction

Milking frequency is a determining factor of the yield of milk in cows but, up to now, unmodifiable between animals or days. Milking robots could take on the role of a tool in milking, making it possible to control the milk yield ability of cows. Thus, it could be of interest to limit temporarily the yield of milk in early lactation, by reducing milking frequency, so as to improve the nutritional status of the cows, and to resume the "normal" curve of lactation some weeks later, once feed intake has reached a high level.

In this trial, we assessed the effect of 3 milkings each 2 days during the first 3 weeks of lactation on milk performance and nutritional status of cows for this period and for the following 21 weeks.

Material and methods

Fifteen pregnant Holstein heifers were allotted at calving (between October 18 and November 11, at 34 to 37 months of age), to 2 groups. In the experimental group (E, n=9), the cows were milked 3 times each 2 days, at 6h and 21h on one day and at 15h on another day, during the first 21 days of lactation, and then twice a day, at 6h and 15h, during the following 21 weeks. In the control group (C, n=6), the cows were milked twice a day, at 6h and 15h, throughout the trial. All animals were housed in the same tied-stall shed and milked in their stall with a machine equipped with an automatic cluster remover. During late pregnancy, the cows received a complete diet composed of maize silage (55 to 60%), concentrate (35 to 30%) and soya-bean meal (10%) (dry matter -DM- basis) in a quantity limited to 12 kg DM + 1 kg hay. After calving, they received ad libitum the same complete diet + 1 kg hay + 200 g of a concentrate enriched in minerals.

Milk yield was recorded at each milking and sampled at 2 or 3 consecutive milkings in groups C and E, respectively, each week. Fat, protein and lactose contents were measured by infra-red spectrophotometry, and somatic cell content by automatic counting (Milkoscan 605 and Fossomatic respectively; Foss Electric, Denmark). In the samples taken during week 3 and between weeks 12 and 15 after calving, total N, non-casein N and non-protein N were analysed according to Rowland (1938), and immunoglobulins G1 (IgG1) were assayed by radial immunodiffusion (Levieux, 1991). Food intake was measured 4 days weekly. Cows were weighed twice during the first week of lactation, then biweekly. Energy balance was calculated from the production results (milk production, . . .) and from the energy value of the diet, in the net energy system of INRA (Jarrige, 1989).

For the different items measured, means for weeks 1 to 3, 4 to 10, 11 to 17, and 18 to 24 of lactation (termed period 1, 2, 3 and 4 thereafter) and for the whole trial (weeks 1 to 24) were subjected to variance-covariance analysis. Unless otherwise indicated, group (E or C) was the only variate used.

Results

Three cows (1 in group C) were eliminated for health problems seemingly unrelated to the treatments.

Milk yield in group E was lower than in group C, by 2.9 kg/d (11%; P= 0.12) over the trial as a whole, but by 3.8 kg during the last 2 periods (Table 1). The amount of milk collected at 6h (15h after the previous milking in both groups) was 14.9 and 12.9 kg for groups C and E respectively, in week 2 of lactation, and 15.0 and 14.9 kg in week 3.

Table 1. Milk production and nutritional indices.

		Weeks of lactation				
		1-3	4-10	11-17	18-24	1-24
Milk	Group E	19.9^{b}	26.1	24.0^{b}	21.6^{b}	23.4^{b}
(kg/d)	Group C	22.6	27.4	27.8	25.3	26.3
Proteins	E	35.2^{a}	30.1^{b}	32.7	34.1	32.7
(g/kg)	C	31.6	28.5	32.1	34.3	31.7
Fat	E	51.2^{c}	41.8^{c}	39.9	43.2	42.8
(g/kg)	C	55.3	44.0	39.0	42.0	43.4
Lactose	E	47.6	49.5^{c}	48.4	48.9	48.8
(g/kg)	C	47.3	48.6	47.9	48.6	48.2
Somatic cells	E	216	119	123c	96	124
(×1000/ml)	C	151	98	73	66	86
Dry matter	E	13.1	17.3^{b}	19.6	19.2	18.0^{c}
intake (kg/d)	C	12.4	15.3	18.9	19.1	17.1
Liveweight	E	665*	631^{b}	653^{b}	676^{c}	
(kg)[1]	C	643*	576	587	610	
Energy	E	-3.1^{b}	-0.6^{a}	2.7^{a}	2.8^{b}	1.0^{a}
balance (FUm)	C	-5.5	-3.3	0.5	1.1	-1.2

1 Statistical analyses: liveweight in week 1 (*) minus liveweight in weeks 4-10 or 11-17 or 18-24.

a,b,c staticically significant difference between E and C groups ($a = P<0.05$, $b = P\leq0.12$, and $c = P\leq0.21$)

Table 2. Content (g/kg) of various protein fractions in milk at week 3 and between weeks 12 and 15 of lactation, and significance (P).

	Week 3			Between weeks 12 and 15		
	group C	group E	P	group C	group E	P
Caseins	23.5	24.4	0.53	26.2	25.5	0.75
Soluble proteins	4.6	6.0	0.02	5.0	5.9	0.04
IgG1	0.48	0.63	0.07	0.34	0.41	0.04

The concentration of proteins in milk was higher in group E than in group C for the first 2 periods, by 3.6 and 1.6 g/kg respectively (Table 1), largely (61% in week 3) because of a higher content in soluble proteins, including IgG1 (Table 2). Differences between groups in the concentration of soluble proteins remained significant 10 weeks after the end of the treatment. Fat, lactose and somatic cell contents were never different at the 0.12 level of significance. However, in group E in comparison with group C, fat content tended to be lower for the first 2 periods (44.6 versus 47.4 g/kg in mean), somatic cell content to be higher for period 3, and lactose content to be higher for period 2 (Table 1).

Amounts of dry matter ingested by groups C and E were 17.1 and 18.0 kg/d respectively over the whole trial (P=0.14; variates utilised: group, liveweight at week 1 of lactation, and milk yield ability = daily milk yield over the whole trial + mean daily difference between the 2 groups for cows of group E). The greatest difference was observed in period 2 (2.0 kg/d). Liveweight decreased during early lactation, but much less in group E than in group C (39 and 74 kg between weeks 1 and 7; P=0.11). It then increased similarly in the 2 groups until the end of the trial (55 versus 50 kg). Energy balance in group E was significantly less negative or more positive than in group C at each period.

Discussion

Because of small number of cows and absence of covariates in the statistical analyses, only tentative conclusions can be drawn from this trial.

The reduction in milking frequency decreased milk yield during the treatment in spite of the even distribution of the 3 milking times (15-18-15h) over the 2 days, contrary to what might have been expected from the results of Wheelock et al. (1966), who reported a constant rate of milk secretion for up to 18 h, but in agreement with the results of Woolford et al. (1985) observed in a production trial. That milk yield did not increase after the resumption of twice-daily milking is not consistent with the fact that similar amounts of milk were collected from the 2 groups in week 3 (but not in week 2) at the 6h milking, which suggests that the milk yield ability of the udder was unaffected, and is at variance with the complete recoveries observed in cows by Wheelock et al. (1966), and in goats by Wilde & Knight (1990), when long intervals were left between milkings after the peak of lactation. However our results are in agreement with those of Claesson et al. (1959) who experimented once-daily milking as from calving, and consistent with the findings of Walsh (1976) who observed in cows that omission of milkings has more deleterious effects on milk yield when begun immediately after calving than later. Udder functionality continues to develop in early lactation and this is probably involved in the differences between trials. The increase in the difference in milk yield between the 2 groups after treatment could be due to the irregular secretion in group C.

Changes in composition of milk in group E, compared to group C, resulted from the longer intervals between milkings (higher content in soluble proteins: Wheelock et al., 1966; tendency for higher content in somatic cells: Radcliffe et al., 1973) and from the better nutritional status (lower fat and higher protein contents: Rémond & Journet, 1987). The narrowing of the gap between protein contents in the 2 groups during period 3 and its levelling out in period 4, in spite of the large differences in energy balance, is however surprising.

Higher food intake in group E than in group C, in early lactation could be both a cause, and a consequence, of the higher nutritional status of the former group (Journet & Rémond, 1976). Cows not-dried-off in late pregnancy, which produced less milk than conventionally managed ones in the following lactation, were also observed to eat more in the first weeks after calving (Rémond et al., unpublished data).

Conclusion

A reduction in milking frequency in primiparous cows during early lactation, while producing only a moderate decrease in milk yield initially, seems to lead to long-term negative consequences on the yield and on some aspects of milk composition, but to a marked improvement in the nutritional status of the animals. Many factors remain to be explored, particularly the rank of lactation -primiparous cows should be more sensitive than multiparous according to Woolford et al. (1985)-, characteristics of the treatment such as duration..., and management of the milking regime once the treatment is ended.

Acknowledgments

We thank R.Lefaivre and J.P. Rigaudière for technical assistance, and J.P. Pezant and his team for the care of the animals.

References

Claesson, O., A. Hansson, N. Gustafsson & E. Brännäng, 1959. Studies monozygous cattle twins. XVII. Once-a-day milking compared with twice-a-day milking. Acta Agriculturae Scandinavica 9:38-58.

Jarrige, R. (Ed.), 1989. Ruminant Nutrition. Recommended allowances and feed tables. INRA, John Libbey Eurotext, Paris-London-Rome.

Journet, M. & B. Rémond, 1976. Physiological factors affecting the voluntary intake of feed by cows: a review. Livestock Production Science 3:129-146.

Levieux, D., 1991. Dosage des IgG du lait de vache par immunodiffusion radiale semi-automatisée, pour la détection du colostrum, des laits de mammites ou de fin de gestation. I. Mise au point du dosage. Lait 71:327-338

Radcliffe, J.C., L.F. Bailey & M.L. Horne, 1973. Periodic omission of dairy cow milkings. I. Effect on milk yield and composition and on udder health, 40:247-254.

Rémond, B. & M. Journet, 1987. Effet de l'alimentation et de la saison sur la composition du lait. In: Le lait, matière première de l'industrie laitière. INRA Publications, Versailles, France, p. 171-186.

Rowland, S.J., 1938. The determination of the nitrogen distribution in milk. Journal of Dairy Research 9:42-46.

Walsh, J.P., 1976. Bovine milk secretion following the omission of milkings immediately postpartum and during mid-lactation. Irish Journal of Agricultural Research 15:91-106.

Wheelock, J.V., J.A.F. Rook, F.H. Dodd & T.K. Griffin, 1966. The effect of varying the interval between milkings on milk secretion. Journal of Dairy Research 33:161-176.

Wilde, C.J. & C.H. Knight, 1990. Milk yield and mammary function in goats during and after once-daily milking. Journal of Dairy Research 57:441-447.

Woolford, M.W., P.J.A. Copeman, A.R. Napper, D.S.M. Phillips, J.H. Williamson & E.J. Uljee, 1985. Milking intervals: are changes worthwhile? In: Proceedings Ruakura Farmer's Conference, 37:120-128.

The effect of feeding during milking on milk production and milk flow

K. Svennersten & B. Samuelsson

Swedish University of Agricultural Sciences, Department of Animal Nutrition and Management, P.O. Box 7024, S-750 07 Uppsala, Sweden

Summary

Different tactile teat stimulations have been applied to test whether or not the milk ejection reflex was strengthened by concomitant oxytocin secretion. As oxytocin is also released during feeding, this study examines whether feeding during milking affects milking parameters such as milk yield, milking time, milk flow and udder evacuation. The experiment was performed on twelve dairy cows in mid-lactation and the cows were exposed to milking, milking and feeding with silage and hay, milking and feeding with concentrates. Feeding during milking resulted in higher milk production, decreased milking time, increased udder evacuation and higher milk flow.
Keywords: milking, feeding, milk yield, milk flow, dairy cows.

Introduction

It is a well known fact that milking activates a neuroendocrine reflex and oxytocin is released (Ely & Petersen, 1941). Oxytocin is of importance for milk let-down. Recently it has been reported that also feeding also induces oxytocin secretion (Svennersten et al., 1991). Furthermore, feeding concentrates just before, or together with milking has been reported to influence milk production and oxytocin secretion (Brandsma, 1978; Svennersten et al., 1990). However, if the milking routine, including feeding during milking, is of importance in dairy production it also needs to influence parameters such as milking time and milk flow, because milking is a time-consuming activity in the dairy industry. Therefore, the aim of the present study was to find out how feeding (either concentrates or silage) influences milking parameters such as milk production, milking time, milk flow and the amount of residual milk.

Materials and methods

The experiment was divided in three periods. Each period included three different treatments. The treatments were:

I. milking without feeding;

II. milking with simultaneous silage feeding;

III. milking with simultaneous concentrate feeding.

Each period lasted seven days. The experiment was performed on twelve dairy cows in mid- or late-lactation. Each cow received all the treatments during different periods of time.

The cows were milked twice a day at 8.5 and 15.5 hours milking intervals. In treatment I the cows were fed after milking had been completed, while in treatment II and III the cows were given silage or concentrates when pre-stimulation began.

The milking routine was as follows: the teats were cleaned with a paper towel, control milk was drawn, and then teat cups were attached. After milking had been completed, 10 ml of milk was drawn off (sample of post-milk). Samples from the bucket milk were also collected. The milking machine was an Alfa-Laval with the vacuum level set at 50 kPa, the ratio at 70:30 and the rate at 60 per minute. The milking machine was constructed to register the milk flow (peak flow, average flow and amount of milk ejected during the first two minutes of milking), milking time and yield of milk.

The amount of residual milk was determined during the last morning milking in all three periods after intra-muscular injections of oxytocin had been given. After milking had been completed two injections of 15 IU oxytocin were given 15 min apart. The milking was started three minutes after each injection had been given. The amount of residual milk was determined volumetrically.

The milk samples collected were analysed with the infrared (IR) technique, MS-93 (Foss Electric, Hilleröd, Denmark). The milk was analysed for fat content.

All data were subjected to least squares analyses of variance using the General Linear Model (GLM) procedure of SAS (Anonymous, 1985). The results were expressed as least square means. The statistical model included treatment, block, period, the interaction between block and period, and cow within each block.

Results

This report presents the results from morning milkings. For further information see the submitted article in the Swedish Journal of Agricultural Sciences (Samuelsson, 1992).

There was a statistically significant increase in the milk yield when cows were fed either concentrates or silage when being milked, while the fat content remained unchanged (Table 1). The fat content in the milk sample taken after milking was completed was significantly higher in treatment II and III (Table 1).

The amount of residual milk, calculated as a percentage of total milk during the morning milking when residual milk was determined, was 15.35, 14.68 and 12.53 % in treatment I, II and III respectively, with a statistically significant difference between treatment I and III ($pr<0.05$, $se=1.16$).

The milking time tended to decrease in treatment III. The peak flow increased significantly both in treatment II and III, while the average flow increased significantly in treatment III. The amount of ejected milk during the first two minutes of milking showed a tendency to increase in treatment III (Table 1).

Table 1. Results (means and standard error) of the experiment on 12 cows in treatments during morning milking where cows were milked (I), milked and fed silage (II), milked and fed concentrate (III).

	Treatment		
	I	II	III
Milk yield (kg)	16.07 ± 0.16	16.87 ± 0.16	16.77 ± 0.16
% fat in bucket milk	3.62 ± 0.04	3.61 ± 0.04	3.69 ± 0.04
% fat in last 10 ml milk	10.57 ± 0.12	11.29 ± 0.12^{2}	11.62 ± 0.13^{2}
Milking time (min)	8.82 ± 0.17	8.96 ± 0.16	8.42 ± 0.16^{1}
Peak milk flow (kg/min)	3.38 ± 0.04	3.60 ± 0.04^{2}	3.62 ± 0.04^{2}
Average milk flow (kg/min)	1.90 ± 0.04	1.98 ± 0.04	2.10 ± 0.04^{2}
% of milk received in first 2 min	32.96 ± 0.68	33.44 ± 0.67	34.62 ± 0.67^{1}

Statistically significant differences from treatment I: 1 = $P<0.10$; 2 = $P<0.001$.

Discussion

This experiment established that feeding during milking decreases milking time and increases peak flow and average flow. The fat content in the very last milk increased due to simultaneous feeding and the amount of residual milk decreased. This demonstrates that there is a more efficient milk removal when cows were fed during milking than when cows were milked without feeding. The size of the improved milking parameters are almost the same as those achieved in milking experiments where the effect of manual pre-stimulation has been studied (Merrill et al., 1987; Sagi et al., 1980; Zinn et al., 1982). It is also significant that positive effects on milk production and milking parameters were detected although the animals received a proper manual pre-stimulation.

In previous experiments it has been demonstrated that feeding stimulates oxytocin secretion (Svennersten et al., 1991) and that feeding during milking increases the possibility of oxytocin secretion (Svennersten et al., 1990). The observed effects of a more efficient milk ejection and milk removal could, therefore, be the direct effect of a more efficient stimulation of oxytocin secretion caused by feeding.

Conclusion

From the results from this study we conclude that feeding concentrates during milking is a way to stimulate milk removal and milk production, and thus this routine ought to be recommended in dairy production.

References

Anonymous, 1985. SAS user's guide: Statistics. Version 5 Edition. SAS Institute Inc., Cary, NC, USA.

Brandsma, S., 1978. The relation between milking, residual milk and milk yield. In: Proceedings of the international symposium on machine milking, National Mastitis Council, Louisville, Kentucky, USA., p. 47-56.

Ely, F. & W.E. Petersen, 1941. Factors involved in the ejection of milk. Journal of Dairy Science 24:211-223.

Merrill, W.G., R. Sagi, L.G. Petersson, T.V. Bui, H.N. Erb, D.M. Galton & R. Gates, 1987. Effects of premilking stimulation on completed lactation milk yield and milking performance. Journal of Dairy Science 70:1676-1684.

Sagi, R., N.R. Scott & R.C. Gorewit, 1980. Interaction between stimulation and machine milking. ASEA paper no. 80-3030.

Samuelsson, B. & K. Svennersten, 1992. The effect of feeding during milking on milk production and milk flow. Swedisch Journal of Agricultural Science (submitted for publication).

Svennersten, K., R.C. Gorewit & K. Uvnäs-Moberg, 1990. Simultaneous feeding during milking enhances milking related oxytocin secretion and milk production in dairy cows whereas atropinization and food deprivation decreases it. In: Central and local mechanisms involved in the control of milk production and milk let down. Dissertation. Swedish University of Agricultural Sciences, Uppsala, Sweden. Report 199.

Svennersten, K., L. Nelson, & K. Uvnäs-Moberg, 1991. Feeding induced oxytocin release in dairy cows. Acta Physiologica Scandinavica 140:295-296.

Zinn, S.A., R.C. Gorewit & R. Sagi, 1982. Milking responses of cows given premilking stimulation at four lactational stages. Journal of Dairy Science 65:668-671.

Effects of frequent milking on heart rate and other physiological variables in dairy cows

C. Royle, P.C. Garnsworthy, A.J. McArthur & T.B. Mepham

University of Nottingham, Faculty of Agricultural and Food Sciences, Sutton Bonington Campus, Loughborough, LE12 5RD, United Kingdom

Summary

The study aimed to investigate physiological responses to machine milking in cows milked and fed 5× daily.

In 6 dairy cows, mean heart rate increased by 20.5% in response to machine milking. This response occurred immediately on application of the milking cluster and was sustained for the duration of milking. When cows were milked 5× daily the tachycardiac response to milking was the same at each milking. It did not differ significantly from that in animals milked 2× daily and did not change over a period of seven weeks frequent milking.

Long-term (7 weeks) 5× daily milking (n=3) produced variable milk yield responses, with a mean increase of 5.8%. Milk and plasma composition were not significantly changed throughout the experiment. In short-term (5 day) 5× daily milking studies, at two levels of feed, milk yield increased by 5.5% and 8.0% for medium and high levels of feed, respectively. Again, milk yield responses were variable between animals. Milk and plasma compositions were largely unaffected by frequent milking, although individual animals showed significant changes in milk concentrations of monovalent ions.

Keywords: milking frequency, heart rate, milk composition.

Introduction

The development of automated milking systems, in which cows may present themselves for milking up to six times per day (Rossing, 1985), may soon allow full exploitation of the galactopoiesis associated with frequent milking (Elliott, 1961) without incurring high labour costs. At a superficial level, automated milking systems would appear to satisfy certain welfare criteria, in that animals may choose when and how often they are milked. Nevertheless, the increased milk yield might be anticipated to place additional strain on the animal's metabolism, and there is thus a need to evaluate more fully the physiological implications of frequent milking.

The experiments reported here adopted two approaches. The first of these was to investigate acute heart rate responses to the milking stimulus. We have looked at the effect of machine milking (both 2× and 5× daily) on heart rate.

The second approach was to investigate changes in milk yield, milk composition and blood composition during both long- and short-term frequent milking, the latter carried out at two levels of feed intake.

Materials and methods

For all the experiments, six multiparous Holstein-Friesian cows from the University of Nottingham experimental herd were used during mid-lactation. Throughout the experiments they were housed in concrete-floored stalls lined with straw. Milking was carried out in the stalls by machine (Fullwood and Bland, Ellesmere, Shropshire, U.K.), in a fixed order, at approximately 06:30h, and 16:30h. Water and hay were available ad libitum and 8 kg dairy concentrates were fed daily, divided equally between the two milkings. In addition, the cows received 2.5 kg beet pulp at morning milking and 2.5 kg grass nuts at afternoon milking.

Heart rate measurements

Heart rate was monitored continuously using a non-invasive telemetric device (Sport-tester PE3000). This was designed for use by human athletes and adapted for use on cows in this laboratory. Using this equipment, mean heart rate over 15 second periods could be recorded for up to 4.5 hours with minimal disturbance to the normal milking routine. Data stored in the receiver were subsequently transferred, via an interface, to a computer for analysis.

Frequent milking

Three frequent (5× daily) milking studies were carried out, one long-term (spring 1991) and two short-term (spring 1992).

The long-term study comprised a two week control period, during which all six cows were milked twice daily; a seven week treatment period, during which three control cows continued to be milked 2× daily whilst three test animals were milked 5× daily (extra milkings at 09:30h, 13:30h and 20:30h); and a two week post-treatment period, during which all cows were again milked twice daily. Throughout the study the control cows received 4 kg concentrates at each milking. The test animals received the same ration during twice daily milking, but during frequent milking received 3 kg at 06:30h and 16:30h and 1 kg at each extra milking.

Milk samples were taken at each of the milkings on one day per week. Blood samples were taken hourly on one day per week from indwelling jugular venous catheters. Catheters, prepared from single-lumen polyethylene tubing, were introduced using Seldinger's (1953) technique the day before sampling started. Blood samples were collected in polystyrene tubes containing 2 drops of heparinized saline solution (100 units/ml in sodium chloride 0.9% w/v: Heparin from C.P. Pharmaceuticals Ltd., Wrexham, U.K.), centrifuged for 10 min at 900 g and the plasma removed. Heart rate was measured on at least two days per week for each animal, avoiding blood sampling days.

The two short-term studies (S1 and S2) each consisted of a three day control period, a five day treatment period (5× daily milking) and a three day post-treatment period (2× daily milking). In S1 six cows received 8 kg concentrates per day throughout the experiment, whilst in S2 they received 10 kg per day. During 2× daily milking these rations were divided equally between the two milkings. During 5× daily milking the amounts of concentrates given at 06:30h, 09:30h, 13:30h, 16:30h and 20:30h were 3 kg, 1 kg, 1 kg, 2 kg, 1 kg and 3 kg, 1 kg, 1 kg, 4 kg, 1 kg for S1 and S2 respectively. Milk samples were taken at each milking, and blood samples five times daily, throughout the studies. The catheter insertion and sample handling procedures were as for the long-term experiment.

In all three frequent milking studies blood plasma and milk were stored at -20 °C prior to analysis. Milk fat was determined by the method of Fleet & Linzell (1964). Milk sodium, potassium, chloride and lactose and plasma sodium, potassium, glucose, urea and serum albumin concentrations were determined using a Technicon autoanalyzer (Technicon Instruments Corporation, Tarrytown, New York).

Results

Heart rate studies

There was a marked tachycardia at milking in all cows (mean ± S.D.; for 6 min before milking, 68.4 ± 4.7 beats per minute; during first 6 min of milking, 82.4 ± 7.4 beats per minute; $P<0.001$, paired t test). Heart rate increased immediately after application of the milking cluster, reaching a plateau after 2-3 min and remaining elevated for the duration of milking (mean: 6 min). After cluster removal heart rate declined to pre-milking levels within 10-15 min (Figure 1).

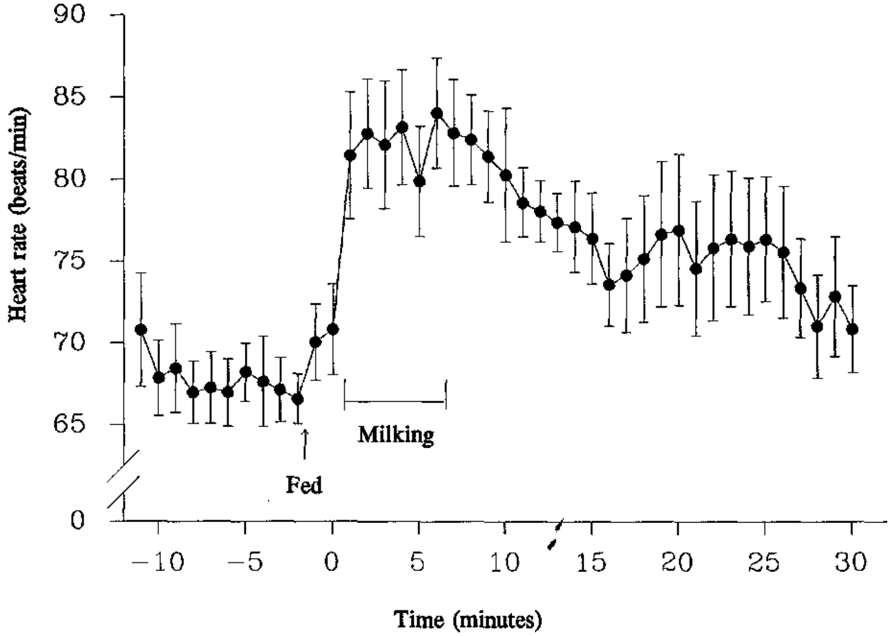


Figure 1. Variation of heart rate during milking for dairy cows (mean ± S.E.M.; n=6).

Table 1. Percentage increases in heart rate (mean ± S.E.M.) at milking during a 7 week period of 5× daily milking. Values obtained by comparing mean heart rate during the first 6 min of milking with that during the 6 min before milking.

Milking time	Week 1	Week 4	Week 7
06:30h	19.7 ± 4.9	21.3 ± 2.1	22.5 ± 3.3
09:30h	20.4 ± 2.2	20.8 ± 0.9	19.2 ± 2.6
13:30h	21.1 ± 1.5	18.9 ± 3.6	21.8 ± 2.4
16:30h	20.2 ± 2.8	22.0 ± 2.1	20.5 ± 1.2
20:30h	18.9 ± 1.3	19.7 ± 1.8	17.7 ± 4.7

When cows were milked frequently, tachycardia was observed at each milking. The magnitude of the response did not change significantly throughout the day or over the time course of the experiment, and was not significantly different from that in cows milked twice daily. Table 1 shows mean percentage increases in heart rate at each milking for frequently milked cows at the start, middle and end of the frequent milking period.

Frequent milking studies

Long-term: For each animal the mean daily milk yield over the last week of the control period was compared with that over the first week of the treatment period. The control cows all showed a decline in milk yield over this period (-2.5%, -1.0% and 3.5%), whilst two of the three test animals showed an increased milk yield (6.4% and 15.0%). The third test animal showed a decline in yield (-3.9%). In all the animals milk and plasma composition did not change significantly throughout the experiment (data not shown).

Short-term: For each animal the mean daily milk yield over the control period was compared with that over the treatment period. In experiment S1, where feed remained constant throughout, four cows showed an increase in milk yield with 5× daily milking. In experiment S2, where feed was increased for the duration of frequent milking, milk yield was increased in five animals. In both cases the milk yield responses varied greatly (Table 2).

Table 2. Mean daily milk yields (kg/day) during short-term 5× daily milking experiments S1 and S2.

Cow no.	4	20	242	299	378	448	Mean
S1 2× daily	21.6	25.0	19.2	26.7	23.6	14.0	21.7
S1 5× daily	23.2	25.9	18.9	28.2	23.5	17.9	22.9
% change	7.3	3.6	-1.8	5.5	-0.6	28.1	5.5
S2 2× daily	19.9	24.8	17.2	25.2	21.9	13.6	20.4
S2 5× daily	22.8	23.7	18.3	27.0	22.1	18.1	22.0
% change	14.5	-4.4	6.0	7.2	0.9	32.7	8.0

In neither experiment were there significant changes in plasma composition. During 5× daily milking, milk potassium concentration increased from 41.5 ± 1.2 meq/l to 42.9 ± 1.5 meq/l in S1, and from 40.9 ± 1.2 meq/l to 42.2 ± 1.0 meq/l in S2 (mean ± S.E.M., both $P<0.05$, paired t test). These increases were accompanied by a non-significant decrease in milk sodium concentration. Milk fat, lactose and chloride did not change with 5× daily milking.

Discussion

Resting heart rates recorded here are comparable with those reported by other authors (Zerbini et al., 1992). One interpretation of the marked tachycardia observed at milking is that the machine milking stimulus is stressful, since heart rate is a putative stress index (Fraser & Broom, 1990). In support of this claim, the plasma concentration of cortisol, another putative stress index, has also been reported to increase in cows at milking (Gorewit et al., 1992). Our own unpublished results confirm these data (mean ± S.D.; 0-1 min pre-milking, 5.0 ± 1.1 ng/ml; 0-1 min post-milking, 8.3 ± 1.7 ng/ml; $P<0.05$, paired t test).

However, the claim that these observations are indicative of stress is open to question. Thus the heart rate response to a single milking was identical whether an animal was milked twice or 5× a day, so frequent milking did not appear to affect the acute response to milking. The effect that an increased frequency of these responses will have on the animal in the long-term remains to be established; and the full significance of these heart rate data will be more apparent when studies on hand-milking and suckling have been completed.

Since at milking the cows always received feed, which is itself known to elicit tachycardia (e.g. in sheep by Webster, 1967), the tachycardiac response at milking might not be solely due to the milking stimulus. However, we have shown that milking, independently of feeding, elicits a tachycardiac response the magnitude of which is indistinguishable from that produced by feeding alone (Royle et al., 1992). From a practical point of view, the precise physiological stimulus for tachycardia would seem to be less important than the fact that it occurs.

In both long-and short-term frequent milking studies, 5× daily milking increased milk yield, though with considerable variation between animals. These results agree with those previously reported for frequently-milked cows (e.g. van der Iest & Hillerton, 1989). Wilde et al. (1987) identified three phases of the response to frequent milking:

1. an acute response, occurring within hours, due to the more frequent removal of a feedback inhibitor present in the milk;
2. an increase in the synthetic capacity per cell, occurring within two weeks;
3. the development, over a period of weeks, of a different mammary cell population.

In the short-term studies reported here, milk yield increased on the first day of frequent milking and declined rapidly on resumption of 2× daily milking. These rapid changes in milk yield are consistent with the first (acute) phase of the response. On resumption of 2× daily milking in the long-term study both responding animals showed a sharp decline in milk yield. This would suggest that after 7 weeks the third (development) phase of the response had not yet begun.

The short-term studies reported here indicate that an increase in milk yield is possible without an increase in feed intake, although 5/6 cows showed an enhanced milk yield response to 5× daily milking when the amount of food offered was increased.

With the exception of milk potassium in the short-term studies, there was no significant change in milk or plasma composition. Whilst further evidence is needed, particularly in respect of changes occurring when feed intake is reduced, these data give no indication that the animal's metabolism will be adversely affected by frequent milking.

References

Elliott, G.M., 1961. The effect on milk yield of three times a day milking and of increasing the level of residual milk. Journal of Dairy Research 28:209-219.

Fleet, I.R. & J.L. Linzell, 1964. A rapid method of estimating fat in very small quantities of milk. Journal of Physiology 175:15-17P.

Fraser, A.F. & D.M. Broom, 1990. Farm animal behaviour and welfare. Third edition. Bailliere Tindall, London. p. 266-279.

Gorewit, R.C., K. Svennersten, W.R. Butler & K. Uvnäs-Moberg, 1992. Endocrine responses in cows milked by hand and machine. Journal of Dairy Science 75:443-448.

Rossing, W., 1985. Can a robot be used for milking in a concentrate feeding box? Landbouwmechanisatie 36:119-121 (in Dutch).

Seldinger, S.I., 1953. Catheter replacement of the needle in percutaneous arteriography. Acta radiologica 39:368-376.

Van der Iest, R. & J.E. Hillerton, 1989. Short-term effects of frequent milking of dairy cows. Journal of Dairy Research 56:587-592.

Webster, A.J.F., 1967. Continuous measurement of heart rate as an indicator of the energy expenditure of sheep. British Journal of Nutrition 21:769-785.

Wilde, C.J., A.J. Henderson, C.H. Knight, D.R. Blatchford, A. Faulkner & R.G. Vernon, 1987. Effects of long-term thrice-daily milking on mammary enzyme activity, cell population and milk yield in the goat. Journal of Animal Science 64:533-539.

Zerbini, E., T. Gemeda, D.H. O'Neill, P.J. Howell & R.C. Schroter, 1992. Relationships between cardio-respiratory parameters and draught work output in F_1 crossbred dairy cows under field conditions. Animal Production 55:1-10.

Production, duration of machine-milking and teat quality of dairy cows milked 2, 3 or 4 times daily with variable intervals

A.H. Ipema & E. Benders

DLO Institute of Agricultural Engineering (IMAG-DLO),
P.O. Box 43, 6700 AA Wageningen, The Netherlands

Summary

In an experiment lasting one year three groups of HF/FH dairy cows with milking frequencies of 2 (F2), 3 (F3) or 4 (F4) times daily were compared in terms of milk production, dry matter intake, duration of machine milking and teat end quality. The data were analysed for lactation weeks 1 to 12, 13 to 25, 26 to 35 and 36 to 42. Some analyses were done for the dry period too.

In lactation weeks 13 to 25 the milk yields in the groups F2, F3 and F4 were respectively 30.2, 34.6 and 33.8 kg per day; in lactation weeks 26 to 35 the yields of these groups were respectively 21.0, 26.0 and 26.2 kg per day. In both periods the differences between group F2 and F3 and between F2 and F4 were statistically significant ($p < 0.05$). In lactation weeks 13 to 25 the milk fat contents of groups F3 and F4 were respectively 4.29% and 4.26%, which is statistically significantly lower than a value of 4.63% for group F2. The milk fat and protein production only showed significant differences between groups F2 and F4 in lactation weeks 26 to 42. From data calculated over a complete lactation period of 42 weeks it was concluded that the milk yield and milk fat and protein production increased by 14% and 10% respectively, when the milking frequency was raised from 2 to 3 times daily; for the same parameters, milking 4 times compared with milking 2 times produced increases of 15% and 11% respectively.

The average dry matter intake of groups F2, F3 and F4 was respectively 21.0, 21.7 and 21.9 kg per day (differences not significant). The body scores in group F4 during all lactation periods were statistically significantly lower than in group F2.

At the higher milking frequencies, average increases of the duration of machine milking were 40% (F3 versus F2) to 56% (F4 versus F2). Group F4 showed higher scores for teat end deviations at the end of lactation ($p < 0.05$).
Keywords: milking frequency, milk yield, machine milking duration, teat quality.

Introduction

Dairy farming is undergoing ongoing automation. In several places in Europe automatic milking systems are being refined (this proceedings, 1992).

With an automatic milking system it will be possible to milk a cow at any moment of the day and to increase its daily milking frequency.

When automatic milking systems are introduced on commercial farms it should be known what milking frequency is preferable for the individual cow. Therefore research has to be done on the effects of increased milking frequencies. This should lead to indications for the optimal milking frequency depending on factors such as age, stage of lactation and potential production. The milking frequency is important because of the capacity of automatic milking systems. The number of animals that can be milked at a certain frequency per milking place determines the number of automatic attachment systems (robots) that are necessary and therefore influences the investment required.

The introduction of automatic milking systems will bring many changes, especially for the cow. Both physiological and behaviourial aspects will be affected. In this paper special attention will be paid to the effects of frequent milking with variable intervals on factors such as production, duration of machine milking and teat end quality.

Materials and methods

The research was carried out over one year. In the first 8 months of the experimental period 39 dairy cows of the HF/FH breed were available. In the second part the number of cows was reduced to 36. Early in the experiment some cows were replaced because of health and/or fertility problems. The cows were divided into three frequency groups F2, F3 and F4 with 'norm' milking frequencies of respectively 2, 3 and 4 times daily. The groups were comparable as regards age and stage of lactation. About one-third of the animals in each group were heifers.

The cows were kept in a cubicle house and were able to go to the milking parlour voluntarily. They were only admitted to the milking parlour after a certain interval which depended on the milking frequency and was 10, 6 and 4 hours for the frequency groups F2, F3 and F4. If a cow reported earlier, she was refused for milking. If a cow did not report for milking by herself within a certain interval of time, she was fetched by the milker. The criteria for fetching were respectively 14, 8 and 6 hours. Dry cows stayed in the groups; however, they were not allowed to enter the milking parlour.

The parlour was manned 24 hours a day. After a cow had entered the parlour, milking started after a short udder preparation with a dry towel. The milk yield and duration of machine milking were recorded from all milkings. The milking cluster was detached automatically when the milk flow was less than 0.2 kg per minute. The vacuum level for milking was 44 kPa, the pulsation rate 58 pulsations and the pulsation ratio 65/35. Once a week all milkings during one day were sampled for milk fat and protein analyses.

The cows were fed with the automatic feeding system described by Ipema & Rossing (1987). Fifteen feeding stalls were continuously available. Two different feed mixtures (A and B) were fed. Mixture A consisted (on dry matter basis) of 36% grass silage, 19% maize silage and 45% concentrates; mixture B consisted of 66% grass silage and 34% maize silage. The amount of each feed each cow was allowed depended only on the stage of lactation. In lactation weeks 1 to 25 an extra 4 kg of concentrates were given daily in the milking parlour and mixture A was available ad lib. In lactation weeks 26 to 35 the ration was supplemented daily by an extra 1 kg of concentrates in the milking parlour, about 15 kg dry matter of mixture A and mixture B ad lib. From lactation week 36 until the dry period the amount of mixture A was further restricted at about 8 kg dry matter per day and mixture B was still available ad lib. During the dry period mixture B was fed restricted (about 8 kg dry matter per day). The intakes of the different feeds (mixtures A, B and concentrates in the parlour) were recorded daily.

Once every three weeks the body scores of all cows were established. The body scores for this HF/FH breed range between 3 (moderate condition) and 4 (good condition).

Once every 4 weeks images of all 4 teat ends were obtained from all milk-yielding cows, using a registration system custom-built for this (Hogewerf et al., 1991). The images of the teat ends were subsequently reviewed using the criteria 'erosion' and 'eruption' of the orifice. These criteria were scored 0, 1, 2 or 3, representing 'no', 'slight', 'moderate' and 'bad' deviations.

All data were converted into means per cow per lactation period. This was done for 5 periods; the dry period and 4 lactation periods. The lactation periods mainly correspond with the periods in which a certain feeding regime was practised. The period 1 to 25 weeks of lactation was subdivided into the period 1 to 12 weeks (normally the period in which the cows are not served) and the period 13 to 25 weeks.

The data of the three groups were statistically tested per lactation period. For these analyses 12 trios were used per lactation period. A trio consisted of three comparable cows (about the same age and stage of lactation), that were assigned randomly to the three experimental groups. In the statistical tests (analysis of variance) a trio was considered to be a block.

Results

Visiting and milking frequency

On average, the cows tried to visit the milking parlour 6.7 times daily in the lactation period 1 to 12 weeks. In lactation weeks 13 to 25 this visiting frequency fell to 5.9 times daily and to 5.8 times daily in lactation weeks 26 to 35. In lactation weeks 36 to 42 there was an increase to 6.2 visits per cow per day. In lactation weeks 1 to 12 group F4 had a statistically significant ($p < 0.05$) lower visiting frequency than group F2.

The actual milking frequency for group F2 varied over the lactation periods from 2.00 to 2.09 milking per day. For group F3 these values were between 2.99 and 3.05 and for group F4 between 3.88 and 3.92. In all lactation periods the milking frequencies were statistically significantly different between groups ($p < 0.001$).

Table 1. Milk production per group and lactation period.

Parameter	Period (weeks)	F2	F3	F4
Milk yield (kg/d)	1 - 12	37.9	41.6	41.7
	13 - 25	30.2^{a}	34.6^{b}	33.8^{b}
	26 - 35	21.9^{a}	26.0^{b}	26.2^{b}
	36 - 42	17.1^{a}	20.6	21.9^{b}
Milk fat (%)	1 - 12	4.62	4.30	4.37
	13 - 25	4.63^{a}	4.29^{b}	4.26^{b}
	26 - 35	4.87	4.67	4.78
	36 - 42	5.33	5.18	5.12
Milk protein (%)	1 - 12	3.23	3.23	3.26
	13 - 25	3.61	3.49	3.52
	26 - 35	3.79	3.69	3.78
	36 - 42	3.96	3.94	3.89
Milk fat and protein (g/d)	1 - 12	2962	3151	3157
	13 - 25	2476	2677	2618
	26 - 35	1885^{a}	2174	2231^{b}
	36 - 42	1571^{a}	1869	1948^{b}

^{a,b} statistically significant difference ($p < 0.05$).

The percentage of the total milkings that cows had to be fetched to the parlour in order to reach the 'norm' milking frequency were 12%, 30% and 49% for the groups F2, F3 and F4 respectively. In the first lactation period these values were lower than in later lactation periods.

Milk production

The milk yields of the groups F3 and F4 were statistically significantly higher than that of group F2 in the lactation weeks 13 to 25 and weeks 26 to 35 (Table 1). In lactation weeks 36 to 42 only the difference in milk yield between group F2 and F4 was statistically significant.

The milk fat content was statistically significantly lower in the groups F3 and F4 in lactation weeks 13 to 25, and these groups showed a tendency for lower milk fat contents in the other lactation periods too. No statistically significant differences were found in the milk protein contents.

In the two last lactation periods the difference in milk fat and protein production between groups F2 and F4 was about 350 g ($p < 0.05$).

From the production results per lactation period it can be calculated that on full lactation base (42 weeks) the average daily milk yields were respectively 28.2 (100%), 32.2 (114%) and 32.3 kg (115%) for the groups F2, F3 and F4. For milk fat and protein production the figures for the groups were 2323 (100%), 2558 (110%) and 2568 g per day (111%).

Feed consumption

The total dry matter intakes (Table 2) were calculated from the concentrates intake during milking and the intakes from mixture A (concentrates, grass and maize silage) and from mixture B (grass- and maize silage).

Table 2. Dry matter intake (kg/d) per group and lactation period.

Period (weeks)	F2	F3	F4
1 - 12	22.8	23.5	23.8
13 - 25	23.5	24.2	24.3
26 - 35	19.5	19.6	20.0
36 - 42	15.8	16.7	16.7
dry	8.1	8.4	8.7

The total dry matter intakes averaged over all three groups in lactation weeks 1 to 12 consisted of 53% concentrates (dry matter basis); for the lactation weeks 13 to 25, 26 to 35 and 36 to 42 these values were respectively 52%, 39% and 25%. In the dry period the cows only had access to mixture B, which contained no concentrates.

In none of the lactation periods were differences in dry matter intake between groups statistically significant. From the results in Table 2 it was calculated that over the whole lactation (42 weeks) the daily dry matter intake for the three groups was, on average, respectively 21.0 (100%), 21.7 (103%) and 21.9 kg (104%).

Body condition

Over all lactation periods group F2 showed statistically significantly ($p < 0.05$) higher body condition scores than group F4 (Table 3). In group F3 these differences were only statistically significant in the second part of the lactation. In the dry period there were no statistically significant differences in the body scores.

Table 3. Body score index per group and lactation period.

Period (weeks)	F2	F3	F4
1 - 12	3.45[a]	3.33	3.28[b]
13 - 25	3.45[a]	3.37	3.30[b]
26 - 35	3.65[a]	3.42[b]	3.39[b]
36 - 42	3.75[a]	3.55[b]	3.43[b]
dry	3.90	3.82	3.76

[a,b] statistically significant difference ($p < 0.05$).

Duration of machine milking

In lactation weeks 1 to 12 the machine milking per day in groups F3 and F4 lasted respectively 6.4 and 8.7 minutes longer than in group F2 (Table 4). At the end of lactation the differences were respectively 4.7 and 8.2 minutes. The duration of machine milking in group F4 was statistically significantly higher than in group F3 in this last lactation period.

Averaged over the complete lactation period (42 weeks) the daily machine milking for groups F2, F3 and F4 lasted respectively 14.1 (100%), 19.8 (140%) and 22.0 (156%) minutes.

Table 4. Duration of machine milking (min/d) per group and lactation period.

Period (weeks)	F2	F3	F4
1 - 12	15.9[a]	22.3[b]	24.6[b]
13 - 25	15.3[a]	21.4[b]	22.8[b]
26 - 35	12.6[a]	17.5[b]	19.8[b]
36 - 42	11.1[a]	15.8[b]	19.3[c]

a,b,c statistically significant difference ($p < 0.05$).

Teat end quality

Figure 1 shows that group F4 had higher rating for the deviations 'erosion' and 'eruption' of the teat ends. The differences between groups F2 and F3 versus F4 increased towards the end of lactation and became statistically significant ($p < 0.05$) in the last lactation period.

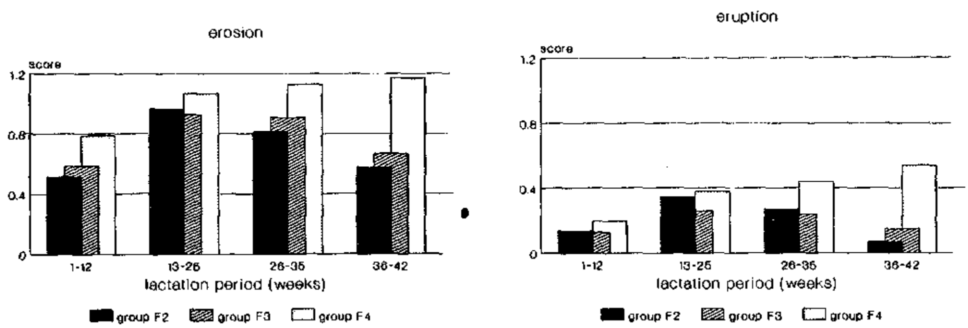


Figure 1. Teat end quality scores per group and lactation period.

Discussion

In this experiment an increase in the milking frequency from 2 to 4 times per day gave an increase in milk yield of 15% and in milk fat and protein production of 11%. This corresponds with earlier research (Ipema et al., 1987, Bieber, 1988). Increasing the milking frequency from 2 to 3 times daily, however, gave almost the same production results as an increase from 2 to 4. Zipper (1990) also hardly found any production results as an increase from 2 to 4. Zipper (1990) also hardly found any differences in the milk yield between 3 or 4 times daily milking. He assumes that the same increase in yield at 3 and 4 times daily milking together with a decrease in the milk fat content indicates production is limited by an insufficient energy supply. Decreased milk fat contents at higher milking frequencies were also found by Ordolf (1989), Ipema & al. (1987) and Ipema & al.(1991). In this research an increase in milk fat and protein production of 10-11% for the frequency groups F3 and F4 involved an increase in dry matter intake of only 3-4%. The lower body scores for the higher frequency groups suggest that the increased production was partly realized by utilizing body reserves.

Duration of machine milking increased by about 40% between groups F2 and F3 and by 56% between groups F2 and F4. Zipper (1990) found increases of 24% when the milking frequency was raised from 2 to 3 times daily and of 49% when raised from 2 to 4 times. In an experiment with 2 and 6 times daily milking an increase of more than 100% in the duration of machine milking was measured (Ipema et al., 1991). This longer duration of machine milking causes the milking machine to affect the teats for a longer time. A second point of interest in the higher milking frequencies is that the intervals between consecutive milkings are shorter, which means that there is less time for the teats to recover. The assessment of the teat ends revealed that increasing the milking frequency up to 4 times daily negatively affected the teat end quality. Hamann & Stanitzke (1990) proved that differences in the teat constitution are caused by the milking technique and the milking frequency. Deviations in the teat quality increase the risk of udder infections.

Conclusions

Increasing the milking frequency from 2 to 3 times daily increased the milk yield by about 14% and the milk fat and protein production by 10%. The production effect tended to be more pronounced in the second part of lactation.

Under the rationing and milking conditions of this experiment a further increase of the milking frequency to 4 times daily brought hardly any additional production.

Increasing the milking frequency to 4 times daily caused more stress on the teats, which suggests that at higher milking frequencies more attention should be paid to the milking techniques applied.

References

Bieber, F., 1988. Biologisch-Technologische Grundlagenuntersuchungen zu alternativen Milchgewinnungsverfahren. Diplomarbeit Humboldt University Berlin, Germany, 83 pp.

Hamann, J. & U. Stanitzke, 1990. Studies on pathogenesis of bovine mastitis by comparison of milking conditions as calf suckling, hand milking and machine milking: reactions of the teat tissue. Milchwissenschaft 45(10):632-636.

Hogewerf, P.H., S.F. van Heulen & H.J.J. Janssen, 1991. Equipment for taking video images of teats in dairy farming. Computers and Electronics in Agriculture 6:235-242.

Ipema, A.H., E. Benders & W. Rossing, 1987. Effects of more frequent daily milking on milk production and health of dairy cattle. Proceedings of Third Symposium Automation in Dairying. IMAG, Wageningen, The Netherlands, p. 283-293.

Ipema, A.H. & W. Rossing, 1987. Automatic individual feeding of dairy cattle. Proceedings of Third Symposium Automation in Dairying. IMAG, Wageningen, The Netherlands, p. 41-51.

Ipema, A.H., C.C. Ketelaar-de Lauwere & J. Metz-Stefanowska, 1991. The influence of six times per day milking on milk production, technology and cow behaviour. IMAG-DLO, Wageningen, The Netherlands, Report 91-20, 24 pp.

Ordolf, D., 1989. Voraussetzungen und Grundlagen automatischer Milchgewinnung. Forschungsbericht Agrartechnik des Arbeitskreises Forschung und Lehre der Max-Eyth-Gesellschaft (MEG) 191: 188 pp.

Zipper, J., 1990. Mehrmaliges Melken in Milchproduktionsanlagen mit hoher Tierkonzentration. Beitrage zum internationalen Kolloquium "Aktuelle Fragen des maschinellen Melkens". University Leipzig, Germany, p. 249-256.

Experiences with continuous robot milking with regard to milk yield, milk composition and behaviour of cows

J.H. Kremer & D. Ordolff

Federal Dairy Research Centre, P.O. Box 6069, D-2300 Kiel 14, Germany

Summary

Robot milking was the subject of a research project. In a change-over experiment 2 groups of 14 cows each were kept alternately for 50 up to 100 days in an experimental group or in the control group in a loose housing barn with feeding cubicles. All cows except those in first lactation had previously been kept in a stanchion barn. In the experiment covering a period of 465 days 55 cows were included. In the experimental group 13 365 milking operations were carried out by an automatic milking unit.

Data on milk yield, milk composition and the behaviour of cows were recorded. In the experimental group the average frequency of voluntary visits to the milking station was 45.9%; on average, the cows were milked 2.8 times per day. The least squares mean of milk yield was 19.6 kg in the experimental group and 20.5 kg in the control group. The experimental group produced milk with lower concentrations of fat and protein than the control group. On average, attaching all 4 teat cups took 2.8 minutes. The relatively long time required to attach the milking cluster, and the design of the milking station were the main reasons for these results.

Keywords: robot milking, milking frequency, milk yield, milk components, behaviour.

Introduction

Several simulations of milking frequency have given positive results regarding animal behaviour, milk production and milk quality (Waterman & Gorewit, 1980; Poole, 1982; Bruins, 1983; Ipema et al., 1987; Nuber, 1989; Ordolff, 1989). The prototype of a milking robot from Düvelsdorf, Ottersberg (Scheidemann, 1990; Dück, 1992) was used for milking at the experimental farm of the Institute for Milk Production. Apart from its suitability for practical application the aim was to evaluate its acceptance by cows (animal behaviour) and the effects on milk production, milk composition (including milk acetone, milk urea, free fatty acids) and udder health. The results on udder health, milk acetone, milk urea and free fatty acids are available but are not given in this paper.

Materials and method

In the research project lasting from September 2, 1990 until December 9 1991 the experiment was subdivided into 6 periods. Within these periods 2 groups of 14 cows were kept alternately for 50 up to 100 days in an experimental and a control group in a loose housing barn with feeding cubicles (change-over experiment). All cows except those in first lactation had previously been kept in a stanchion barn. Age, stage of lactation and milk yield of the animals in the experiment corresponded to normal practical conditions.

At the start of the experiment all cows were at the beginning of lactation. All animals were allocated to the groups at random, with the proviso that there should be 30% heifers in each group (60% in the last period of the experiment). To have cows in all periods of lactation in both groups, at the end of each period animals in advanced lactation were replaced by fresh milking cows. Neither group included dry cows. In both groups the cows had permanent access to the feeding place and to the resting areas. The cows of the control group were tied in a stanchion barn and milked with a milking pipeline system twice a day, whereas the animals of the experimental group could individually choose both the time and the frequency of milking. To restrict the stress for the animals and to use the robot efficiently, milking intervals were determined according to the quantity of milk to be expected on the basis of previous observations. In the case of a voluntary visit, a cow was milked if the predicted milk yield was at least 5 kg. The predicted milk yield was estimated by relating the yield of the last milking to the milking interval. Once the predicted yield was 10 kg the cows were fetched for milking. The milking station for the experimental group was sited to allow voluntary visits of cows. No devices were installed to sort cows. The milking station was equipped with 2 boxes, as in a linear parlour. The floor was about 73 cm above ground level. Two ramps were installed for entering and leaving the station. Concentrates were distributed by a dispenser in the milking station. To accustom the cows to the station the control group was fed concentrates using a transponder feeding box of similar design.

Udder preparation before milking was carried out manually using dry paper towels. If needed, the udder was washed.

Data were evaluated with the statistical programs SAS (Anonymous, 1990) and LSMLW (Harvey, 1987).

When analysing the results for the parameter milk yield the following possible influences were taken into consideration: The random effect of the cow as well as the treatment, the experimental period, number and stage of lactation and interactions as fixed effects.

To eliminate data which could have been influenced by the period of adaptation, data from the first 2 weeks of each experimental period were not included.

Results

By the end of the experiment 55 cows had been milked in the automatic station 13 392 times. Automatic attachment of the milking cluster did not work before March 15, 1991. Until then, the teat cups were attached manually. Finally, automatic attachment was successful in 95% of cases (i.e. the first attempt to attach the teat cup succeeded within 5 minutes, otherwise the robot stopped the procedure). On average, attaching all 4 teat cups took 2.8 minutes. The standard error was 0.6 minutes. One per cent of all attempts succeeded in less than 1 minute, 18% within 2 minutes, 67% within 3 minutes and 87% of all attempts within 4 minutes. Regression analysis proved that the milk parameters worsened with increasing time required for attaching the teat cups. Every additional minute caused a loss of 0.28 kg milk yield and 0.19% fat content. The average frequency of milking was 2.8 per cow and per day with a variation of 0.7. A total of 45 000 milk samples was analysed in the experiment.

Table 1. Proportion of voluntary visits of all visits for milking (in per cent).

	Number of lactations per cow [1]			
	1	2	≥ 3	Total
Experimental period				
1	30.6	45.3	34.4	37.6
2	31.2	68.5	38.2	52.4
3	60.0	60.4	57.9	58.6
4	38.7	69.4	27.7	50.5
5	97.0	71.9	30.2	37.9
6	56.9	26.3	13.4	33.6
Total	49.3	56.6	34.9	45.9

[1] Experimental group; 55 cows with 162 period means from 12 365 single observations.

Proportion of voluntary visits

45.9% of all visits for milking were voluntary. The proportion varied between periods, from 33.6% to 58.6%. For cows in first lactation 49.3% of all visits were voluntary, for cows in second lactation the figure was 56.3% and for older cows it was only 34.9%. The wide range of variation between the different periods was also due to individual differences between the animals (Table 1).

Parameters of milk yield

Milk yield

Throughout the whole experiment the least squares mean of the experimental group was 0.89 kg/d ($P \leq 0.001$) below the mean of the control group (Table 2). Only in experimental period 2 was a higher yield observed in the experimental group. From the beginning of the fourth experimental period the teat cups were attached automatically by the milking robot. Comparing the least squares means of the first 3 periods with the last 3 periods it is obvious that the fully automatic attachment of the teat cups caused a decrease in milk yield. The difference, calculated as a linear contrast, resulted in a least squares mean of 1.9 kg ($P \leq 0.001$).

Table 2. Least squares means (LSQ_M) and standard errors (SE) of the experimental and control groups regarding the milk yield in each experimental period.

	Treatment			
	experimental group [1]		control group [2]	
Experimental period	LSQ_M	SE	LSQ_M	SE
1	18.6	1.3	20.1	1.5
2	22.3	1.4	20.9	1.4
3	20.6	1.0	20.5	1.0
4	18.9	1.5	22.4	1.5
5	17.9	1.0	18.9	1.1
6	19.3	0.9	20.1	0.8
Total	19.6	0.7	20.5	0.7

[1] 55 cows with 162 period means from 12 365 single observations.
[2] 2795 single observations.

Milk composition

Throughout the experiment the least squares mean of the fat content in the experimental group was 0.52% ($P \leq 0.001$) less than the least squares mean in the control group (Table 3).

Table 3. Least squares means (LSQ_M) and standard errors (SE) of the experimental and the control groups with regard to the contents of fat, protein and lactose in milk in the experimental period.

Parameter/	experimental period	Treatment: experimental group [1]		Treatment: control group [2]	
		LSQ_M	SE	LSQ_M	SE
Fat	1	5.05	0.24	4.71	0.26
	2	3.97	0.25	4.87	0.25
	3	4.64	0.18	5.25	0.18
	4	4.17	0.27	4.86	0.28
	5	4.02	0.20	4.78	0.19
	6	3.27	0.16	3.77	0.16
	Total	4.19	0.11	4.71	0.12
Protein	1	3.65	0.11	3.65	0.13
	2	3.21	0.11	3.55	0.12
	3	3.49	0.09	3.65	0.09
	4	3.25	0.13	3.51	0.13
	5	3.30	0.09	3.69	0.09
	6	3.48	0.08	3.72	0.25
	Total	3.40	0.05	3.62	0.05
Lactose	1	4.90	0.09	4.55	0.09
	2	4.61	0.09	4.63	0.93
	3	4.68	0.07	4.76	0.07
	4	4.48	0.10	4.79	0.10
	5	4.29	0.08	4.66	0.08
	6	4.44	0.06	4.67	0.06
	Total	4.58	0.03	4.67	0.03

[1] 55 cows with 162 period means from 12 365 single observations.
[2] 2795 single observations.

The first experimental period was the only period in which the fat content observed in the experimental group was 0.34% ($P \leq 0.001$) higher. In the following periods only statistically significantly lower values were found. The comparison within the experimental group of periods 1 to 3 and periods 4 to 6 clearly indicates a reduction in fat contents due to automatic attachment of the teat cups. The least squares mean of fat in the periods 1 to 3 was 0.74% ($P \leq 0.001$) higher than the least squares mean of periods 4 to 6. The least squares mean of fat content in both groups was remarkably low in period 6. It was 3.27% fat in the experimental group and 3.77% fat in the control group. During the whole experiment the protein content of the milk of the experimental group was 0.23% ($P \leq 0.001$) lower than in the control group. In each period the inferiority of the experimental treatment was clearly visible. For the protein content of milk the negative reaction of cows to automatic attachment of the teat cups was less obvious than for fat content and milk yield (Table 3). The reduction of the protein content was 0.11% ($P \geq 0.05$).

The values for lactose content were only slightly lower in the experimental group (0.009%; $P \geq 0.05$) (Table 3). The decrease in the least squares mean of lactose content in periods 4 to 6 compared to the values in periods 1 to 3 again indicates a negative response of the cows to the fully automatic action of the robot. The reduction of the least squares mean was 0.34% lactose ($P \leq 0.001$)

(Table 3). Since the lactose contents in periods 3 to 6 were less than 4.6% we suspected that milk secretion might have been impaired. This hypothesis, however, could not be verified by somatic cell counts of milk, because these were normal.

Since the values for the milk components of both groups in the final experimental period were rather low, both groups were kept another 50 days in the same barn which, after the end of the experiment, had been converted into a stanchion barn. There they were milked twice a day. Feed composition and quantity remained unchanged. The fat content of the former experimental group rose from 3.3% at the end of the experiment to 4.8%; the fat content of the former control group rose from 3.8% to 4.9%. Milk yields remained constant.

Discussion

The data on behaviour of the cows showed that the chosen arrangement of the milking parlour, aiming at voluntary visits of cows, resulted in only 45.9% of voluntary visits. Thus considerable improvements are necessary. However, no cows originating from loose housing systems were available for the experiment. Cows coming from stanchion barns are known to have problems in adapting to loose housing conditions. It was obvious that younger cows adjusted more easily to new housing conditions. It was surprising that cows in second lactation visited the station more frequently than cows in first lactation, although their visits were at a relatively low level as well. Therefore a system for forced rotation of animals should be installed to achieve sufficient milking frequency (Rossing, 1990).

According to the literature a higher frequency of milking should result in an increase of milk yield compared to twice-a-day milking. In the experiment this could not be verified.

The effect of increased milking frequency on milk yield did not match our expectations. The experimental group produced 0.9 kg less milk than the control group. Concentrations of milk components were obviously lower too. In a further evaluation cows were sorted according to the frequency of voluntary visits. Even for the cows with a high frequency of voluntary visits lower values were found for all components.

When comparing the periods with automatic versus manual teat cup attachment it was found that fully automatic operation resulted in lower yields, presumably because the time lag between udder preparation and start of milking was too long.

It was concluded that during the experiment the cows had been suffering from stress. First of all the change from stanchion barn to loose housing conditions might have caused stress, because the cows had to struggle to establish their social position within the group, and because they were forced to take care of feed and water on their own. Another reason for stress may have been the restricted space available in the barn, mainly for the experimental group; although these conditions were identical for both groups. The design of the milking station was probably a very important factor too, for the animals were forced to reach it by climbing steep ramps, which some of them did not like at all. Due to technical restrictions it was impossible to install the station at floor level which would have considerably reduced the stress for the cows. The negative results in milk yield, however, were surprising, because the cows got used to the procedure of being milked by the robot and, with some exceptions, neither any kicks against the robot arm or any general uneasiness of cows in the milking station were observed. These results clearly show that improvements are required to remove anxiety from cows.

Another cause of stress to cows may have been the fact that the complexity of the experiment required a staff of 33 persons, working in several shifts with teams of two persons. So the cows were faced with a continuous change of attendants.

Conclusion

It has to be concluded that the design and the siting of an automatic milking station within the barn must be carefully planned. The requirements of design and operation certainly go beyond conditions in self-feeding boxes for concentrates. The risk of poor acceptance of the station due to anxious animals must be avoided, so more research is required to find potential reasons for uneasiness.

References

Anonymous, 1990. SAS User's guide: Basics & Statistics. Version 6.04. SAS Institute INC.

Bruins, W.J., 1983. Drie keer per dag melken. Bedrijfsontwikkeling 144:283-284.

Dück, M., 1992, Evolution of Düvelsdorf milking robot. In: A.H. Ipema, A.C. Lippus, J.H.M. Metz & W. Rossing (Eds.): Proceedings of the International Symposium on Prospects for Automatic Milking, EAAP publication No. 65, Pudoc Scientific Publishers, Wageningen, The Netherlands, p. 49-54.

Harvey, W.H., 1987. Users guide for LSMLMW, Ohio State University, U.S.A.

Ipema, A.H., E. Benders & W. Rossing, 1987. Effects of more frequent daily milking on production and health of cattle. In: Proceedings of the third Symposium Automation in Dairying, IMAG, Wageningen, The Netherlands, p. 283-293.

Nuber, B., 1989. Simulationsstudien zum automatischen Melken. Dissertation Universität Hohenheim, Germany.

Ordolff, D., 1989. Voraussetzungen und Grundlagen automatischer Milchgewinnung. Habilitation Universität Hohenheim, Germany.

Poole, D.A., 1982. The effects of milking cows three times daily. Animal production 34(2):197-201.

Rossing, W., 1990. Entwicklungen beim automatischen Melken. In: Robotereinsatz in der Landwirtschaft am Beispiel des Melkens; Tagung Braunschweig-Völkenrode. VDI/MEG Kolloquim Landtechnik, Düsseldorf, Germany.

Scheidemann, B., 1990. Ein kartesisch arbeitender Melkroboter - Aufbau und Erfahrungen. In: Robotereinsatz in der Landwirtschaft am Beispiel des Melkens; Tagung Braunschweig-Völkenrode. VDI/MEG Kolloquim Landtechnik, Düsseldorf, Germany.

Waterman, D.F. & R.C. Gorewit, 1980. The effects of three times a day milking on milk yield, milk components and udder health. Journal of Dairy Science 63(1):119.

The effect of increased milking frequency and automated milking systems on the behaviour of the dairy cow

A. Winter, R.M. Teverson & J.E. Hillerton

AFRC Institute for Animal Health, Compton, Newbury, Berkshire, RG16 0NN, United Kingdom

Summary

The successful integration of automated milking into commercial farms will depend partly on the behaviour of dairy cows within these new systems. Since the biological efficiency of the dairy cow may be improved by increasing the frequency of milking, the effect of increasing the number of daily milkings from two to four on diurnal behaviour patterns and maintenance activities was assessed for a group of 20 cows.

Significant disruptions to diurnal patterns of activity were not recorded despite one milking on the four times a day regime occurring at midnight. Adaptation to increased frequency of milking was achieved through maintenance of lying time and compensatory feeding occurring at milking time.

In a separate trial the introduction of a non-return gate in an experimental automated milking system, which imposed an anticlockwise movement to the feed area, reduced the frequency and increased the duration of feed visits. There was an overall reduction in feeding synchrony. This effect was only recorded for lactating cows. Dry cows made fewer visits.
Keywords: dairy cows, milking frequency, behaviour, feeding, automation.

Introduction

The efficient introduction of automated milking systems which allows an increased frequency of milking dependent on voluntary attendance by the cow, will require a change in dairy cow management. The technical development of automated systems has advanced such that "on demand" milking is possible on an extended basis. An important component of the introduction of automation is the cows interaction with, and response to, these "new" milking management techniques.

Dairy cattle are herd animals with a complex social hierarchy and distinctive behaviourial patterns, which have been well documented and characterised (Arave & Albright, 1981). Cows are usually active during the day and rest during the night. Synchrony of behaviour is pronounced, occurring in response to social factors, environmental cues and management systems. Synchrony of feeding is persistent and the least readily disrupted herd characteristic (Potter & Broom, 1987). Extended queuing times and blocked entry and exit areas could reduce availability of automatic milking stalls, and optimum frequency of milking for individual cows might not be achieved.

To assist the introduction of automated milking systems to dairying, it is important to identify aspects of herd behaviour which may not be compatible with efficient use by the herd. Some modification of inherent behaviourial patterns may be necessary if the welfare of the cow is not to be reduced.

At Compton we have focused on the effect of increased milking frequency on diurnal patterns of behaviour and maintenance activities. Associated studies were carried out within an experimental automatic milking system to assess the effect of feed availability on frequency of attendance for milking as a function of feeding frequency.

Behaviourial responses to increased milking frequency

Materials and methods

A group of 20 first lactation cows were housed in cubicles and fed fresh forage at a feed manger once per day. Concentrates were fed at an automatic concentrate dispenser within the cubicle house. All cows were milked in a 3 stall tandem parlour at 06:00h and 18:00h for 21 days then changed to a four times a day regime with additional milkings at 12:00h and 00:00h for 42 days. The twice daily regime was then re-imposed for 14 days. The average daily duration of attendance at the parlour on the two times a day regime was 270 minutes and on the four times a day 408 minutes.

To record the daily activity of 10 cows within the group observations were carried out manually at 10 minute intervals over a 48 hour period. There were five observation periods, covering stabilisation and adaptation to the differing milking regimes. On the twice daily regime observations were carried out on days 10 and 11(1), 65 and 66(4) and 73 and 74(5). On the four times a day regime observations were made on days 24 and 25(2) and 45 and 46(3).

Diurnal patterns of behaviour were described for the maintenance activities; feeding, lying and standing. The daily duration of these activities was calculated for individual cows and as an average for each observation period. A paired Students t-test was used to analyse differences between observation periods, milking regimes and cows.

Results

The first observation period was taken as the "normal" pattern of activity on the twice daily milking regime. The diurnal activity pattern obtained for feeding and lying for this observation period (Figure 1) showed similar activity patterns to those obtained for the second four times a day milking period (Figure 2).

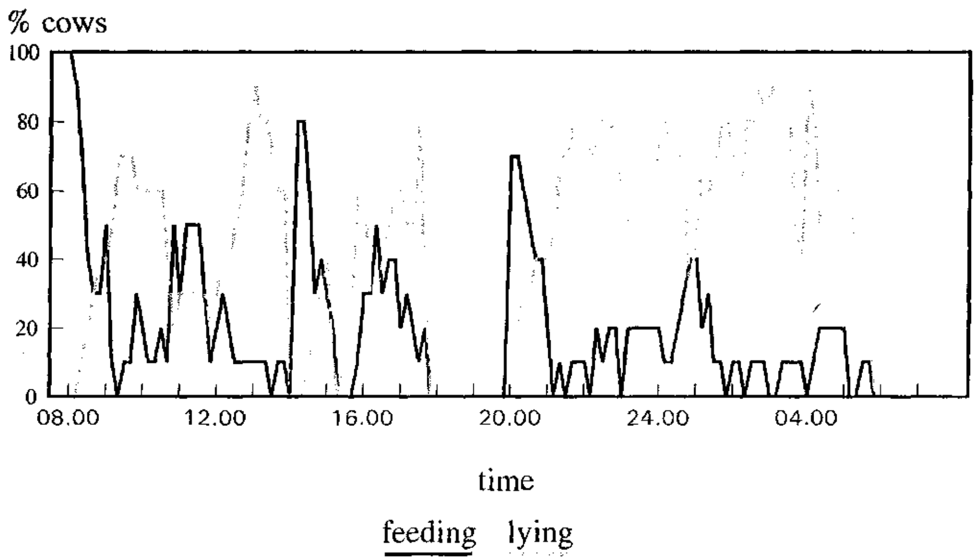


Figure 1. Diurnal activity patterns for feeding and lying in cows (percentage of cows feeding or lying per 10 minutes) milked twice per day (observation period one).

The overall diurnal pattern of activity for all periods was similar and characterised by activity during the day and rest at night with feeding peaks associated with return from milking. This also occurred on the four times a day regime, except at the 00:00h milking (Figure 2). On return cows rapidly resumed lying and this activity was more persistent over the night period.

There was no significant variation ($p \leq 0.05$) in total lying time, despite total milking time increasing by 51% (Table 1).

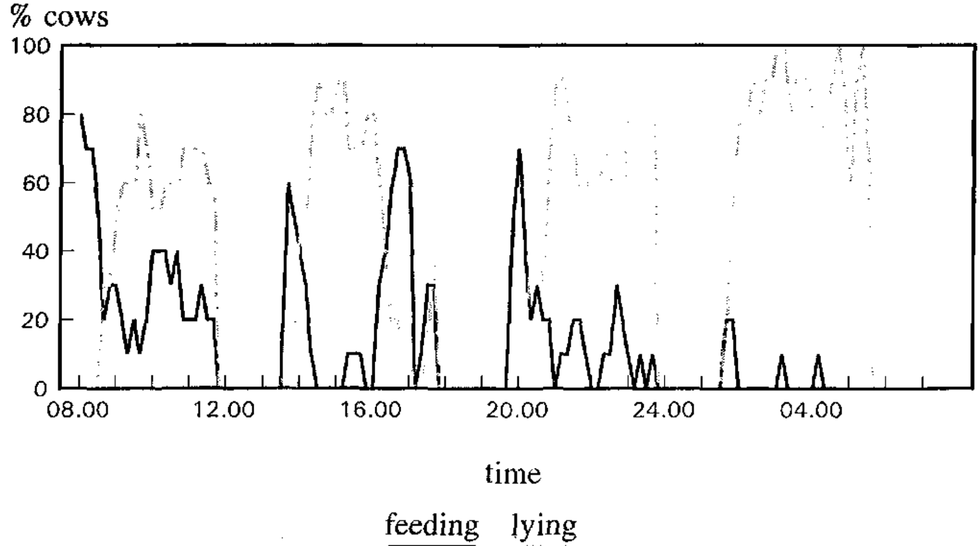


Figure 2. Diurnal activity patterns for feeding and lying in cows (percentage of cows feeding or lying per 10 minutes) milked four times a day (observation period three).

Table 1. Total activity values per 24 hours for each observation period (time in minutes).

Activity	Observation periods 1	2	3	4	5
Feeding	272[a]	310[b]	305[b]	256[a]	279[a]
Lying	611	597	577	588	613
Standing	563	589	597	562	544
Ruminating	478	511	508	412	422

[a,b] statiscally significant difference ($p \leq 0.05$).

Time interval analysis of lying activity revealed that compensatory lying occurred during the "evening" period (18:00-00:00h) on the four times a day regime. There was no significant variation in duration and number of lying bouts between milking regimes. There was a significant increase in feeding time with increased milking frequency. This was achieved by a reduction in feeding time in the cubicle house, and compensatory feeding in the collecting yard following milking.

The cows adapted rapidly to the increased number of milkings. Aberrant behaviour was not recorded. Milk yield increased by 12-14% (Knight et al., 1992) on the four times per day regime.

Behaviour in response to "passive" and "active" selection to feed in an experimental automatic milking management system

Materials and methods

Two trials were carried out consecutively to assess the effect of the introduction of non-return gates between feeding and lying areas on diurnal activity and synchrony of feeding activity in a simulated automatic milking system (AMS). Access to the feed manger was via a selection stall (which was non-functional) and one non-return gate. Exit from the feed area was by a non-return gate imposing an anti-clockwise movement to the feed area. All water was provided in the straw yard, the lying area, and a complete forage ration was provided at the feed manger once per day on return from morning milking. Milking took place outside the system at 07:30 and 16:30h. The average duration of milking was 50 minutes.

Two treatment periods of 5 days were imposed. The initial 5 days allowed "passive" feeding with access to feed by both entry and exit gates. In treatment 2 "active" feeding was via the non-return gates at entry and exit. Each treatment consisted of a 2 day stabilisation period, followed by 3 consecutive days with continuous observations. The activity of all 10 cows including time of entry and exit to the feed area was recorded. The trial was then repeated with 10 dry cows to examine the effect of the selection system without milking.

Results

Diurnal patterns of activity were different in the two groups of cows, and in the lactating cows in the two treatments. Six distinct feeding peaks were identified with a significant level of synchronisation, as defined by the Kappa statistic (Rook & Penning, 1991), for "passive" feeding by the lactating cows (Figure 3).

There was a loss of distinctive feeding peaks and reduction in overall synchrony in dry cows. Feeding activity was concentrated between 07:30-19:00h. A similar pattern was obtained with dry cows on treatment 2. The response of lactating cows to "active" feeding resulted in a significant change in the feeding pattern (Figure 4).

Feeding peaks were less clearly defined with feeding activity spread over a greater proportion of the day. There was a reduction in the number of cows feeding at any one time. The change in feeding behaviour was reflected in total activity values. Feeding time increased during treatment 2 in both groups of cows. As a consequence of increased feeding time,the lying times of lactating cows were maintained and standing times in the straw yard were reduced. In contrast the lying time of dry cows was reduced. The total time spent in feeding and ruminating was not significantly different between groups.

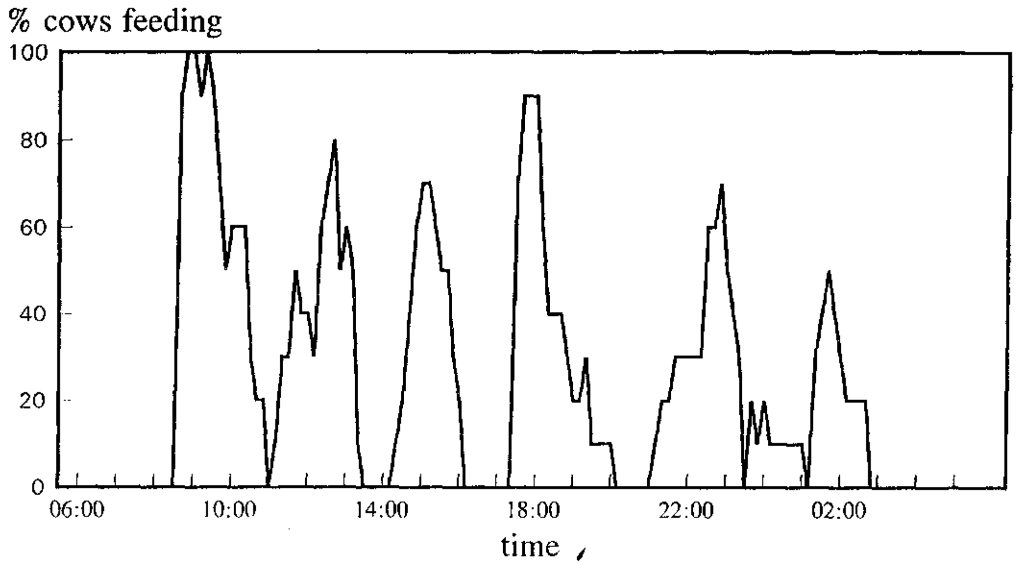


Figure 3. Diurnal feeding activity of lactating cows for "passive" selection to feed (treatment 1).

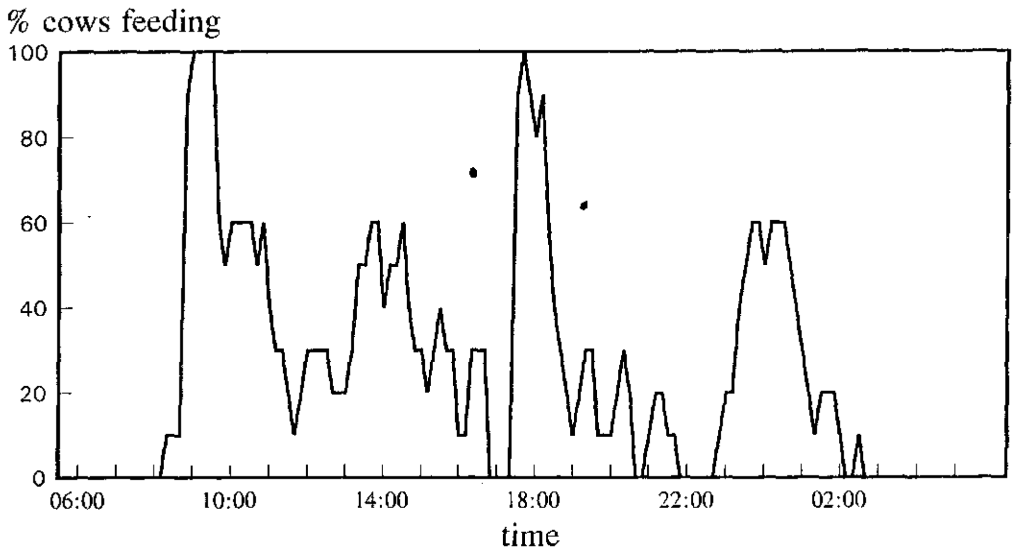


Figure 4. Diurnal feeding activity of lactating cows for "active" selection to feed (treatment 2).

Feeding frequency

There was a significant reduction in the number (p=0.0005) and an increase in duration (p=0.0014) of visits during treatment 2 by lactating cows. Visits by dry cows were significantly fewer (p=0.01) and of longer duration. The frequency of distribution of feeding "bouts" reflected the differences in feeding activity. The number of short feeding bouts (10-30,20-60 minutes) declined per 24 hour period for treatment 2 in both groups of cows. Use of dry cows within the automated system did not provide a valid model of the activities of lactating cows, if presentation for milking is to be related to feeding frequency.

Table 2. Average frequency and duration of visits to the feed area of dry and lactating cows for each treatment.

		Dry cows	Lactating cows
Visits/day (number)	1	5.9	8.8^{b}
	2	5.9	6.7^{a}
Duration/day (minutes)	1	75.0	43.0^{a}
	2	88.0	64.0^{b}

[a,b] statistically significant difference ($p \leq 0.05$; paired Students t-test).

Discussion

These two trials form part of a series of studies of behaviour designed to assess the effect of automated milking on inherent behaviour patterns of the dairy cow.

At present the possibility of improving the biological efficiency of milking by increasing milking frequency is limited by the time taken for milking since cows are milked together. The increase in "enforced" standing time during the four times a day milking trial was accommodated by compensatory feeding and lying behaviour. Maintenance of lying time provides an important measure of adaptation in the dairy cow, although finite lying times have not been established. Different feeding, housing and milking systems have affected lying time (Wierenga & Hopster, 1990; Ipema et al., 1988). Disruption of the night resting period has been shown to have a significant effect when compared to daytime resting periods (Wierenga & Van de Burg, 1988). Compensatory lying during the day was possible during the four times a day regime since feeding time within the cubicle house declined when feed was available at milking. Lying time may not have been maintained, if forage had not been provided at milking.

The overall periodicity of activity and inactivity was maintained. These results suggest that increased frequency of milking can be accommodated by the dairy cow under present management conditions. However the implications of disturbing the generally inactive night period must be considered and provision for compensatory behaviour made.

Automated milking systems should reduce milking time as cows will no longer be milked in batches. This will increase the time available for maintenance activities to sustain increased yield. The physiological and psychological stimuli controlling voluntary attendance for milking have not been established. The stimulus provided by food has been used to encourage attendance. The division of the feeding and lying area by a non-return gate significantly affected the frequency and duration of feeding, in a similar manner to that reported by Ketelaar-de Lauwere (1991). Visits were fewer and more time was spent in the feed area. This was associated with an overall reduction in synchrony. This could have been associated with the removal of the constraint of twice daily milking for the dry cows or a function of the housing conditions (O'Connell et al., 1987). Different levels of synchronisation may not necessarily effect total activity times (Wierenga & Hopster, 1990). Daily food intake and total rumination time have been shown to be positively correlated (Metz, 1975). Ruminating time was maintained suggesting that the increase in feeding time could be attributed to less efficient, more "idle" feeding as a consequence of the design of the system. Cows were often not inclined to leave the feed area, or were blocked in by cows at the exit gate.

A similar response was obtained with dry cows and this was associated with fewer visits of longer duration. Dry cows may have been less inhibited by the gate system as a result of their reduced feeding frequency. The small number of visits made was not effected by the introduction of the gates. Ipema et al. (1987) with a simulated frequent milking regime reported that the number of milkings per cow per day was fairly constant during a lactation. The different results obtained for both groups of cows appeared to be a function of their different diurnal feeding activity which was related to stage of lactation and different physiological requirements. Overall diurnal patterns were similar, but synchrony and periodicity were different, such that the movement of dry cows within the system was not representative of lactating cows.

Inherent diurnal patterns of activity will be expressed within an automated system. Short term changes in synchronisation may be made possible by designing the feeding and lying areas to optimise use of the system by all cows.

Acknowledgements

We are grateful to Mr A.W. Walton for tending the animals and Mr T.T.F Mottram for assistance in the automatic milking system.

References

Arave, C.W. & J.L. Albright, 1981. Cattle behaviour. Journal of Dairy Science 64:1318-1329.

Arave, C.W., J.F. Hurnik & T.H. Friend, 1983/84. Some observations on the role of behaviour in cattle production and future research needs. Applied Animal Ethology 2:271-276.

Ipema, A.H., E. Benders & W. Rossing, 1987. Effects of more frequent daily milking on production and health of dairy cattle. In: Proceedings of the third symposium Automation in Dairying, IMAG, Wageningen, The Netherlands, p. 283-293.

Ipema, A.H., H.K. Wierenga, J. Metz, A.C Smits & W. Rossing, 1988. The effects of automated milking and feeding on the production and behaviour of dairy cows. In: Automation of feeding and milking: production, health, behaviour, breeding. Proceedings of the EAAP-Symposium of the Commissions on Animal management and health and cattle production, Pudoc, Wageningen, The Netherlands, p. 11-23.

Ketelaar de Lauwere, C.C., 1991. Effects of a selection unit for automatic milking on dairy cow behaviour. In: Applied Animal Behaviour: Past, present and future. Proceedings of the International Congress, Edinburgh. Universities Federation for Animal Welfare, Potters Bar, UK, p. 89-90.

Knight, C.H., J.E. Hillerton, M.A. Kerr, R.M. Teverson, A. Turvey & C.J. Wilde, 1992. Seperate and additive stimulation of bovine milk yield by the local and systemic galactopoietic stimuli of frequent milking and growth hormone. Journal of Dairy Research 59:243-252.

Metz, J.H.M., 1975. Time patterns of feeding and rumination in domestic cattle. Medelingen Landbouwhogeschool, Wageningen, The Netherlands, 75-12, p. 1-66.

O'Connell, J., P. Giller & W.J. Meaney, 1987. Dairy cow behaviour. Differences at pasture and in winter housing. Farm Food Research 18:10-12.

Potter, M.J. & D.M. Broom, 1987. The behaviour and welfare of cows in relation to cubicle house design. In: H.K. Wierenga & D.J. Peterse (Eds.): Cattle housing systems, lameness and behaviour. Martinus Nijhoff, Dordrecht, The Netherlands, p. 129-147.

Rook, A.J. & P.D. Penning, 1991. Synchronisation of eating, ruminating and idling activity by grazing sheep. Applied Animal Behaviour Science 32:157-166.

Wierenga, H.K. & A. Van de Burg, 1988. Concentrate intake and behaviour of dairy cows with programmed concentrate distribution. Verslag van een studiedag, Wageningen, 20 December, 1988. Pudoc, Wageningen, The Netherlands, p. 7-10.

Wierenga, H.K. & H. Hopster, 1990. The significance of cubicles for the behaviour of dairy cows. Applied Animal Behaviour Science 26:309-337.

The use of a selection unit for automatic milking: consequences for cow behaviour and welfare

C.C. Ketelaar-de Lauwere

DLO Institute of Agricultural Engineering (IMAG-DLO),
P.O. Box 43, 6700 AA Wageningen, The Netherlands

Summary

The use of a selection unit developed to control cows' visits to an automatic milking system was studied. Two types of selection were compared: during passive selection the cows could decide themselves whether to visit the selection unit; during active selection the cows had to visit it, as the only route from the lying area to the feeding area was via this unit.

Passive and active selection were compared in 3 trials with 20 HF × FH cows in each. When passive selection was imposed upon the cows first and then active selection, significantly more visits ($p < 0.01$) were made to the selection system during active selection. However, when active selection preceded passive selection, the number of visits did not differ. It appeared that the cows moved significantly less through the cowshed and spent significantly less time at the feeding gate during active selection ($p < 0.05$).

It is concluded that passive selection is preferable for reasons of cow's welfare, while it can be as effective as active selection if preceded by some training period of active selection, provided this period is not too long.

Keywords: automatic milking, dairy cows, selection unit, behaviour, welfare.

Introduction

The success of an automatic milking system (AMS) largely depends on the cows which have to visit the system at regular intervals. Research in which a milking-robot was simulated in a concentrate feeder by men, has shown that some cows will visit an AMS too often, which strains the capacity of the system, and that others will visit the system too infrequently, and have to be fetched by the farmer (Ipema et al., 1988). Therefore a selection unit was developed. When a cow enters this system she is automatically identified and the computer then decides whether to allow her access to the AMS. Metz-Stefanowska et al. (1989) were the first to test a prototype of a selection unit on a group of cows.

Several types of selection are possible. In 'passive' selection the cow decides whether to visit the selection unit. In 'active' selection the cow has to go there, because the equipment has been arranged in such a way in the cowshed that (for example) the only route from the lying area to the feeding area is through the selection unit. So one-way traffic is forced upon the cows.

In this study passive and active selection were compared with each other and with a reference situation in which no selection took place.

The research aimed to elucidate the cows' use of the selection unit, their pattern of movement through the cowshed during different forms of selection and their welfare.

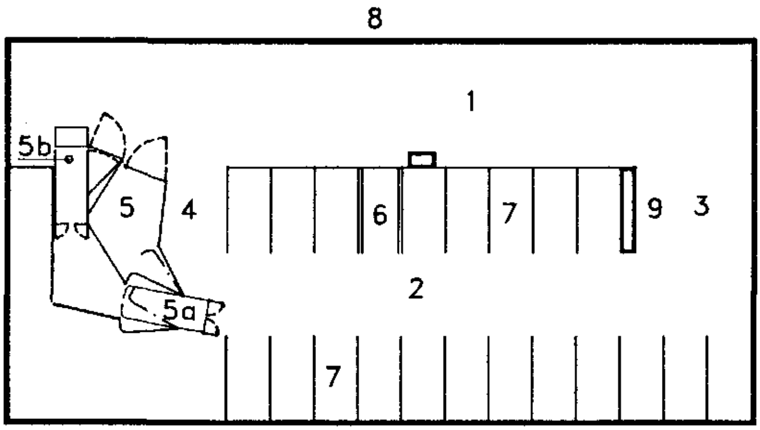


Figure 1. Plan of the cowshed. 1 = feeding area; 2 = lying area; 3 = passage along the wall; 4 = passage next to selection system; 5 = selection system; 5a = selection unit; 5b = special concentrate feeder; 6 = 'normal' concentrate feeder; 7 = cubicles; 8 = feeding rack; 9 = water trough.

Material and methods

On "De Ossekampen" experimental farm of Wageningen Agricultural University an experiment was carried out in 3 trials with 20 cows (HF × FH) in each. The animals were kept in a cubicle house in which the lying area was separated from the feeding area. The cows could go to and fro between the lying area and the feeding area via two passages, one next to the wall of the cowshed and the other right next to the selection system (Figure 1). The system itself, consisting of a selection unit and a special concentrate feeder which the cows could leave at the front, had its entrance in the lying area and its exit in the feeding area. A milking robot was simulated by this special concentrate feeder, so in this experiment the cows were not actually milked automatically. According to the fixed-time schedule the cows could obtain 250 g of concentrates once every six hours in the special feeder. The rest of their ration was fed in a normal concentrate feeder, which was positioned in the lying area in a row of cubicles. Grass silage was fed ad libitum at a feeding gate which contained more places than there were cows in the group. The cows were milked twice daily in a milking parlour at approximately 6.00h and 16.00h. During the day the cowshed was illuminated by a double row of TL light and during the night by a single row.

The cows were submitted to various situations. In the 1st and 2nd trials, after a reference situation in which no selection took place, passive selection was imposed upon the cows first and after that active selection. Both trials reverted to a reference situation at the end. During passive selection the cows could enter the selection system voluntarily. They could also go from the lying area to the feeding area or back through one of the two passages. During active selection the cows had to visit the selection system because it was their only means of access to the feeding area from the lying area. The only way to go from the feeding area to the lying area was by passing through a one-way gate, which was positioned in the passage running along the wall of the cowshed. The 3rd trial also started and ended with a reference situation. In between the cows were first submitted to two forms of active selection and then to two forms of passive selection. These forms varied in the number of passages which were available in the cowshed, namely two one-way gates vs. one one-way gate during active selection (referred to as active 2 and active 1, respectively) and one free passage vs. two free passages during passive selection (referred to as passive 1 and passive 2, respectively) (Ketelaar-de Lauwere, 1992).

Behaviour was monitored by video in every situation of each trial. There were two types of observations. During continuous observations the time and number of visits to the selection system and to the passages next to the wall and/or next to the selection system were recorded. The aim of these observations was to ascertain the cows' use of the selection system and their pattern of movement through the cowshed. During time-sampling observations the behaviour of each cow was recorded once every 10 minutes, with the aim of getting an impression of the cows' activity. Lying or standing in the cubicle, standing on the slatted floor in the lying or feeding areas and standing at the feeding rack were recorded.

In every situation of each trial in principle 3× 24 hours of continuous observations and time-sampling observations were carried out. The cows were allowed one week to become accustomed to a new situation before the observations started.

The data were statistically analysed with the paired T-test (Parker, 1979). The 1st and 2nd trials were analysed together, because they were similar, and the 3rd trial was analysed separately.

Results

The cows' use of the selection unit

Figure 2 shows the cows' use of the selection unit in the 3 trials. In the 1st and 2nd trial, it can be seen that the number of cows which never visited the selection system was higher during passive selection and that the number of cows which visited the system 3 times or more was higher during active selection ($p < 0.01$). However, in the 3rd trial, when active selection was imposed first upon the cows and after that passive selection, it can be seen that the number of cows which never visited the system was the same during all forms of selection and the number of cows which visited the system 3 times or more was almost equal. Only a slight decrease was seen during passive 2 when free passage between the lying and the feeding areas was possible directly next to the selection system. This result differed statistically significantly from passive 1 and active 2 ($p < 0.05$).

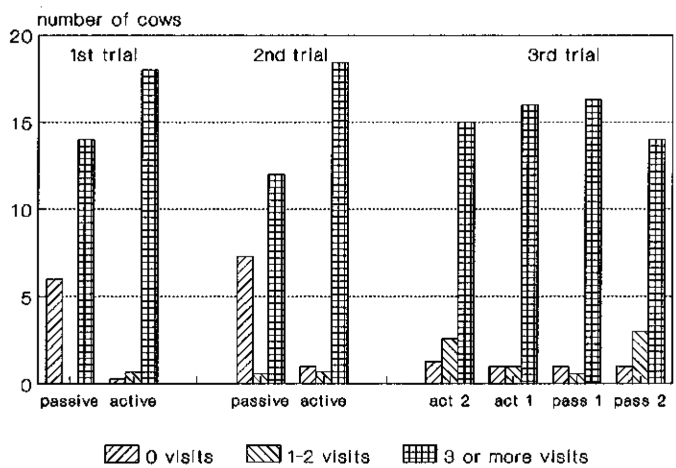


Figure 2. The number of cows which visited the selection system during different forms of selection in the 3 trials.

The cows' activity

In none of the trials was a difference seen between the different situations in the lying pattern of the cows during 24-hour periods.

However, the cows showed some differences in behaviour between the situations. The most striking result was that the cows spent significantly less time at the feeding gate in all 3 trials during active selection ($p < 0.001$ in the 1st and 2nd trials and $p < 0.05$ in the 3rd trial) (Table 1).

Table 1. The percentage of time the cows spent standing at the feeding gate in the different experimental situations of the 3 trials.

1st and 2nd trial				3rd trial					
refbeg	passive	active	refend	refbeg	act2	act1	pass1	pass2	refend
22.2	20.6	17.3	22.0	20.4	16.7	18.6	22.7	21.7	20.9

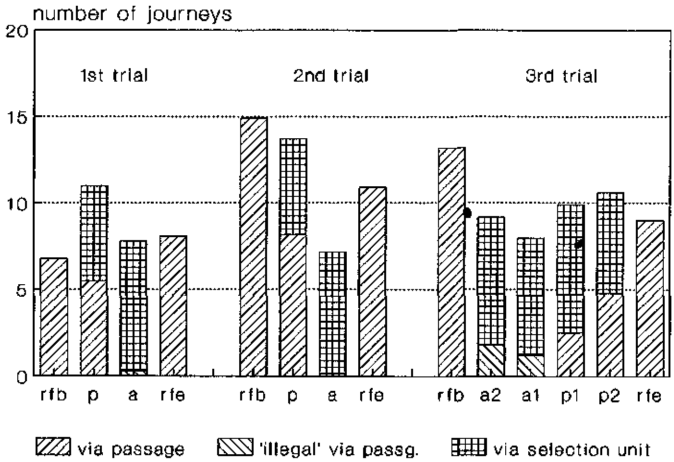


Figure 3. The average number of journeys from the lying area to the feeding area for each experimental situation in the 3 trials. rfb, rfe = reference begin, end; p, p1, p2 = passive selection, one or two free passage(s); a, a1, a2 = active selection, one or two one-way gate(s); 'illegal' via passg.' = cows which went through one-way gate in the wrong direction.

In the 1st and 2nd trials during active selection, the average number of journeys per cow from the lying area to the feeding area via one of the passages or the selection unit was significantly lower than in the other situations ($p < 0.01$) (Figure 3). In the 3rd trial this number was also the lowest during active 1. This differed significantly from passive 1 and 2 and the reference situation at the beginning of the trial ($p < 0.05$). During active 2 the average number of journeys from the lying area to the feeding area was also lower by comparison with these situations, but not statistically significantly.

The cows' pattern of movement in the 3rd trial

The results showed that the cows used the passages between the lying and the feeding areas differently before and after one-way traffic had been forced upon them during active selection.

After active selection was ended, they preferred the passage along the wall of the cowshed when going from the feeding area to the lying area, and they used the passage directly next to the selection system more often to go from the lying area to the feeding area (Table 2).

Table 2. The average number of journeys per cow from the lying area to the feeding area or back via one of the passages or the selection system as percentage of the total number of passages. Trial 3.

	Reference begin	Passive 2	Reference end
Feeding -> lying area:			
alongside wall	19.8[a]	33.0[b]	22.9[a]
next to selection system	29.8[a]	17.0[b]	26.8[b]
Lying -> feeding area:			
alongside wall	23.3[a]	xx	17.9[b]
next to selection system	27.1[a]	xx	32.4[a]

a,b statistically significant difference ($p < 0.05$).

xx not comparable with reference because cows could also use selection unit.

Discussion

From the results of the 1st and 2nd trials it might be concluded that active selection is a better technical solution because more cows visited the system frequently than during passive selection, when some cows never visited the system.

However, from a behaviourial point of view, active selection seemed to have a negative effect. The animals spent less time at the feeding gate and there was less free movement through the cowshed. Active selection seemed to inhibit the cows' activity. It might be that visiting the selection system was somewhat unattractive, because of its unpredictable consequences. Indeed, when a cow entered the system, she did not know whether she would be routed to the special concentrate feeder and get a reward, or whether she would be routed back to the cowshed without getting that food. According to Wiepkema (1988) predictability of the environment is an important item for an animal's welfare. In the present case, rewarding a cow each time she visited the selection unit might have had a positive effect. Preliminary data indeed confirm this assumption (Ketelaar-de Lauwere et al., in preparation).

According to Wierenga (1991) one can measure an animal's welfare by looking at the price it has to pay to adapt to its environment. As spending less time at the feeding gate during active selection means that the animals take in less roughage, this price was relatively high.

According to Potter & Broom (1987), as long as synchronization of behaviour is possible, the total movement through a cowshed due to a restricted number of passages can be very low without negatively affecting the animal's welfare. In that case the cows will all move in the same direction (for example to the feeding gate) at approximately the same time so that not many confrontations will occur. During the active selection, cows had to move in the same direction because one-way traffic had been forced upon them. On the other hand, they have to pass through the selection unit one by one, which can cause queueing and thus confrontations.

In the 3rd trial, when first active selection was imposed upon the cows and after that passive selection, the number of cows which never visited the selection system or visited it 3 times or more no longer differed between both types of selection. Furthermore, the results showed that the cows changed their pattern of movement through the cowshed after the period of one-way traffic during active selection. The cows kept to the route which had been forced upon them before, even though this was no longer necessary. It seems that an animal will not change certain habits very quickly, if those habits have previously been associated with high confidence ratings (Inglis, 1983). Therefore, a solution might be to use passive selection after a certain training period of active selection. Another experiment showed that for at least 6 weeks cows kept to a certain route through the cowshed which had been forced upon them during an earlier 6-week period of one-way traffic (Ketelaar-de Lauwere; in preparation).

Conclusions

- Active selection guarantees visits of all cows to the automatic milking system, but it inhibits the cows' movements through the cowshed and the animals spend less time at the feeding gate. Therefore, it should not be applied for long periods.
- It seems possible to guarantee enough visits to an automatic milking system also during passive selection too, after a certain (not too long) training period of active selection.

References

Inglis, I.R., 1983. Towards a cognitive theory of exploratory behaviour. In: J. Archer & L. Birke (Eds.): Exploration in animals and humans. Van Nostrand Reinhold, Cambridge, UK, p. 72-116.

Ipema, A.H., H.K. Wierenga, J. Metz, A.C. Smits & W. Rossing, 1988. The effects of automated milking and feeding on the production and behaviour of dairy cows. In: Automation of feeding and milking: production, health, behaviour, breeding. Proceedings of the EAAP-Symposium of the Commissions on Animal management and health and cattle production, Pudoc, Wageningen, The Netherlands, p. 11-24.

Ketelaar-de Lauwere, C.C., 1992. The use of a selection unit for automatic milking; The influence on the behaviour and welfare of dairy cows, IMAG-DLO, Wageningen, The Netherlands, Report 92-4.

Metz-Stefanowska, J., H.G. Pluygers, W. Rossing & C.C. Ketelaar-de Lauwere, 1989. First experiences with the use of a selection unit for dairy cows. IMAG, Wageningen, The Netherlands, Report 113,

Parker, R.E., 1979. Introductory statistics for biology, 2nd. Edition. Camelot Press, Southampton, UK.

Potter, M.J. & D.M. Broom, 1987. The behaviour and welfare of cows in relation to cubicle house design. In: H.K. Wierenga & D.J. Peterse (Eds.): Cattle housing systems, lameness and behaviour. Martinus Nijhoff Publishers, Dordrecht, The Netherlands, p. 129-147.

Wiepkema, P.R., 1988. Control and cognition, key concepts in applied ethology. In: J. Unshelm, G. van Putten, K. Zeeb & I. Ekesbo (Eds.): Proceedings of the international congress on applied ethology in farm animals, Skara, KTBL, Darmstadt, Germany, p. 128-134.

Wierenga, H.K., 1991. Behaviour of dairy cows under modern housing and management. Thesis, Agricultural University, Wageningen, The Netherlands.

Behaviour of cows before, during and after milking with an automatic milking system

J. Metz-Stefanowska, P.J.M. Huijsmans, P.H. Hogewerf, A.H. Ipema & A. Keen

DLO Institute of Agricultural Engineering (IMAG-DLO),
P.O. Box 43, 6700 AA Wageningen, The Netherlands

Summary

The behaviour of 13 cows kept in a loose housing system was studied during a period of 18 days, before, during and after milking with an automatic milking system (AMS). The milking robot was accessible through the selection stall during 3 periods each day: 06.00h-10.00h, 10.00h-14.00h, 18.00h-22.00h. Cows that did not come voluntarily to the milking robot were fetched; this happened in 45% of cases. After milking, the cows stayed in the feeding sector. After compulsory milking, the cows that had to be fetched from cubicles did not attempt to compensate for their interrupted lying-down period.

Some relations were found between the number of visits paid by cows to the concentrates dispenser and the type of visit to the AMS (voluntary or fetched) and milking period.

Cows became accustomed to the use of the AMS (the number of voluntary milkings increased during the study), but behavioural features such as shuffling, kicking, position in the milking order remained more or less the same in the course of study.
Keywords: automatic milking, dairy cows, behaviour.

Introduction

Apart from studying various engineering aspects of milking with an automatic oncenmilking system (AMS) (Bottema, 1992; Hogewerf et al., 1992), the behaviour of cows before, during and after the visits to the AMS was investigated. Earlier research on the feasibility of milking in the concentrates dispenser (Rossing et al., 1985) showed that cows varied in the number of visits they paid to the concentrates dispenser: some cows came more frequently than needed, others not frequently enough.

The aim of the study was to analyse the place of voluntary visits to the milking robot within a cow's activity pattern. The behaviour of voluntary milkers was compared with the behaviour of cows that did not come voluntarily. The effect of different intervals between milking periods was taken into account. The other aim of this research was to evaluate the process of cows becoming accustomed to being milked by robot over a period of time. Finally, it was hoped that the study would contribute to optimizing the lay-out of the cowshed containing the robot.

Materials and methods

Thirteen cows (crosses of HF and FH breeds) were milked three times a day with a robot over a period of 18 days, in April 1991. The cows were in the second half of lactation (mean 194th day) with one exception (84th day). Eight cows were in their second lactation, three in their third, one in her fifth and one in her first. The milk yield ranged 15-27 kg per cow per day with an average of 22 kg.

The cows were kept in a compartment of a loose housing system, with 18 cubicles for lying and a separate feeding gate (Figure 1).

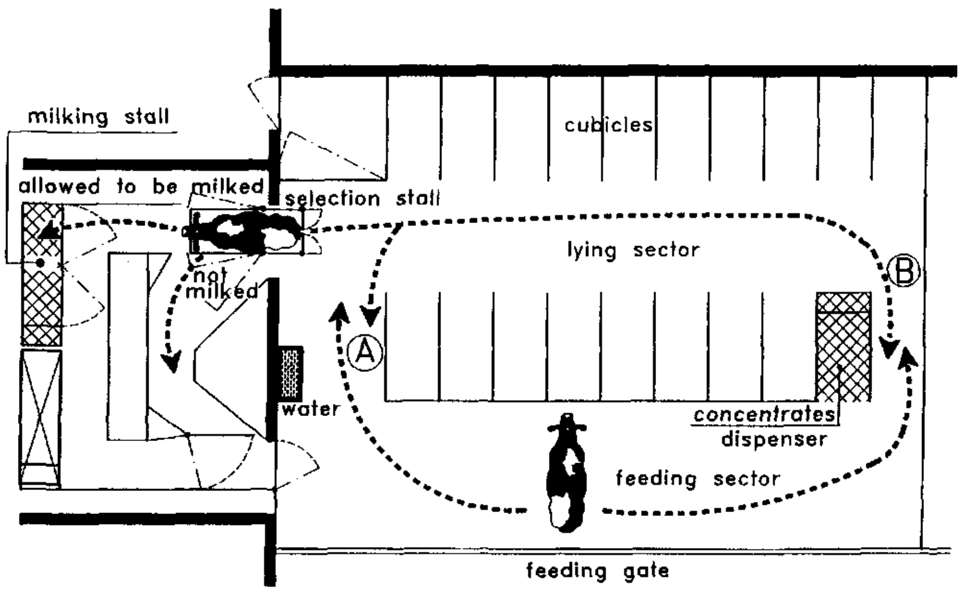


Figure 1. Lay-out of the compartment of the cowshed: left the AMS.

Cows could move freely between the lying and feeding sectors via two passages (A and B). The AMS had an entrance (through a selection stall) in the lying sector and an exit that opened out towards the feeding sector. The concentrates dispenser and watering trough were placed in the feeding sector: the former close to the passage to the lying sector (indicated as B in Figure 1), the latter close to the exit from the AMS.

The automatic milking system was accessible to the cows for three periods every day:

- milking period 1 between 06.00h and 10.00h;
- milking period 2 between 10.00h and 14.00h;
- milking period 3 between 18.00h and 22.00h.

During each milking period each cow was admitted once to the milking robot via the selection stall. Any cow that had been milked but that returned to the selection stall during the same milking period was refused access to the milking stall. She was diverted to the left, back to the feeding sector (Figure 1). Once the milking stall was occupied by a cow the entire system was no longer accessible: the selection stall was closed.

Cows got their concentrates in the milking stall (1 kg per milking) and the remaining portion (varying between zero for two cows and a maximum of 8 kg per day per cow) in the concentrates dispenser in the feeding sector. During the study the concentrates ration was constant. All visits to the selection stall, the milking stall and the concentrates dispenser were recorded automatically.

The behaviour of cows in the cowshed was recorded by video during six days spaced regularly over a period of 18 days. From the video records data about the behaviour of each cow one hour before and one hour after visit to the AMS were analysed; the analysis comprised 234 visits to the AMS. Three categories of behaviour were taken into account: lying in the cubicles, standing in the lying sector (including cubicles) and standing in the feeding sector (standing or eating). All episodes of drinking water were noted.

The behaviour of cows in the milking stall of the AMS was recorded manually during every milking in special protocols (data about 689 cases in 18 days were available). The following elements were distinguished: the place where a cow was fetched for milking, eagerness or hesitation during passing from selection stall to milking stall, quiet standing or restless standing (shifting her weight from one foot to the other = shuffling about) in milking stall during attachment of cluster and milking, episodes of kicking, defecating and urinating, and finally, eagerness/reluctance to leave the milking stall.

"Voluntary" cows are those cows that reported to the AMS during a given milking period and "fetched" cows are those cows that did not appear in the AMS themselves, but had to be brought to the AMS by a stockman before the end of a given milking period. Differences in the number of visits to the concentrates dispenser by the same cows in relation to type of visit to the AMS (voluntary/fetched) and milking period (1,2,3), allowing for random differences between cows and between days, were tested in an unbalanced analysis of variance, with effects modelled on the logarithmic scale as explained in Engel & Keen (1992). Differences in the behaviour of cows in the course of time were tested using the Wilcoxon matched-pairs signed-ranks test (Siegel, 1956). All correlations were calculated according to Spearman (Siegel, 1956).

Results

The number of voluntary visits paid to the selection stall remained at more or less the same level in the course of the study (Figure 2). Cows that most often reported voluntarily at the selection stall had a smaller milk yield (r_s=-0.71, $P \leq 0.01$) and therefore a smaller concentrates ration (r_s=-0.82, $P \leq 0.001$). The visits to the selection stall were followed by milking or diverting a cow to the left if she came more often than once in a given milking period.

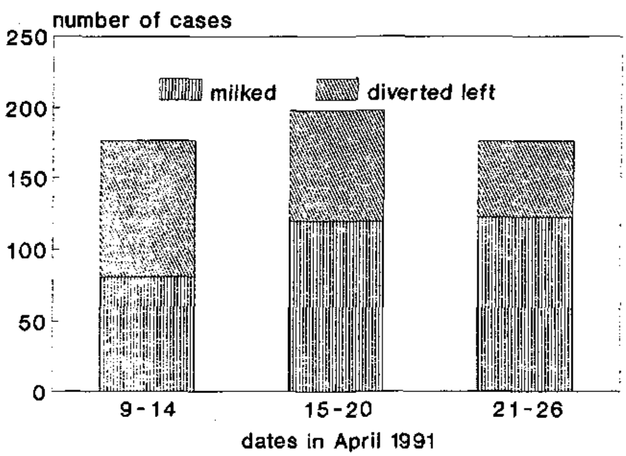


Figure 2. The number of voluntary visits paid to the selection stall in the course of the study.

The number of cows milked voluntarily increased between first and second subperiods ($P \leq 0.05$) and between the first and third ($P \leq 0.01$). The number of cows diverted by the selection stall remained at the same level during first and second subperiods and diminished significantly in the third subperiod ($P \leq 0.05$). An analysis of 13 cows individually about their visits to the selection stall and what happened with them later in the course of the study revealed that:

- five cows had a constant number and proportion of visits followed by milking or followed by diverting left;
- three cows had a constant number of voluntary milkings, but were diverted left much less;
- five cows had a larger number of voluntary milkings, three of them were almost never diverted left, one was diverted left much less, one was diverted left more often.

In milking period 1 cows were voluntarily milked in 63.2% of cases compared with 31.6% and 70.6% respectively in milking periods 2 and 3. During the study the increase in voluntary milking was smallest in milking period 2.

Cows that were milked voluntarily more often during milking period 1 were also more often milked voluntarily in milking period 2 ($r_s = +0.71$, $P \leq 0.01$) and milking period 3 ($r_s \leq +0.87$, $P \leq 0.001$). Cows that came voluntarily earlier during milking period 1 also came earlier during milking period 2 ($r_s \leq +0.77$, $P \leq 0.001$) and milking period 3 ($r_s = +0.76$, $P \leq 0.001$). Cows that were more often voluntarily milked were the same as those who came earlier i.e. had a higher position in the milking order (expressed by number from range 1-13) ($r_s = -0.92$, $P \leq 0.001$). Cows that had a higher number of voluntary milkings were most often diverted left in the selection stall ($r_s = +0.86$, $P \leq 0.01$), because they reported for milking more frequently than necessary.

After milking, in 38% of the cases cows stayed in the milking stall of the AMS and had to be pushed out. This behaviour remained more or less the same throughout the study (no statistically significant differences between three subperiods). Also, no significant relation was found between staying in the milking stall after milking and the number of voluntary milkings ($r_s = +0.24$) or concentrates ration ($r_s = -0.30$).

Cows were fetched most often from the feeding sector, next most often from lying in cubicles (Figure 3). The category "fetching in standing position in the lying sector" was most seldom. In the course of the study fetching declined statistically significantly only from the feeding sector ($P \leq 0.01$).

The behaviour of cows inside the AMS was analysed on the basis of all milkings. Hesitant behaviour while entering the milking stall was observed in 14.2% of cases (it decreased from 20% during the first six days to 10% during the last six days). Shuffling about took place in 13.6% of cases during attempts at automatic cluster attachment and in 12.7% of cases during milking. Kicking occurred in 7.9% of cases during attempts at automatic cluster attachment and in 4.7% of cases during milking. Both types of the above mentioned behaviour stayed at the same level for 18 days and concerned the same cows: seven cows shuffled, four cows kicked.

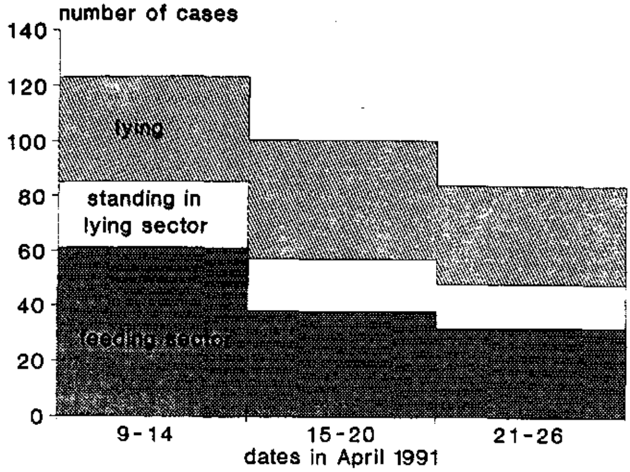


Figure 3. Number of cases cows were fetched for automatic milking in the AMS from different places in cowshed.

Further it was observed that cows defecated during 10.3% of the milkings and urinated during 6.8% of the milkings; this occurred more often during or after fetching. At the beginning of the study cows defecated and urinated more often inside the milking stall: later in the study they tended to do so when they left it.

Figure 4 presents data on the behaviour of 13 cows during one hour before visiting the AMS and one hour after visiting the AMS during six days of observations. During every milking period these 78 cases were divided into voluntary and fetched cows. The proportion of voluntary to fetched cows was almost the same for milking periods 1 and 3; during milking period 2 this was exactly the other way around i.e. fewer voluntary cows. It is striking that in the hour preceding the visit to the AMS cows were often present in the feeding sector. Two out of six situations (milking period 1 for voluntary cows and milking period 3 for fetched cows) deviated: the cows spent less than 50% of their time in the feeding sector in the last hour before milking in the AMS. Because voluntary cows were always milked earlier than fetched cows, a time effect is apparent. After their rest in cubicles, voluntary cows went directly to the AMS after the start of milking period 1. Fetched cows first went to the feeding sector. During the evening milking (period 3) the resting period of some cows was disturbed by fetching, as these cows were in cubicles. Interestingly, after milking the cows remained in the feeding sector in all cases. The fetched cows in the one-hour period after milking did not compensate for their interrupted lying.

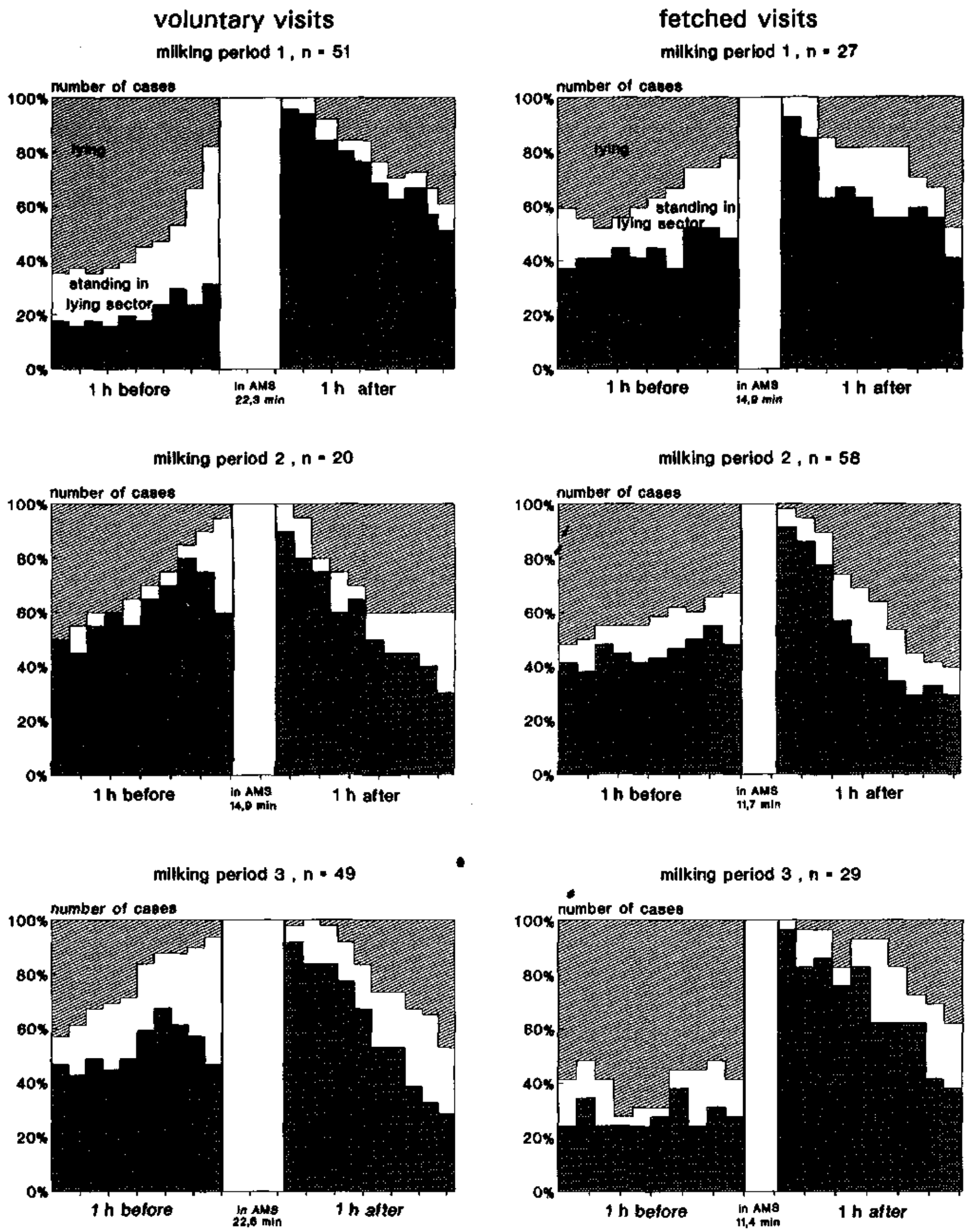


Figure 4. Behaviour of cows 1 hour before and 1 hour after milking in the AMS (from 6 days on video); left-hand graphs: voluntary visits, right-hand graphs: fetched visits.

The activity of cows around the concentrates dispenser in the cowshed during one hour before the visit to the AMS and one hour afterwards was also studied (Table 1).

Table 1. Mean number of visits per cow to the concentrates dispenser and water trough before and after milking in the AMS (from 6 days video) as estimated by the analysis of variance.

	Before AMS		After AMS	
	voluntary cows	fetched cows	voluntary cows	fetched cows
Concentrates dispenser				
milking period 1	0.37^{a}	0.82^{b}	0.77	0.82
milking period 2	1.52^{c}	0.70^{b}	0.57	0.67
milking period 3	0.53^{ab}	0.48^{ab}	0.93	0.85
Visits to the water through all periods together	0.12^{A}	0.14^{A}	0.38^{B}	0.35^{B}

a,b,c statistically significant difference ($P \leq 0.05$)
A,B statistically significant difference ($P \leq 0.01$)

The same six days were chosen for analysis as those discussed above. It was decided to look at all visits together (rewarded + unrewarded) to examine the cows' activity for the following reasons: the type of visit to the AMS may depend on the reward (or lack of reward) in the concentrates dispenser, and only 6 hours of data (i.e. 1 hour before and 1 hour after each milking) were used. These figures were corrected for differences in the number of voluntary and compulsory visits paid by the same cows. The analysis of variance revealed that there were no differences between days and that individual behaviour was rather consistent. Statistically significant differences in the numbers of visits to the concentrates dispenser were found between voluntary and fetched cows only before visiting the AMS: there were differences in milking periods 1 and 2. For voluntary cows the number of visits before milking in period 2 deviated from the other two periods. The number of visits to a concentrates dispenser after milking in the AMS seems not to be related to the type of visit and to the milking period. The correlation between the number of visits to the concentrates dispenser during one hour before milking in the AMS and the number of compulsory milkings was $r_s = +0.78$ ($P \leq 0.01$) and was $r_s = +0.72$ ($P \leq 0.01$) between the number of compulsory milkings and the number of visits to the concentrates dispenser during one hour after milking in the AMS. These correlation coefficients were not statistically significant for voluntary visits.

During all three milking periods all cows drank water more frequently in one hour after milking than in one hour before milking ($P \leq 0.01$).

Discussion

The number of voluntary milkings in the AMS increased during the course of the study. Cows became accustomed to using the system (decrease in fetching), understood it better (less fetching from feeding sector, less diverting to the left in selection stall) and felt more comfortable (less hesitation when entering, defecation inside milking stall at the beginning of study, later during leaving). Nevertheless, cows showed individual features such as: shuffling about, kicking, milking order. This behaviour remained constant throughout the 18 days. A fixed order during milking seems to be useful for milking with a robot, since cows are expected to report at a definite times. According to Rathore (1982) the milking order of cows in a milking parlour is connected with milk yield; cows with a higher milk yield are first in the queue for milking.

In our study cows with a smaller (none) concentrates ration in the concentrates dispenser and smaller milk yield visited the selection stall most frequently. These cows were apparently most motivated to go to the AMS to get their reward there. In a group of 36 cows using two concentrates dispensers Metz & Spahr (1989) found that when a cow received no reward in one of the two feeders the next visit was most likely to the other feeder. When a visit was rewarded, the probability of a second visit to one of the two feeders was equal. In the other study on the use of the selection stall as an admission place to the concentrates dispenser for dry cows being given the same reward Metz et al. (1989) reported that some cows came to the selection stall particularly often and this behaviour was repeated in subsequent days. It can be concluded that cows are motivated to get concentrates as reward, but there is variation in the number of attempts to get a reward and this variation is individually determined (a fairly constant level of attempts on consecutive days).

Table 1 should be considered together with Figure 4. The differences in behaviour between the type of visit to the AMS were observed in the one-hour period prior to milking. They reflect the milking schedule. In the morning when the AMS started to be occupied by voluntary milkers, other cows were more frequently present in the feeding sector and paid more visits to the concentrates dispenser. In the period prior to the second milking, voluntary cows were more often present in the feeding sector and paid more visits to the concentrates dispenser than fetched cows. Before the third milking voluntary cows were more frequent in the feeding sector than fetched cows, but the number of visits paid to the concentrates dispenser was more or less equal for all cows. Differences in behaviour could be partly explained by the fact that the milking robot was not continuously accessible. Nevertheless the problem of fetching cows remains. One option might be to select them in the feeding sector before the offering of concentrates; this means creating a new milking order. Voluntary cows would still be expected to come because they paid extra visits to the selection stall.

In our research it was striking that after milking (regardless of type and time of milking) cows stayed in the feeding sector. Thirty minutes after milking at least 50% of the cows were still present in the feeding sector. Metz et al. (1987) reported on the increase in feeding activity of cows after milking. Shultz (1985) found that an over-abundance of feed accessible to the cows after milking reduced the cow's need to lie down after milking. This had a positive effect on the health of the udder, because teats closed without contact with bedding.

After milking in the AMS and the intake of 1 kg of concentrates, all cows visited the watering trough more frequently than before milking. We found that the habit of drinking water after an intake of concentrates or during/after eating forage remained unchanged despite structural changes introduced in the cowshed (unpublished data).

Cows kept in one group eat or lie down together during some periods of the day more than in the other periods. This is often caused by a constant regime of feeding or milking. Metz et al. (1987) described the daily pattern adopted by cows kept in three situations with various levels of automation. The group of cows without automation and with constant feeding and milking times showed the largest variation in their daily pattern. The group of cows with automated forage supply and milking in the concentrates dispenser throughout the day showed a more smooth daily pattern; the activities of individual cows were more spread over the day. It is not clear how far a cow kept in an automatic system remains dependent on the group or how far she follows her own rhythm. Automatic individual feeding and milking demands more individual behaviour from the cow. The question about the welfare of the cow kept in automatic system also remains open.

Conclusions

1. Cows are able to use the AMS voluntarily and they become accustomed to it.
2. The problem of "fetching" cows might be solved in some way by rewarding them with concentrates, but at least no earlier than in the selection stall.
3. The relationship between milking, eating and drinking suggests that the automatic milking system should be sited in the feeding sector.

References

Bottema, J., 1992. Automatic milking: reality. In: A.H. Ipema, A.C. Lippus, J.H.M. Metz & W. Rossing (Eds.): Proceedings of the International Symposium on Prospects for Automatic Milking. EAAP Publication No. 65, Pudoc Scientific Publishers, Wageningen, The Netherlands, p. 63-71.

Engel, B. & A. Keen, 1992. A simple approach for the analysis of generalized linear mixed models. GLW-DLO, Wageningen, The Netherlands. Research Report LWA-92-6 (in press).

Hogewerf, P.H., P.J.M. Huijsmans, A.H. Ipema, T. Janssen & W. Rossing, 1992. Observations of teat cup attachment in an automatic milking system. In: A.H. Ipema, A.C. Lippus, J.H.M. Metz & W. Rossing (Eds.): Proceedings of the international symposium on prospects for automatic milking. EAAP publication No. 65, Pudoc Scientific Publishers, Wageningen, The Netherlands, p. 80-90.

Metz, J., H.K. Wierenga & A.H. Ipema, 1987. Verhalten von Kühen beim automatischen Füttern und Melken. KTBL-schrift no. 319, p. 138-154.

Metz-Stefanowska, J., H.G. Pluijgers, W. Rossing & C.C. Ketelaar-de Lauwere, 1989. First experiences with the use of a selection unit for dairy cows. IMAG, Wageningen, The Netherlands, Report 113, 21 pp.

Metz-Stefanowska, J. & S.L. Spahr, 1989. Behavioural observations on a group of cows using a dual computer-controlled concentrates dispenser. IMAG, Wageningen, The Netherlands, Report. 89-1, 23 pp.

Rathore A.K., 1982. Order of cow entry at milking and its relationships with milk and consistency of the order. Applied Animal Ethology 8:45-52.

Rossing W., A.H. Ipema & P.F. Veltman, 1985. The feasibility of milking in a feeding box. IMAG, Wageningen, The Netherlands, Report 85-2, 39 pp.

Shultz, T.A., 1985. Feeding affects post-milking cow activities. California Agriculture, November-December:29-30.

Siegel S., 1956. Nonparametric statistics for the behavioural sciences. McGraw-Hill, New York, USA, 312 pp.

Feeding strategies and automatic milking

H. Pirkelmann

Technical University of Munich, Vöttinger Straße 36, D-8050 Freising-Weihenstephan, Germany

Summary

With suitable strategies for feeding management an important contribution can be made to the realization of automated milking. In general there should be a regular daily rhythm in feed consumption in order to obtain the necessary milking frequency. Based on results of feeding experiments, this aim can be achieved both by feeding roughage and concentrates. Milking stations in the area where there is access to roughage require changes in cowshed layout. In contrast to this, combining concentrates feeding and milking in one station allow a greater flexibility in arrangements.
Keywords: feeding strategy, automatic milking station, milking frequency.

Introduction

Automatic milking requires that the cows visit the milking station voluntarily. Because the cows should be milked several times a day they have to be incited to come to the milking place. Feeding offers a good way of meeting this goal, because eating is an elementary function in animal behaviour and influences purpose-orientated movement. Ration composition and feeding strategy can affect the daily rhythm of feed intake. Furthermore equipment combining the functions of feeding and milking have to be integrated into complete housing systems.

General demands

Apart from relieving the work load, automatic milking has the goal to achieve the better adaptation of the milking process to the physiological conditions of milk production in the udder and to improve udder health (Rabold, 1990). As a result milking has to be done several times a day and spread equally throughout the day. The milking rhythm determined by the animal and the frequency desirable should be evaluated according to yield and must not disturb other operations in the cowshed.

General requirements are:

- feeding according to yield has to be ensured by ration composition and feed intake.
- the milking station has to be visited by all lactating cows independent of milk yield level and social ranking in order to achieve the 2-4 milkings a day desired (Rossing, 1990).
- for economic reasons the number of cows per milking station should be as high as possible in order to utilize the high investments in technical equipment.

For the evaluation of feeding strategies which correspond to combined techniques in feeding and milking, reference can be made to the extensive literature available on feed consumption of dairy cows (Kirchgeßner & Zchwarz, 1984; Kempkens, 1989; Pirkelmann, 1990). All the components of the feed must be considered in this respect. Roughage as well as concentrate feeding open up various possibilities for influencing the animal's behaviour.

Influence of roughage feeding

If cows have free access to roughage they will, on average, consume it some 7 to 10 times a day. In this context, the energy content is only of marginal importance. In a herd subdivided into three groups according to daily milk yield, the frequency and time of consumption did not change significantly with increasing energy content (Figure 1).

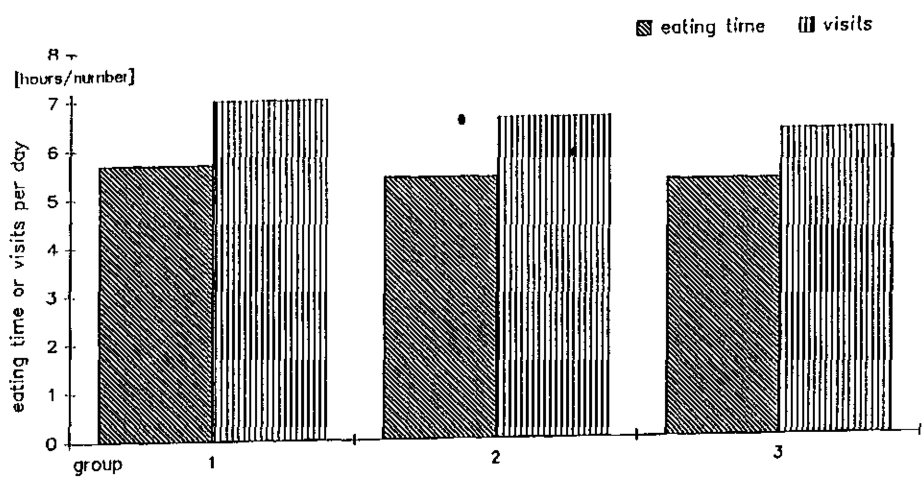


Figure 1. Duration and number of periods of roughage intake in a group feeding system for dairy cows.

The rhythm of consumption is influenced by the frequency of feed allotment. When the feed is given more frequently, it leads to strong periodicity and a synchronization of herd behaviour during feeding times. If the ration is given only once a day, the feeding area is used more constantly (Pirkelmann, 1990). It is only during the night, mostly between 2 am and 5 am, that there is a distinct resting period (Figure 2).

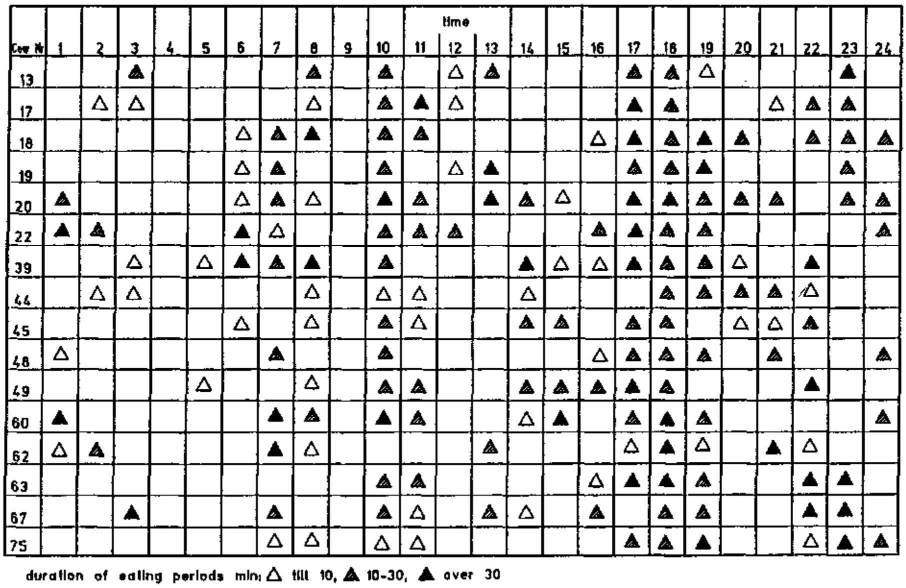


Figure 2. Eating behaviour of cows with feed intake (mixed ration).

This relatively regular daily rhythm offers good opportunities for automated milking. However, it must be noted that it is not possible to combine roughage feeding with the milking station, because only three cows can be fed at one eating place. In case of more cows per feeding place the roughage intake might be reduced.

Furthermore, there should be a separation- and milking unit at the entrance to the feeding area. A proposal for the layout of such a cowshed is shown in Figure 3. On the way from the lying to the feeding area the cows, grouped according to yield, pass through a separation gate. If the computer decides that the cow should be milked, it opens the entrance to the milking station. If it is not milking time or the station is already in use, direct access to the feeding area is given. It is possible to get back to the lying area by passing separate one-way entrances.

To ensure a safe recording of every cow, the number of cows in one group must correspond to the capacity of the milking station. If it is required, the station can be used with or without a concentrate feeding system.

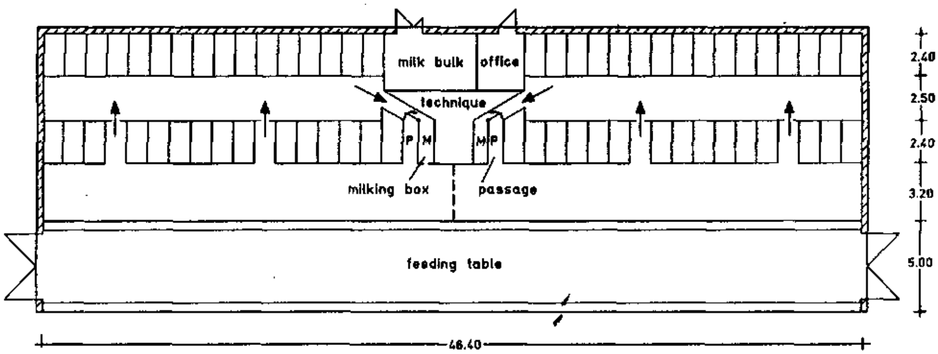


Figure 3. Proposal for locating the milking box at the entrance to the feeding area.

Combination of concentrate feeding and milking station

Where concentrates are concerned the aim is to organize a combined station for feeding and milking. Using the comprehensive investigations which have been made on animal behaviour in concentrate feeding stations it can be stated that, given that installation and maintenance are carried out properly, feed will be taken without problem (Kempkens, 1989; Wierenga & Hopster, 1991). Apart from the number of animals per station, the feeding programme is one of the factors that influences daily rhythm and frequency of visits strongly. Variable time programmes with low minimum dispensing amounts cause very regular occupation of the feeding stations during the day, but they lead to a high number of unnecessary visits and high activity. In contrast to this, fixed time programmes with only a few intervals result in periodic visits and cows crowding in front of the station at the beginning of each interval.

When the amount in the minimum feed portion is increased within the variable time programme and if the number of intervals in the fixed time programme are also increased, the above mentioned differences will nearly be compensated and the two systems will give similar results.

The frequency of visits can also be effected by the programmed amount of concentrate. Referring the author's own experiments, animals without, or with only a right to very small amounts of concentrate, do not come into the feeding station in a regular way and sometimes they do not enter it at all (Figure 4). Hence it is necessary to compensate the interruptions in milking: a minimum amount of about 2 kg of concentrate should be given. At the end of lactation effects of overfeeding can be compensated by group feeding of roughage. The energy content of the basic ration for the low-yielding group must be adjusted, so that the amount of concentrate which is necessary for milk production does not lead to overfeeding.

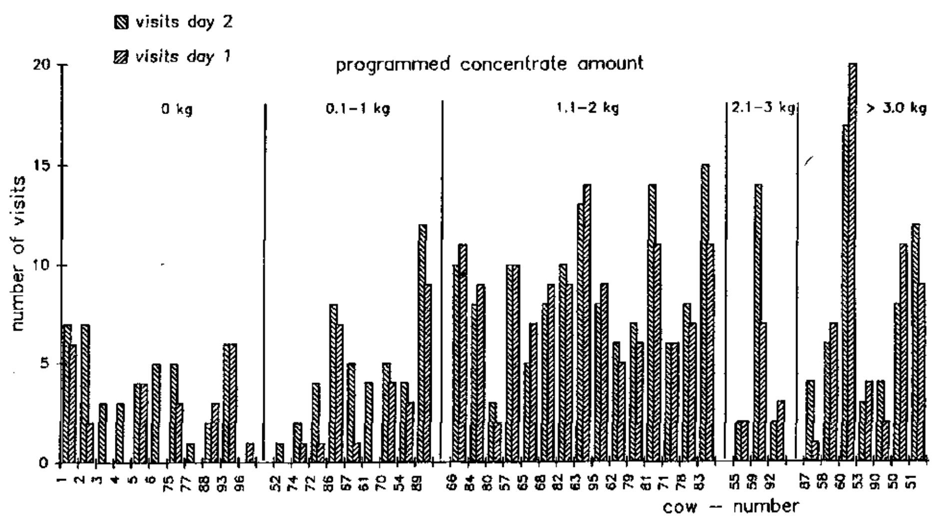


Figure 4. Frequency of visits to the stations of an automatic concentrate feeder.

The addition of concentrates to the roughage for high yielding cows in group feeding can relieve the concentrate feeding station and also promote the milking process because the frequency of visits is more regular. Grouping of the herd is possible by means of electronic animal identification and computer controlled selection gates (Pirkelmann & Wendl, 1988).

The location chosen for the feeding stations is of great importance in the whole process. To avoid crowding of cows, often resulting in fights, a remote location for the concentrate feeding station is recommended. Where the concentrate feeding is combined with milking, however, a central position for the station is necessary. To avoid disturbances in animal behaviour, the station should be located at a place where the access area is sufficiently large. The waiting animals then cannot block the entrance. For an uninterrupted change of cows, a walk-through box with separate entrance and exit is preferable to a "blind" box (Artmann, 1990). After being fed concentrates, the animals very often drink water (Kempkens, 1989). The watering trough should be placed in a remote location so that when the cows leave the station they are led relatively far away from it. This effect is assisted by roughage given ad lib. It results in an regular visit to the feeding area and helps to avoid periodic crowding in front of the concentrate feeding station. An example of a possible layout of a cowshed is shown in Figure 5. Adaptation is possible in all types of loose housing systems. The combined stations for feeding and milking have to be equipped with computer controlled entrance and exit gates.

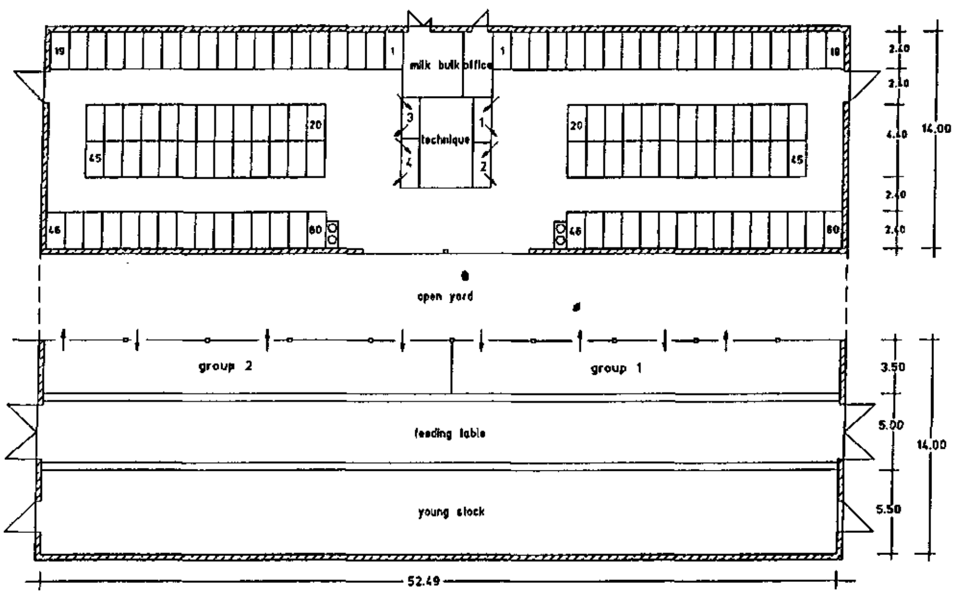


Figure 5. Proposal for a loose housing system with boxes for combined concentrate feeding and milking.

Conclusions

Feeding as a very important factor influencing the behaviour of dairy cows, can be a valuable aid to steering the cows in automated milking. Roughage as well as concentrates are suitable for inciting cows to visit the milking station regularly. However, the design and the feeding combination differ.

- Where roughage feeding is concerned the milking stations have to be situated on the way from the lying area to the feeding area. A separation gate leads the cows to the milking station or directly into the feeding area through a bypass.
- Where concentrates are concerned combined stations for concentrate feeding and milking are used.
- Taking into consideration eating frequency and time needed for feed intake and milking (including ineffective times) 25 - 30 cows can be milked when these methods are employed.

References

Artmann, R., 1990. Konzepte und Entwicklungen zur Automatisierung des Melkens. In: Robotereinsatz in der Landwirtschaft am Beispiel des Melkens; Tagung Braunschweig-Völkenrode. VDI/MEG Kolloquim Landtechnik, Düsseldorf, Germany 9:45-69.

Kempkens, K., 1989. Der Einfluß von Kraftfutterabruffütterung und Grundfuttervorlage auf das Verhalten von Kühen im Liegeboxenlaufstall. MEGSchriftenreihe, 170.

Kirchgeßner, M. & F.J. Schwarz, 1984. Einflußfaktoren auf die Grundfutteraufnahme bei Milchkühen. Übersicht Tierernährung 12:187-214.

Pirkelmann, H., 1990. Verfahren der Milchviehfütterung. RKL Schriftenreihe, p. 1060-1130.

Pirkelmann, H. & G. Wendl, 1988. Elektronikeinsatz zur leistungsgerechten Milchviehfütterung. Landtechnik 44(Sonderheft):383-387.

Rabold, K., 1990. Ergebnisse von Simulationsstudien zum automatisierten Melken. In: Robotereinsatz in der Landwirtschaft am Beispiel des Melkens; Tagung Braunschweig-Völkenrode. VDI/MEG Kolloquim Landtechnik, Düsseldorf, Germany 9:228-239.

Rossing, W., 1990. Entwicklungen beim automatischen Melken. In: Robotereinsatz in der Landwirtschaft am Beispiel des Melkens; Tagung Braunschweig-Völkenrode. VDI/MEG Kolloquim Landtechnik, Düsseldorf, Germany 9:202-211.

Wierenga, H.K. & H. Hopster, 1991. Timing of visits to the concentrates feeding station by dairy cows In: Behaviour of dairy cows under modern housing and management, IVO-DLO, Zeist, The Netherlands, Report B-366.

4. Herd management

Scope of management and management decisions

A.A. Dijkhuizen*, R.B.M. Huirne* & J.B. Hardaker**

* *Wageningen Agricultural University, Department of Farm Management, Hollandseweg 1, 6706 KN Wageningen, The Netherlands*
** *University of New England, Department of Agricultural Economics & Business Management, Armidale, Australia*

Summary

Good management is essential for efficient operation of any farm, but the concept of management is nebulous and difficult to define. Therefore, scope of management and management decisions are discussed first in relation to the three major management functions: planning, implementation and control. Then management information systems are described, with special attention to decision support and expert systems. Finally, concepts of decision theory are presented, providing a helpful procedure for rational decision making. Moreover, the theory makes it possible to determine the economic value of additional information (e.g. to be obtained through automatic milking systems), as illustrated in an example.
Keywords: management, information systems, decision analysis, value of information

Introduction

Management is becoming increasingly important in today's livestock farming. It can be described as the decision-making process in which limited resources are allocated to a number of production alternatives (Kay, 1986). This allocation of resources should be organized and operated in such a way that the farmer's goals and objectives are achieved. Goals are considered to be more general statements and refer to the end point of all efforts in management; objectives are more specific and refer to activities to reach goals (Harsh et al., 1981).

According to Simon (1977), the decision-making process can be divided into three major phases:

- intelligence;
- design;
- choice.

Intelligence involves searching the environment for conditions asking for decisions. Data (are processed and examined to identify problems or opportunities. In the design phase possible courses of action are invented, developed and analyzed. This involves processes for understanding the problem, for generating solutions and for testing solutions for their feasibility. Choice, as the last phase of the decision-making process, involves selecting a particular course of action. There is a flow of action from "intelligence" to "choice", but at any phase there may be a return to a previous one.

To carry out different management activities within a farm operation successfully, the farm manager must have analytical experience and access to data in the different areas of farm management (Boehlje & Eidman, 1984), including:

- production;
- marketing;
- finance.

Production is the most obvious area of responsibility for the farm manager. Plans must be made and implemented, utilizing information on production efficiency and input-output relationships from numerous physical and biological sciences. A combination with price and cost information makes it possible to determine the profitability of alternative plans. Farmers, however, must not only produce their products efficiently, but they must also buy the inputs and sell the products in a way and at prices that result in a profit. Moreover, financial funds need to be available and committed to the various requirements (e.g., for automatic milking systems). It is the farm manager who should be able to integrate the various areas properly to achieve maximum overall results.

Farm management is commonly considered a difficult and complex task, especially because it has to be performed under imperfect knowledge of most biological and economic aspects under consideration (Anderson et al., 1977). A farmer's success, therefore, depends strongly on the ability to deal with these uncertain conditions. Within this scope, some common concepts of management and management decisions will further be discussed in the paper.

Management functions and management cycle

Three basic functions of farm management are to be considered (Boehlje & Eidman, 1984):

- planning;
- implementation;
- control.

Essentially, planning involves selecting a particular strategy or course of action from various alternatives. It is the systematic design to direct future activities based on available knowledge, deciding in advance "what to do, how and when". Implementation is the process of acquiring the resources needed and putting the chosen plan into action. Control involves measuring performance and comparing it to standards. Because of the many uncertainties in agricultural production, deviations always exist. Huirne (1990), therefore, developed the concept of relevant deviations, taking into account both economic and statistical importance.

Corrections of deviations between performance and standards takes place in the next management cycle. Corrective actions should first be planned, and then be implemented. In the control phase, it is important to check whether previous corrective actions had the desired effect on performance. This cyclical nature of the management process is illustrated in Figure 1.

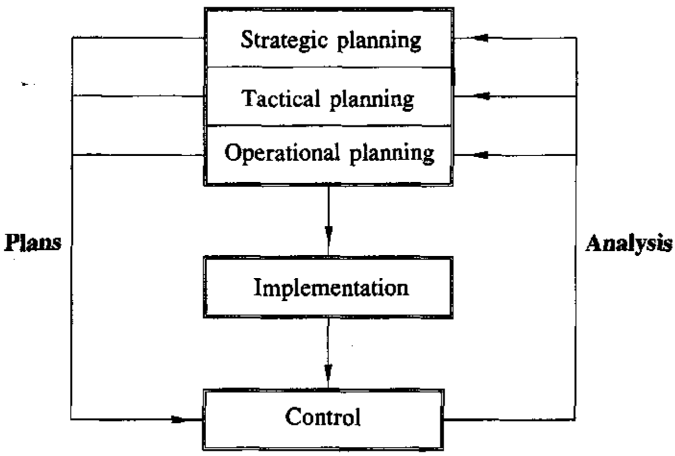


Figure 1. The management cycle.

Depending on the planning horizon, strategic, tactical and operational planning may be considered. Strategic planning results in a long-term plan (more than one year), which includes the plan for farm structure. Whether or not to invest in and start with automatic milking is an example of this type of decision. Tactical or medium-term planning (one year, one season) is carried out inside the scope set by strategic planning. It involves planning to obtain optimal results within the given or proposed farm structure (e.g. herd replacement policies). During operational or short-term planning (weeks), a more detailed plan is introduced from the tactical plans, depending on the actual situation on the farm (e.g. decisions on insemination and/or mastitis treatment of individual cows). Data obtained through an automatic milking system may be made available and appropriate for both tactical and operational planning decisions. Results of control may lead to new strategic, tactical and operational plans, stressing the on-going and cyclical nature of the management process.

Management information systems

Computers play an increasingly important role in modern livestock farming. Their technology is now more powerful, accessible and affordable than ever before, and still on the increase. Automatic milking is, from a management point of view, an important feature that will further increase the amount of animal- and farm-specific data to be used in management control and planning. The current challenge in farm management is to transform these data into information, suitable for use in the decision-making process (Eleveld et al., 1991).

Dannenbring & Starr (1981) classify the wide variety of computer systems that encompass collection, maintenance, and use of information for organizational purposes as management information systems (MIS). Davis & Olson (1985) define a management information system more precisely as an integrated, user-machine system for providing information to support operations, management, and decision-making functions in an organization. The system utilizes computer hardware and software; manual procedures; models for analysis, planning and control and decision making; and a database.

Within the broad term of MIS, two important types of systems are commonly considered:

- decision support systems (DSS);
- expert systems (ES).

A DSS is an MIS application that supports the process of making decisions (Huirne, 1990). It allows the decision maker to retrieve data and test alternative solutions during the process of problem solving, and incorporate a variety of - optimization and simulation - models. These models do not actually take decisions, but are primarily aimed at ranking the available alternatives. Highly repetitive decisions can frequently benefit from DSS. If the basic decision process is the same each time, a model can be made to fit the process, even for a single decision maker. Potential benefits of such systems are faster decision making, improved consistency and accuracy, and improved methods for analyzing and solving problems (Keen, 1986).

An ES is a different class of MIS applications. As defined by Waterman (1986), an ES is a computer program using expert knowledge to attain high levels of performance in a narrow problem area. An ES typically represents knowledge symbolically, and examines and explains the reasoning process. At each stage of the reasoning process, an ES is able to give information about what assumptions it is following, why it has chosen the method it is pursuing, to what conclusions it has already come, and how it has reached these conclusions. The type of knowledge to enter into an ES is not necessarily restricted to that of human experts, but can also come from textbooks, reports, databases, and optimization or simulation models. That is why ESs are also called knowledge based systems (Turban, 1990).

Current commercialized systems for providing information to farmers usually do not go far beyond the traditional record-keeping approach (Jalvingh, 1992). They embody the registration of data on production levels, quantities and prices of inputs and products, and/or on farm costs and returns. Although often called MIS, these systems do not fit the above definition, because:

- there is no concept of an integrated system;
- they do not use models.

Many research activities are under way world wide to extend and integrate these systems with both expert system types of models, often focused on data analysis, and dynamic optimization and simulation models, primarily aimed for planning support. A variety of these focused on dairy herd management are presented and published in the proceedings.

Decision making under uncertainty

Even with advanced information systems available, farm managers seldom, if ever, will have complete knowledge of the input-output relationships and prices involved in making decisions. Following Knight (1921), some authors have distinguished two types of *imperfect knowledge - risk, when the probabilities of the uncertain outcomes* are known, and uncertainty, when they are not. However, this distinction is of little practical use and is discarded by most analysts today. Probabilities can be "known" in the sense implied by Knight only for stationary stochastic processes, i.e., for those sorts of events where there is variability but where the sources and nature of the variability remain constant through time. Such processes are rare in practical decision making (Hardaker, 1982).

One of the most widely applied models for studying decision making under risk is the subjective expected utility (SEU) model (Anderson et al., 1977). The model is used to order actions according to the beliefs and risk attitude of the decision maker. Each outcome is assigned a utility value (i.e., preference), according to a personalized, arbitrarily-scaled utility function. The utility value for each possible outcome of an action is weighted by its (subjective) probability and summed. The resulting expected utility is a preference index for that action. Actions are ranked by their level of expected utility with the highest value being preferred.

Farmers' attitudes toward risk vary depending on their objectives and financial resources, for instances, with most of them, like other people, tending to be risk averse (Hardaker, 1982). The implementation of the SEU-model requires that both the probability distribution of outcomes and the risk preferences of decision makers (i.e., the utility function) be known. Especially utility functions are not always easy to elicit, however. Many authors, therefore, have suggested alternative rules that might be used, leaving it to the individual decision maker to decide what criterion is the most appropriate given his/her own specific situation (Barry, 1984).

A first group of criteria includes those that do not require probability estimates. Within this group *maximin* is a criterion that implies a very pessimistic or conservative risk attitude. Each action is judged solely on its worst outcome, with the one that maximises the minimum gain being selected. A second criterion in this group is *minimax regret*, and similar to the previous one but is based on the proposition that the "correctness" of a decision should be measured by the amount by which the outcome could have been increased had the decision maker had perfect fore-knowledge. The action with the smallest maximum increase (i.e., regret) is then chosen. A third criterion, *maximax*, simply amounts to scanning the outcome matrix to find its most desirable payoff and then taking the corresponding action. This is a totally optimistic criterion, and very much the approach of a pathological gambler.

A first example of criteria that include more than one single value of the outcome distribution (and, therefore, do require probability estimates) is called the *Hurwicz α index rule*. It allows for a weighted average of the minimum and maximum outcome per action, and then selects the action with the highest weighted average. In formula:

$$\text{Max } [I_j = \alpha(M_j) + (1\text{-}\alpha)(m_j)],$$

where α is supplied by the decision maker subject to $0<\alpha<1$, M_j equals the maximum gain of action j, and m_j equals the minimum gain of action j. A second one is commonly referred to as *Laplace principle of insufficient reason*. By this criterion the action with the highest expected outcome is selected, with the expected value based on equal probabilities for all of the outcome. Unlike all the previous criteria account is taken of the outcomes for all events, but the possibility that one event may be (considered) more likely than another is ignored. The probably most widely used criterion in this respect is called *Expected Monetary Value*, and is defined as the summation of the possible levels of outcomes multiplied by their probabilities. If there are m possible states for the j^{th} action with the i^{th} state denoted Θ_i, having outcome O_{ij} and probability P_i, then the expected monetary value of the outcome is given by:

$$E(O_j) = P_1O_{1j} + P_2O_{2j} + \ldots + P_mO_{mj} = \Sigma P_iO_{ij}$$

It assumes that the decision maker's satisfactory is measured by the level of profit, which in fact is a special linear case of the more general expected utility model (i.e., assuming risk neutrality of the decision maker).

None of the previous criteria, however, accounts for any "utility-based" trade-off between the average outcome of each strategy and its variance. Moreover, many of the less advanced criteria (such as maximin or minimax) are considered not to be appropriate from a theoretical point of view (Officer & Anderson, 1968). That is why stochastic efficiency criteria (the third group to be considered) are proposed as a useful alternative, at least for cases where probabilities are reasonably well defined. These criteria are implemented by pairwise comparisons of cumulative distribution functions of outcomes resulting from different actions. Stochastic efficiency rules satisfy the axioms of the SEU-model but do not require precise measurement of risk preferences. However, as opposed to the complete ordering achieved when risk preferences are precisely known, they provide only a partial ordering (King & Robinson, 1984). User-friendly software has become available to make the application of this type of advanced criteria much more easier (Goh et al., 1989).

Determining the economic value of additional information

One of the benefits of automatic milking equipment may be the availability of additional information for use in herd health and production management (Dijkhuizen, 1992). Formally stated, this type of improved information would imply a revision of the (prior) probability distributions under consideration, taking into account the accuracy of the prediction. Such probability revisions can be accomplished in a logically and mathematically correct manner by applying Bayes' theorem (Anderson et al., 1977). Through this theorem prior probabilities, $P(\Theta_i)$, can be combined with the accuracy of the prediction, $P(z_k \mid \Theta_i)$, to estimate posterior probabilities, $P(\Theta_i \mid z_k)$. The posterior probabilities indicate the probability that an event will occur given the prediction that has been made. In these terms the discrete form of Bayes' theorem may be expressed as:

$$P(\Theta_i \mid z_k) = \frac{P(\Theta_i)P(z_k \mid \Theta_i)}{\Sigma_i P(\Theta_i)P(z_k \mid \Theta_i)} = \frac{P(\Theta_i, z_k)}{P(z_k)}$$

This formula provides a procedure to determine the economic value of additional information, as illustrated by the following example.

Example

Consider a simplistic case in which a farmer can choose between two mastitis control programs, a_1 and a_2. The payoff of the programs are expected to differ according to the seriousness of the actual mastitis situation in the herd. This "without" situation can either be good or bad, with an estimated prior probability of 0.5 each. Results are summarized in Table 1.

When taking into account the widely used mean outcome (i.e., expected monetary value) to compare the alternatives, program a_2 is the preferred choice, as shown in Table 1. This choice, however, does not hold for the situation should mastitis turn out to be good, making it a classical example of risky choice.

Table 1. Payoff matrix for two mastitis control programs.

States (Θ_i)	P(Θ_i)	Program a_1	Program a_2
Mastitis good (Θ_1)	0.5	$ 1 000	$-10 000
Mastitis bad (Θ_2)	0.5	$ 7 000	$ 20 000
Expected monetary value		$ 4 000	$ 5 000

Now suppose additional information is available to better predict the actual mastitis situation in the herd. The accuracy of the prediction is assumed to be 70% in the case of "mastitis good", and 80% when "mastitis bad". This information makes it possible to revise the prior probabilities into posterior probabilities, as carried out in Table 2.

When using these revised probabilities (Table 2) to re-calculate the maximum expected monetary value, the outcome is EMV($a_1 \mid z_1$) = $ 2332 and EMV($a_2 \mid z_2$) = $ 11810, respectively. This leads to a weighted average of 0.45 × $ 2332 + 0.55 × $ 11810 = $ 7545, compared to a maximum of $ 5000 in the initial situation (Table 1). The economic value of the additional information in this example, therefore, turns out to be $ 2545. A 100%-accurate (perfect) prediction would even yield a value of 0.50 × $ 1000 + 0.50 × $ 20000 - $ 5000 = $ 5500. The approach is flexible enough to include more realistic cases and better estimates when available.

Table 2. Revising the probabilities (i.e., prior × accuracy / P(z_k)).

States (Θ_i)	P($\Theta_i \mid z_1$)	P($\Theta_i \mid z_2$)
Mastitis good (Θ_1)	.5x.7/.45=.778	.5x.3/.55=.273
Mastitis bad (Θ_2)	.5x.2/.45=.222	.5x.8/.55=.727
P(z_k)	.45	.55

Final remarks

A critical aspect of management is making good decisions. According to Boehlje & Eidman (1984) decision making can best be accomplished by working out Simon's (1977) three major phases, mentioned before, into the following five-step procedure:

- define the problem or opportunity;
- identify alternative courses of action;
- gather information and analyze each of the alternative actions;
- make the decision and take the action;
- accept the consequences and evaluate the outcome.

To implement the decision-making process in the context of managing a farm, the manager must integrate knowledge from many areas including accounting and information systems, economic theory, biological sciences and processes, psychology and sociology, law and political science, and mathematics and statistics. It is a challenge for all disciplines involved to find out what information is really important to farmers, i.e., will influence the outcome of their decision-making process, instead of simply increasing the amount of data that can be made available through advanced equipment and computer technology.

Decision analysis is considered a worthwhile approach for ensuring that individual farmers get advice and make decisions which are consistent with their personal beliefs about the risks and uncertainties surrounding the decision and with their preferences for the possible outcomes. Of course, a good decision does not guarantee a good outcome. But it does assure that the decisions are the best possible given the available information.

References

Anderson, J.R., J.L. Dillon & J.B. Hardaker, 1977. Agricultural decision analysis. Iowa State University Press, Ames, USA, 344 pp.

Barry, P.J. (Ed.), 1984. Risk management in agriculture. Iowa State University Press, Ames, USA, 282 pp.

Boehlje, M.D. & V.R. Eidman, 1984. Farm Management. John Wiley and Sons, Inc., New York, USA, 806 pp.

Dannenbring, D.G. & M.K. Starr, 1981. Management science. An introduction. McGraw-Hill, New York, USA, 763 pp.

Davis, G.B. & M.H. Olson, 1985. Management information systems. Conceptual foundations, structure, and development. McGraw-Hill, New York, USA, 693 pp.

Dijkhuizen, A.A., 1992. Modelling animal health economics. Inaugural speech, Wageningen Agricultural University, Wageningen, The Netherlands, 28 pp.

Eleveld, B., R.B.M. Huirne & A.A. Dijkhuizen, 1991. Integrated information technology in farm management. Proceedings 26th EAAE Seminar, Grignon, VI.1, p. 1-13.

Goh, S., C.C. Shih, M.J. Cochran & R. Raskin, 1989. A generalized stochastic dominance program for the IBM PC. Southern Journal of Agricultural Economics 175-182.

Hardaker, J.B., 1982. Fundamental aspects of risk and uncertainty in agriculture. Agrekon 21:1-12.

Harsh, S.B., L.J. Connor & G.D. Schwab, 1981. Managing the farm business. Prentice-Hall, New Jersey, USA, 384 pp.

Huirne, R.B.M., 1990. Computerized management support for swine breeding farms. PhD thesis, Department of Farm Management, Wageningen Agricultural University, Wageningen, The Netherlands, 165 pp.

Jalvingh, A.W., 1992. The possible role of existing models in on-farm decision support in dairy cattle and swine production. Livestock Production Science (in press).

Kay, R.D., 1986. Farm management. Planning, control and implementation. McGraw-Hill, New York, USA, 401 pp.

Keen, P.G.W., 1986. Value analysis: justifying decision support systems. In: R.H. Prague & H.J. Watson (Eds.): Decision support systems, putting theory into practice. Prentice-Hall, New Jersey, USA, p. 48-64.
King, R.P. & L.J. Robison, 1984. Risk efficiency models. In: Barry, P.J. (Ed.): Risk management in agriculture. Iowa State University Press, Ames, USA, p. 68-81.
Knight, F.H., 1921. Risk, uncertainty and profit. Houghton Mifflin, Boston, USA, 231 pp.
Officer, R.R. and Anderson, J.R., 1968. Risk, uncertainty and farm management decisions. Review of Marketing and Agricultural Economics 36:3-19.
Simon, H.A., 1977. The new science of management decision. Revised version. Prentince-Hall, New Jersey, USA.
Turban, 1990. Decision support and expert systems. Managerial perspectives. Macmillan, New York, USA, 846 pp.
Waterman, D.A., 1986. A guide to expert systems. M.A.: Addison-Wesley, Reading, UK, 419 pp.

The design of the management system for the Silsoe automatic milking system

D.S. Spencer & M.J. Street

AFRC Silsoe Research Institute, Wrest Park, Silsoe, Bedford MK45 4HS,
United Kingdom

Summary

The design and implementation of management software for the AFRC automatic milking system (AMS) is presented. The AFRC's AMS comprises local controllers served by a PC-based management system that may, if so desired, be located remotely from the milking unit. The specification for the management system is assembled by considering the requirements of its clients - the robot, stall and milking controllers, the human operators, and the cows themselves. The management system itself requires extensive database and decision making support; it has been implemented under the OS/2 operating system, with its multi-tasking environment and integrated database manager.
Keywords: automatic milking, management.

Introduction

The introduction of automatic milking will impose novel demands on milking management systems, ensuring the safe and efficient operation of a complex, fully automated milking parlour and supplying some of the knowledge and expertise that was formerly provided by dairy personnel. This paper discusses the requirements made upon a management system by automatic milking and outlines the design and implementation of the management system used by the AFRC automatic milking system (AMS).

An overview of the AFRC AMS

The tasks performed by an AMS can be conceptually divided between several classes of operation: controlling cow traffic, guiding a robotic device and monitoring the milking (Street et al., 1992). In addition to these activities, there is a requirement for an overall co-ordinating management system and for an interface to the human operator. The AFRC AMS has separate local computer controllers for these activities, each chosen for a designated group of tasks. Thus the robot is driven by a VME bus based computer and a PC running DOS is currently used as a stall controller to regulate cow traffic through the milking unit. Most of the functions associated with the milking operation are controlled by a PLC and the system-wide control and management of the AMS is provided by software running on a PS/2. This functional decomposition of the AMS into autonomous processors providing different functions separates the description of the system from the specification of the behaviour of its parts. This has the advantage that after the interface between the components has been specified, modification can be made to the individual controllers without affecting the operation of the system as a whole. Communication between the management computer and the robot and stall controllers for the transfer of data, decisions and co-ordination signals is by 20 character messages over an RS232 serial line.

Analysis of the management requirements of the AMS

An analysis of the functions the AFRC automatic milking management system (AMMS) must satisfy was carried out by considering the requirements of each of its clients. These are shown in the context diagram of Figure 1 as terminators to the AMMS process. The robot, stall and milking controllers require data, management decisions and co-ordination to perform their tasks successfully. The user needs access to system information to update system parameters and requires reports assessing animal and system performance.

When a cow approaches the milking unit, the stall controller identifies her by the tag-number encoded on her transducer and requires a management decision indicating whether she should be admitted to the milking unit or bypassed. This decision can be based upon a number of parameters that can be specified for each cow, such as the minimum interval between milkings, minimum yield or maximum number of visits per day. The acceptance or rejection of a cow for milking is signalled to the stall controller; the rejection of a cow is recorded, together with the reason for rejection, for later analysis. When an accepted cow is in the stall and ready for milking, the stall controller notifies the AMMS which initialises the teat-cup attaching sequence. The management system estimates the current positions of the cow's teats and sends the data to the robot controller. The robot controller operates autonomously in attaching the teat-cups and the AMMS monitors its progress, receiving from it signals indicating the start and finish of the operation and status and error indicators. Following the completion of the teat-cup attach operation, the AMMS signals the milking controller to commence milk flow monitoring. Milking data is transmitted to the AMMS and following the end of milking the AMMS is notified when the cow has left and the milking unit is clear. This sequence gives basic information comprising times, yields, success rates etc. that is necessary to generate system performance analyses.

As the AFRC AMS moves towards unattended operation, the role of the management system will become increasingly critical. The minimum requirements placed upon it will be to monitor the AMS performance and ensure the health and welfare of the animals using it, to monitor milk quality, and to assist in fault prediction and diagnosis. Expertise has to be built into the system to meet these needs.

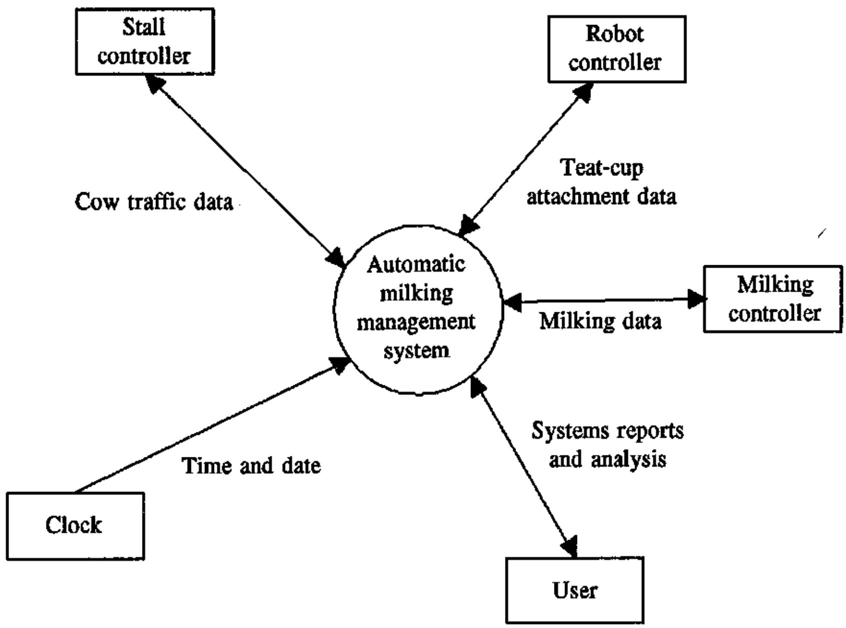


Figure 1. Context diagram showing data flow for the management of the automatic milking system.

Implementation of the AMS management

A management system for an AMS must be able to respond to requests for decisions and data from its clients in a 'reasonable' time period. For routine and non-urgent requests, this has been set at a maximum of 5 seconds. For high priority messages, such as those indicating faults or potential problems, the response must be considerably faster. The further considerations that certain functions of the AMMS may have to run concurrently with others and the AMMS itself may have to run as a background application, lead to the specification of a multi-tasking operating system. The OS/2 operating system was chosen for the implementation of the AMMS, since it is capable of multi-tasking with time slicing and preemptive scheduling. The program is thus able to spawn many threads of execution, all sharing resources such as memory, files, semaphores, pipes and queues, and all executing concurrently. In addition, OS/2 has a sophisticated integrated database management system (DBMS) which uses the relational model of data storage. This data can be accessed directly from within an application using the database access language SQL (Structured Query Language) embedded in a high level programming language such as C.

For optimal response to external events, the AMMS assigns priority classes and levels to tasks that reflect their importance to the system. Each local controller has a time-critical class thread assigned to receive messages. High priority threads are spawned immediately to respond to messages signifying that a controller requires urgent attention; non-urgent incoming messages result in the spawning of regular class threads. Should system loading dictate the need, there is also the option to dynamically change the priority of executing threads. There is thus a flexible base for the development of the AMMS which allows easy modification to accommodate additions to the system, for example developments in the expertise of the management system or an extra milking stall.

The multi-tasking environment enables the AMMS to be run as a high priority background task while other applications are also running. This facility permits a user to access information in the database to analyze performance, generate reports or change system parameters without disturbing the running of the AMS.

Results

The AMMS is currently running as a management controller for the AFRC AMS, providing co-ordination and decisions as required by the system and also recording data for research purposes. The design of the AMMS has proved adequately flexible and extendable for it to have been used for both behaviourial trials, controlling access to a feeding unit (Winter et al., 1992), and for automatic milking trials (Allen et al., 1992).

Typical data recorded by the AMMS for the teat-cup attachment operation is presented in the table. This shows teat-cup attachment data for the left-front teat only of one cow, for a period of 5 days. The TSLM (time-since-last-milking) column shows the time elapsed since the animal was last milked. The x and y co-ordinates of the 4 teats are sent by the robot controller after attaching a teat-cup. The x co-ordinate is measured relative to the rump of the cow; the y co-ordinate has its origin along the cow's body axis.

Table 1. Teat-cup attachment data for the left-front teat.

Day	Time	TSLM	Teat co-ordinates (mm) x	y	Attach time (s)
1	06:19	10:04	354	158	19
	11:09	04:50	331	148	19
	16:38	05:29	353	142	23
	21:13	04:35	310	122	18
2	06:51	09:38	333	142	21
	13:06	06:15	321	132	19
	20:24	07:18	321	119	18
3	06:43	10:19	345	132	19
	12:37	05:54	329	135	18
	17:02	04:25	329	130	19
	21:50	04:48	334	111	17
4	06:34	08:44	332	134	22
	13:06	06:32	353	122	19
	17:18	04:12	329	110	21
5	07:33	14:15	372	122	19
	13:01	05:28	341	130	18
	19:07	06:06	320	135	26

Conclusion

A good management system is essential for the effective system-wide control and co-ordination necessary to ensure the reliability of the AMS and the welfare of its animals. The specification for the management system for the AFRC's AMS has been derived by considering the requirements of both its clients and the system as a whole. Its design and implementation has proved sufficiently flexible to respond to the changing needs of the developing AMS.

The AFRC AMS presently runs with no human help but with operatives close-by to intervene should any problem arise. As yet little account has been taken of the demands placed upon the management system by the introduction of fully unattended automatic milking and further research is necessary to determine those factors necessary for its safe operation.

References

Allen, C.J., T.T. Mottram, A.R. Frost, M.J. Street, R.C. Hall & D.S. Spencer, 1992. Field trials of the Silsoe automatic milking system. In: A.H. Ipema, A.C. Lippus, J.H.M. Metz & W. Rossing (Eds.): Proceedings of the International Symposium on Prospects for Automatic Milking, EAAP publication No. 65, Pudoc Scientific Publishers, Wageningen, The Netherlands, p. 72-79.

Street, M.J., R.C. Hall, D.S. Spencer, A.L. Wilkin, T.T. Mottram & C.J. Allen, 1992. Design features of the Silsoe automatic milking system. In: A.H. Ipema, A.C. Lippus, J.H.M. Metz & W. Rossing (Eds.): Proceedings of the International Symposium on Prospects for Automatic Milking, EAAP publication No. 65, Pudoc Scientific Publishers, Wageningen, The Netherlands, p. 40-48.

Winter, A., R.M. Teverson & J.E. Hillerton, 1992. Frequent milking and behaviourial responses of the dairy cow. Institute of Animal Health, Compton, UK.

Control and management in the automatic milking system dairy farm

S. Devir

DLO Institute of Agricultural Engineering (IMAG-DLO),
P.O. Box 43, 6700 AA Wageningen, The Netherlands

Summary

To achieve a fully automated routine in the automatic milking system of a dairy farm, the daily milking and concentrates supplementation routine must be controlled on-line. A Dairy Control and Management System (DCMS) was developed and tested in IMAG-DLO. The paper discusses its underlying concept, design problems and components.
Keywords: dairy, management, control, automatic milking.

Introduction

The introduction of robotics, on-line data acquisition and processing in the milking parlour, has brought about a further radical change in the concept of the dairy farm. Each cow has its individual milking regime and feed intake pattern, according to her performance. Milking and feeding decisions are taken on-line and then automatically implemented. In this way the daily routine of the AMS dairy farm is fully automated.

In such a situation the Dairy Management System (DMS) is no longer merely a support system for the farmer to consult. A new generation of Dairy Control and Management System - DCMS is taking over. The DMS is becoming a component of the DCMS. The DCMS is a new concept in dairy farm management, based on individual cow approach. The objective is to maximize the milk production of each cow, while using the minimum of resources (feed, labour, milking machine time etc.). The DCMS acquires and analyses both data-base and on-line information to create the background for the operational decisions process. The farmer is not present during milking or feeding, each time a decision has to be made, therefore, the DCMS makes the decision and implements it.

In this paper we will discuss AMS management and the problems characteristics and main concept of DCMS from the production point of view. A DCMS based on selection unit (SU) integrated with self feeders (SF) for individual concentrates supplementation (ICS) and a milking unit (MU) will be briefly described.

Milking and feeding management today

The milking routine today is based on milking twice or three times a day, with the timing and interval between milking, usually being maintained according to the constrains of the specific dairy such as manpower, day light, size of the herd and number of milking units. Most of the DMS programs used in herd management are database types, and help the farmer improve his management decisions using data-processing and decision making (Kroeze & Oving, 1987). Production aspects, such as nutrition, body weight, milk yield and composition, are referenced and analyzed according to the performance of the "average cow" (Hyink & Meyer, 1987). The latter is the performance of a group of cows, characterized by demograph parameters such as parity number, calving season, stage of lactation etc. (Maltz et al., 1990).

The AMS dairy farm

AMS dairy farm architecture and daily routine

The basic architecture of the automatic milking system (AMS) dairy farm, is based on the two main sections (Figure 1):

- The AMS section which is divided into two sub-sections.

  The first is composed of SU combined with SF. When a cow voluntarily enters the SU, an on-line decision has to be made whether to send her to the one of the MU to be milked or supplemented concentrates, whether to supplement her with ICS at the SU or send her back to the herd.

  The second subsection is the MU, integrated with SF. There the cow is milked automatically by the milking robot or simply supplemented with ICS.
- The dairy section includes the feeding and lying area of the dairy (Rossing et al., 1985; Swierstra & Smits, 1989; Mottram & Street, 1991).

The roughage part of the ration is available to the cow at the manger all day. The concentrates part of the ration is supplemented only at the SU and MU, since cows are keen to eat concentrates and sometimes get up especially to visit the SF (Wierenga & Hopster, 1991). The SU and MU are located near the feeding area to make them more attractive to the cows (Metz et al., 1987; Kempers, 1989). Each visit to the SU must be ICS rewarded. Using PC to control the gates, the SF and the milking robot means that the daily milking and ICS milking routine, are fully automated.

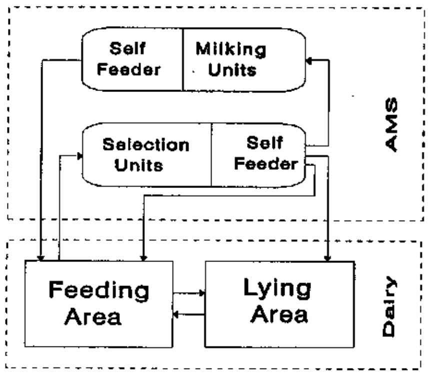


Figure 1. The AMS dairy farm sections.

Problems characteristic of AMS management

Each cow has its own production performance characteristics which may be changed as a result of different milking regimes such as interval between milkings within the day and number of milkings in a day (Rossing et al., 1985). More decisions, such as about milking times and interval are pre-defined, and made at the cow level. Each cow has its individual pattern of visiting the SU (Parsons, 1988) and their occurrence depends on the cow's wish to come to the SU. At certain times during the day, the demand to enter the SU is greater than the other hours (Collis, 1980). A cow which deserves milking might come to the SU, and find it occupied by another cow, or be refused a milking due to the system's decision based on other criteria and priorities. In some cases, a cow may might not adapt herself to the system (Hopster & Wierenga, 1989). The consequences of unrewarded visit to the SU on the cow's behaviour and performance must be considered.

Problems characteristic of the DCMS

The DCMS is an expanded version of the DMS. The DCMS deals with two management levels: the information level and the control level (Figure 2).

At the information level, the DCMS is fed continuously with information from on-line sensors and database and produces output to the database and reports to the farmer.

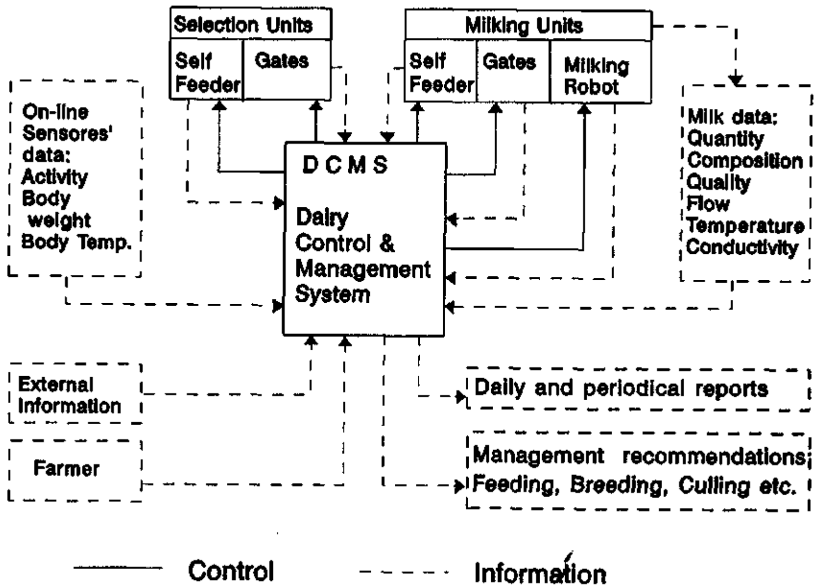


Figure 2. The DCMS information and flow control.

At the control level, a distinction is made between operational and the tactical matters. For the tactical matters, the DCMS compares the cow's individual production and behaviourial performance with pre-defined standards and criteria. If deviations are found, then corrective actions are taken to direct and improve actual performance. For the operational matters, the DCMS directly operates the SU and MU devices, which means, managing the daily milking and ICS routine in the dairy. The farmer cannot interrupt the DCMS decision process while in operation but he can control the whole process by supervising the DCMS with a pre-defined milking and ICS regime.

Five preliminary guidelines, must be defined for the DCMS configuration:

1 The target functions of the AMS system: full automation, maximum production, milk composition and quality, the farmer's quality of life, a saving of labour, or any combination these.

2 The capacity of the MU is restricted and the cows' visits to the AMS are not equally distributed during the day. Controlling or manipulating the cows' visiting pattern, to get a better distribution of visits during the day might be a solution.

3 Individual milking and ICS regime should minimize the total MU occupation time and maximize production of the individual and herd level.

4 Economic standards such as: culling cows due to failure to adapt to the AMS routine, consequences of changing the milking regime on calving interval etc.

5 Hardware and software aspects: the DCMS must be a PC stand-alone system.

The environment which influences the cow's performance is dynamic. Therefore the DCMS should follow, learn and adapt itself continuously for each individual cow. The DCMS decision, which involves comparing performance with standards for the individual cow regards much more complicated specific statistical task because of large variations.

As regards the operational scope the circumstance are even more complicated. The milking and ICS decisions should be made on-line. Each cow must be supplemented according to her production (Kroll et al., 1989) and not according to her visiting pattern. Since almost every visit is ICS rewarded, this may lead to ICS surplus. The SU has "rush hours" in which more cows try to enter. The extreme cases of very high and low visiting frequencies to the SU must be considered.

Control, management and the DCMS on the AMS farm

The DCMS in the dairy

The DCMS, which is a PC application, acquires data, analyses it and makes an on-line decision. Then it instructs the self feeders about the ICS portion and controls directly the SU and MU gates. The milking robot is instructed which cow to milk.

Information is acquired from the SU and MU gates, SU and MU self feeders, MU milking robot, milk characteristics data, on-line sensors, the user (the farmer) and various external information supplied by dairy organizations (Figure 2).

The DCMS

Knowledge based systems, not only provide information but also interpret the known information (Hogeveen et al., 1990). Expert systems (ES) will enhance the potential of complex management decisions to be made with the assistance of an on-farm computer, and interpret and indicate the combination of deviations form single parameter so that information on system malfunctions is received immediately. There are some small non-integrated knowledge-based systems (Hogeveen et al., 1990) for use in dairy farming, but none of them deal with AMS dairy farms.

The DCMS consists of 3 main modules (Figure 3):

- The decision support system (DSS), which is composed of: 1). "Database", equipped with commercial software for ration preparation, breeding, culling strategy such as "cow model", NRC, ARC etc. 2). "Model analysis" which is based on analyzing models oriented to the AMS dairy farm. Examples of such models are: individual milking regime and feeding (production), prediction of next SU visit and individual and herd daily visiting pattern (behaviour), consequences on fertility of changing milking regimes during lactation (Physiology) and culling strategy for cows which could not adapt to the system (Economic).

- Expert system. Draws conclusions on the behaviour and production performance, on the basis of groups of criteria. Not all the criteria contribute equally to the final decision. Decision criteria include, milking and ICS regimes, time intervals between milking, ICS rewarded and unrewarded visits, individual and herd visiting pattern, system capacity and consequences of unrewarded visits or unequal milking intervals.
- Input/Output interface. Acquires information from the sensors and MU and SU devices and transfers it to the database, It also provides the MU and SU with information control from the expert system.

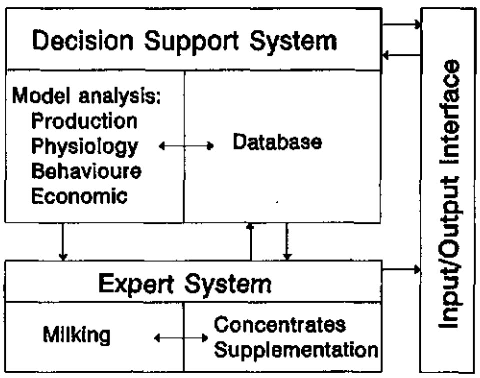


Figure 3. The DCMS main modules.

Conclusions

Using automatic milking systems has not only liberated the farmer from milking, but has also established a new approach in dairy management. This approach expands the share of individual cow management comparing with existing dairy management systems. As regards management individual milking and feeding regimes are feasible. As regards operational an automatic milking and feeding routine is also possible. A Dairy Control and Management System is not only a support system which assists the farmer. It uses a decision support system to control the decision making process and operates the daily milking and feeding routine in the dairy. In this way, the dairy becomes an automatic and more efficient unit. A prototype of DCMS, which automatically controlled the daily routine, was designed and tested at the "De Vijf Roeden" IMAG-DLO experimental dairy farm. The experience obtained will be used to do more experiments in the near future.

References

Collis, K.A., 1980. The effect of an automatic feed dispenser on the behaviour of lactating dairy Cows. Applied Animal Ethology 6:139-147.

Hogeveen, E., E.N. Noordhuizen-Stassen, J.F. Schreinemakers & A. Brand, 1990. Development of an integrated knowledge-based system for management support on dairy farms. Journal of Dairy Science 74:4377-4384.

Hopster, H. & H.K. Wierenga, 1989. Consequences of automatic systems for day and night rhythm of dairy cows. KTBL-Schrift No. 342:170-183.

Hyink, J.W.F. & A.B Meyer, 1987. Cow model. Research Institute for Cattle, Sheep and Horse Husbandry PR, Lelystad, The Netherlands, Publication no. 50.

Kempers, K., 1989. The influence of transponder concentrates feeding and forage provision on the behaviour of cows in loose cubicle housing. Forschungsbericht Agrartechnik des Arbeitskreises Forschung und Lehre der Max-Eyte-Gesellschaft (MEG) No. 170.

Kroeze, G.H. & R.K. Oving, 1987. Management information systems for dairy farming. In: Proceeding of the third Symposium Automation in Dairying. IMAG, Wageningen, The Netherlands, p. 33-344

Kroll, O., E. Maltz, S. Devir, S.L. Sphar & U.M. Peiper, 1989. Technical requirements for the daily assessment of individual cow's dry matter intake in the dairy herd. In: C.J.C. Philips (Ed.): New techniques in cattle production. Butterworth, London UK, p. 233-236.

Maltz, E., S. Devir, O. Kroll, S.L. Spahr, & R.D. Shanks, 1990. Computer feeding according to performance potential to economize on intake of concentrates. ASDS Annual meeting, North Carolina state. Journal of Dairy Science 73(Suppl. 1):233.

Metz, J., K.K. Wierenga & A.H. Ipema, 1987. Behaviour of Dairy cows when fed and milked automatically. KTBL-Schrift No. 319:138-154.

Mottram, T.T. & M. Street, 1991. Design principles for automatic milking systems. Agricultural Engineer 46(2):29-42.

Parsons, D.J., 1988. An initial economic assessment of fully automatic milking of dairy cows. Journal of Agricultural Engineering Research 40:199-214.

Rossing, W., A.H. Ipema & P.F. Veltman, 1985. The feasibility of milking in a feeding box. IMAG, Wageningen, The Netherlands, Report 85-2

Swierstra, D. & A.C. Smits, 1989. Modern dairy farming with automatic milking system. In: V.A. Dodd & M. Patrick (Eds.): Proceeding of the 11th International Congress on Agricultural Engineering, Dublin, Ireland, p. 927-931.

Wierenga, H.K. & H. Hopster, 1991. Behaviour of dairy cows when fed concentrates with an automatic concentrates feeding system. Applied Animal Behaviour Science 30:223-246.

Expert system for cow transfer between feeding groups: potential applications for automatic self feeding and milking

E. Maltz*, P. Grinspan*, Y. Edan*, A. Antler*, O. Kroll** & S. L. Spahr***

* *Institute of Agricultural Engineering, Agricultural Research Organization, The Volcani Center, P.O. Box 6, Bet Dagan 50250, Israel*

** *Israel Cattle Breeders Association, Tel Aviv, Israel*

*** *Department of Animal Sciences, University of Illinois, U.S.A.*

Summary

Milk yield and body weights of dairy cows in a commercial herd were measured daily and analysed, to identify characteristic variables for automatic routine decision to transfer individual cows from a high to a less dense total mixed ration. The variables chosen were used as fuzzy sets in software that was developed to incorporate fuzzy logic and rules for cow transfer derived from physiological analysis of the milk yield and body weight curves. The efficiency of the expert system was assessed by analysing transfer decisions and the performance of cows transferred according to expert system recommendations. The special application of this system in relation to supplementing concentrates individually in an automatic milking system is discussed.
Keywords: expert system, milk yield, body weight, automatic self feeding, automatic feeding, automatic feeding.

Introduction

Individual production relative to body weight (BW) in early lactation (cow potential-P) within parity (PAR) has been found to be a good indicator for transferring cows from a high to lower density total mixed ration (TMR) (Spahr et al., 1992). However, difference within P classes did not affect the decision, and the time of transfer was fixed. Hence, there were limited possibilities for dealing with individual cows. This work takes the individual approach in the TMR feeding system one step further as suggested by Kroll et al. (1988) and Maltz et al. (1992) by calculating the most suitable transfer time for each cow according to her own on-line recorded performance. The optimal transfer time is a physiological "junction" in which energy partition to milk and body mass is not yet decisive. At this time, TMR density can be reduced to ensure that the cut back direction will be to body tissue rather than to milk. This period can be identified when milk yield (MY) and body weight curves are monitored as lactation proceeds. Transfer decisions, if done automatically and reliably, can be a useful aid in dairy management. Cow potential (P), milk yield, body weight and dry matter intake (DMI) have also been suggested to be applied as decision making aids to economize on supplementing concentrates individually (ISC) via computerized self feeders (Maltz et al., 1992). In commercial herds, the dry matter intake cannot be measured individually for each cow. However, conclusions on the dry matter intake can be drawn from milk yield and body weight curves. Automatic on-line decisions regarding concentrates allowances will better exploit the flexibility that computerized self feeders offer. This is particularly significant in automatic milking systems in which milking frequency is flexible and visits to the milking station are rewarded by concentrates.

The objectives of this study were:

1. To characterize variables regarding body weight and milk yield to be used in the decision making process which are related to cow potential, parity and calving season and to identify for each cow the optimal time for nutritional management decisions.
2. To define the rules for decisions i.e., transfer in total mixed ration and concentrates allowances in ISC systems.
3. To develop an expert system for automatic decision making.
4. To assess the efficiency of the expert system.

Materials and methods

The work was carried out in a commercial dairy herd of approximately 300 milking cows owned by the cooperative village Masuot Itzhak. The cows were milked thrice daily at 06.00h, 14.00h and 22.00h in a rotating floating milking parlour. Daily milk records were acquired by Westfalia (Westfalia separator, Oelde, Germany) electronic milk meters and individual identification system. The dairy was equipped with an electronic on-line body weight recording system (Peiper et al., 1987; Peiper et al., 1992). Routine policy for transferring a cow from high (1.76 Mcal NEL) to lower (1.69 Mcal NEL) total mixed ration is a combination of production level, rate of milk yield decline and time post partum. As a result, cows are only rarely transferred to the lower total mixed ration earlier than 12 weeks post partum. Both Total mixed rations were prepared according to NRC (1988) recommendations.

Cow weight after calving served as initial body weight (INBW). Daily milk yield and body weight data were summarized as weekly means for 12 weeks post partum. During this period, cows were not transferred to lower total mixed ration, the effect of pregnancy on body weight changes was negligible, but body weight characteristics could be detected. After 6 months of measurements an expert system using Fuzzy Logic (Dubouis & Prade, 1988) was developed for the transfer decision for each cow. Fuzzy logic is a technique that takes into account uncertainty and its relative value in a decision. We used fuzzy logic theory because it provides a direct method for translating both qualitative and imprecise information into computer algorithms. The computer program has been developed using object oriented programming with Turbo Pascal 6.0.

Results and discussion

Milk yield and weight related to parity, cow potential and calving season

First parity (PAR1) cows and greater a first parity (PAR>1) cows were similar in body weight behaviour (Figure 1), in spite of the initial body weight difference (Maltz et al., 1991b). Except for difference in milk yield, first parity cows differ from PAR>1 cows also in peaking rate and peak time (Figure 1). This is confirmed in previous studies (Maltz et al., 1991a).

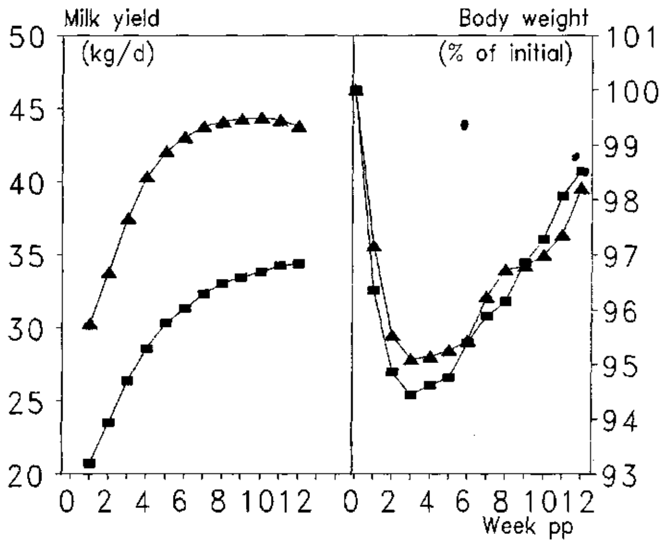


Figure 1. Milk yield (MY) and body weight (BW) curves of first parity cows, n=53 (PAR1, ■) and parity greater than 1, n=96 (PAR>1, ▲).

Figure 2 illustrates the effect of cow potential over milk yield and body weight curves. The magnitude and duration of body weight decline were directly related to cow potential level. The rate of body weight gain following the minimum initial body weight (MINBW), was inversely related to the cow potential level, in accordance with reports by Maltz et al. (1991b, 1992). Low potential (P1) cows, and to some extent medium potential (P2) cows but not high potential (P3) cows, started to gain weight while the milk yield was still increasing. This was especially true for the summer calvers and more so for the first parity cows. The overall milk yield was directly related to the cow potential (Figure 2). Summer calvers divert energy intake into body mass earlier than winter calvers (Maltz et al., 1991). The latter also maintain a period of constant weight before body weight starts to increase moderately. Body weight gain in summer calvers occurs when the milk yield is still increasing, especially in first parity cows.

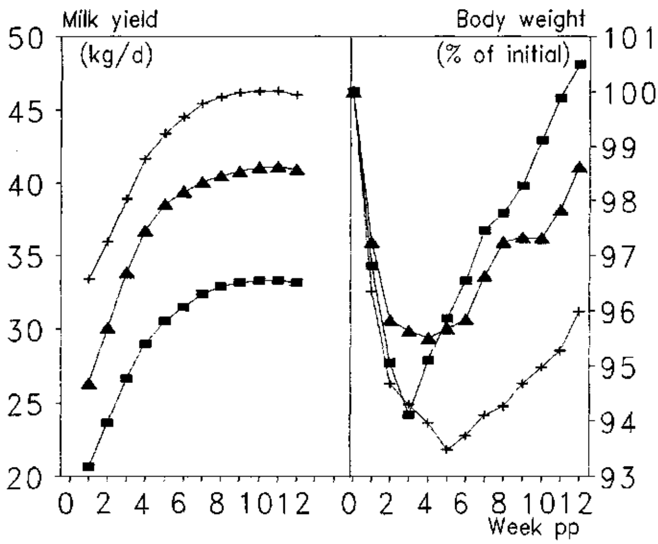


Figure 2. Milk yield (MY) and body weight (BW) curves of cow potentials P1, n=38 (■), P2, n=68 (▲) and P3, n=43 (+).

The same patterns were observed in first parity cows and PAR>1 cows within calving seasons (Figure 3). Cow potential effects on the milk yield and the body weight within the calving season were similar and differ only in the magnitude of the calving season effects described above. In all parities and cow potential levels, the milk yield curves of winter calvers showed a steeper increase toward peak production. It was concluded that during the summer, the milk yield peaking is depressed, hence the increment of the rate of dry matter intake exceeds that of the demand for the milk yield earlier than during the winter, resulting in earlier increment in body weight.

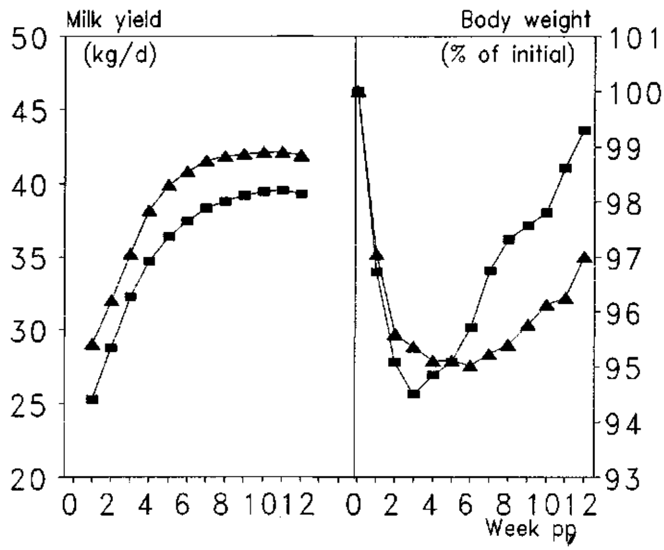


Figure 3. Milk yield (MY) and body weight (BW) curves of summer (first parity (PAR1) n=29; PAR>1 n=57, ■) and winter (first parity (PAR1) n=24; PAR>1 n=39, ▲) calvers.

Variables and rules for transfer decision

From the above analysis, we extracted the variables described below and in Figure 4. as indicators for transferring cows to less dense total mixed ration. The calving season was found to be irrelevant for transfer decision and parity was incorporated only through cow potential. The variables are as follows:

1. TSP - time step for data analysis (TSP).
2. Type of body weight curve (TYPE). Classified into 3 types 1, 2, 3.
3. cow potential (P), Ranked into 3 levels of milk yield as % of body weight within parity. For first parity cows (PAR1): P1=<6.0, P2=6.0-7.0, P3=>7.0 and for PAR>1 cows: P1=<6.5, P2=6.5-7.5, P3=>7.5.
4. Minimum body weight (MINBW), ranked into 2 levels: less then 95% of the initial body weight (big loss) and more than 95% of the initial body weight (small loss).
5. Time to reach the minimum body weight (TMIN), ranked as: less than 4 weeks post partum (short time), more than 8 weeks (long time).
6. Direction and rate of body weight changes expressed as body weight curve slope of the previous 4 time steps (SLBW). Indicates by its value the direction of change and by its absolute value, the rate of change.

7. The distance from the initial body weight in the week the data are analysed (DBW).
8. Direction and rate of milk yield changes expressed as milk yield slope of the previous 4 time steps (SLMY). Indicates the state of lactation curve relative to peak.

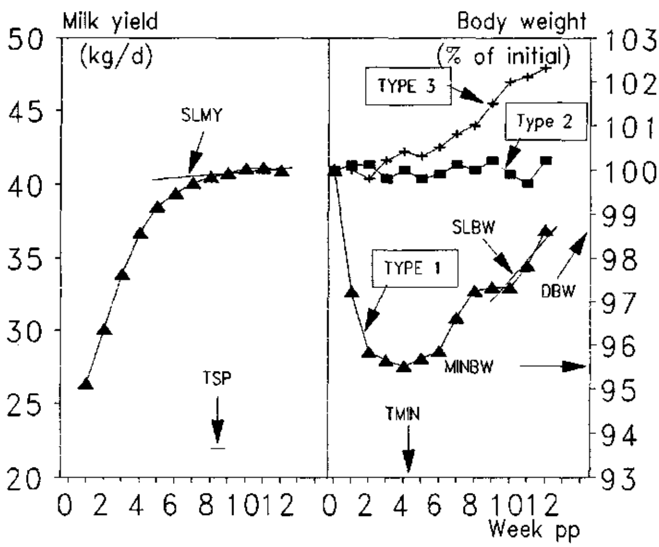


Figure 4. Variables for cows transfer to less dense total mixed ration.

Table 1. Rules for cows to be transferred from high density to less dense total mixed ration when the data of each cow are analysed and the expert system is run weekly.

Rule	TYPE	P	MINBW	TMIN	DBW	SLBW	SLMY
1	1	1,2	big	short	above	(--)	(--)
2	1	1	small	short	(--)	(0,+)	(--)
3	1	2	small	short	(--)	(+)	(0)
4	1	1	(--)	long	(--)	(0,+)	(-)
5	1	2	(--)	long	(--)	(+)	(-)
6	1	3	small	(--)	(--)	(++)	(-)
7	1	3	big	(--)	above	(--)	(-)
8	2	3	(--)	(--)	(--)	(+)	(0,-)
9	2,3	1	(--)	(--)	(--)	(0,+)	(--)
10	2,3	2	(--)	(--)	(--)	(0,+)	(0,+)

(--) = not significant for decision making; (-) = slope negative; (0) = slope parallel to x-axis; (+) = slope positive; (++) = big increase.

Body weight related variables were referred to as % of the initial body weight. All the variables (except time step, minimum body weight and peak milk yield) were incorporated into transfer rules (Table 1) as fuzzy sets. Fuzzy logic was applied to combine the rules. For each cow we received a "decision value" between 0 and 1, with "0" meaning a conclusive "no transfer" and "1" a conclusive transfer. For all "decision values" exceeding 0.5 the software indicated a decision to transfer. A decision to transfer was taken also if a 0.5 value followed an increasing "decision value" in the previous time steps.

Good correlation between peak cow potential and cow potential in week 5 (r=0.945) enabled decisions from week 5 post partum. The transfer time suggested by the expert system was in accordance with the conclusions drawn by Spahr et al. (1992), i.e. transfer time correlated linearly with the cow potential (r=0.85). This indicates the validity of the chosen variables as cow potential characteristics, and that the rules selected are adequate for cow potential related transfer decisions. For the average cow potential (mainly P2), the transfer time ranged between 5 and 19 weeks. This is expected to result in a more accurate identification of which P1 and P2 cows should be transferred to a less dense total mixed ration (Spahr et al., 1992).

Efficiency of expert system for cow transfer

Data on 146 cows were analysed through the expert system weekly. No controversial decision was recorded. This shows the validity of the rules applied. Different rules dictate the transfer time for each cow. Statistical analysis is possible only when enough cows, transferred at the same time for the same reason, are compared with others that should have been transferred for the very same reason but were not. At this stage we do not have sufficient data. However, analysing the performance of cows transferred according to the expert system, and that of cows that were transferred later than suggested shows the efficiency of the expert system. Cows of medium potential were recommended to be transferred at week 7 according to rule 3. One was transferred at week 7 and performed as expected (i.e., the milk yield curve continued as expected and the body weight gain was restrained). The other was transferred at week 14; her weight gain was greater. Similar results were achieved with 20 other cows whose transfer time corresponded to that recommended by the expert system. It was also concluded that cows transferred after weeks 20-24, when the milk yield is declining and the body weight increasing, had a steeper increase in body weight because of the milk yield (Figure 5).

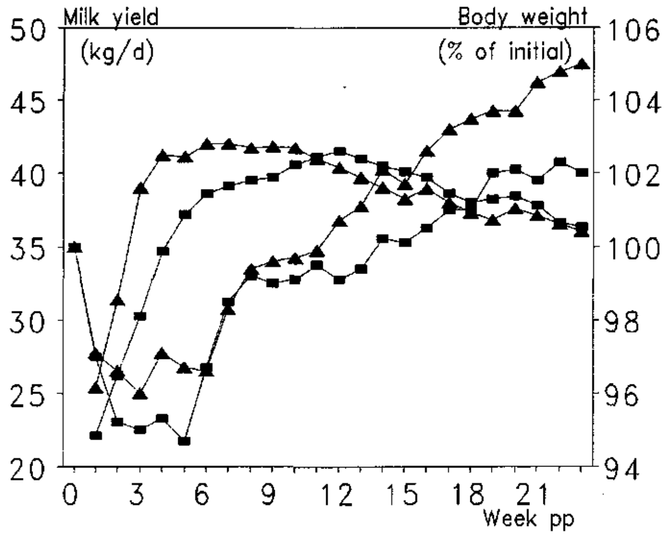


Figure 5. Milk yield and body weight of 2 cows recommended to be transferred at week 7. One transferred at week 7 (■) and one at week 14 (▲).

Conclusions related to automatic milking

Automatic milking enables milking frequency to be increased. This boosts the milk yield, which in turn affects the dry matter intake (Bar-Peled et al., 1992). A combination of automatic milking and supplementing concentrates individually (ISC) can benefit from on-line decisions regarding ISC. For this, on-line DMI estimate must be incorporated into the expert system to ensure ISC rations concentrates for a proper-ration density (Maltz et al., 1991). Experiments with ISC on the effect of the milking frequency on the dry matter intake, will provide the adequate formulation of the dry matter intake relating to milk yield, body weight and ISC. The dry matter intake (now assessed on-line) can be incorporated into the expert system as an input like all other variables that will now also include visiting frequency to the station as a fuzzy set. The output will be on-line ISC decisions. This is particularly important from calving until the dry matter intake peaks. The same variables and rules described above can be used, but in a far more sensitive way. Instead of a transfer decision carried out once in a lactation, an ISC reduction or increase will be indicated and further adjustments can be made according to performance as lactation proceeds.

References

Bar-Peled, U., E. Maltz, A.R. Lehrer, Y. Folman, I. Bruckental, J. Kali, H. Gacitua, E. Maltz, H. Tagari & B. Robinzon, 1992. Milk production and some related nutritional and reproductive variables of dairy cows under two different milking regimes in early lactation. In: A.H. Ipema, A.C. Lippus, J.H.M. Metz & W. Rossing (Eds.): Proceedings of the International Symposium on Prospects for Automatic Milking, EAAP publication No. 65, Pudoc Scientific Publishers, Wageningen, The Netherlands, p. 219-226.

Dubois, D. & H. Prade, 1988. Possibility Theory. An Approach to Computerized Processing of Uncertainty. Plenum Press. New York & London.

Kroll, O., E. Maltz & S.L. Spahr, 1988. Herd and feed management in milk production. In: Proceedings of the DLG-Congress for Computer Technology, Frankfurt, Germany, p. 492-510.

Maltz, E., O. Kroll, R. Sagi, S. Devir, S.L. Spahr & A. Genizi, 1991a. Milk yield, parity and cow potential as variables for computerized concentrates supplementation strategy. Journal of Dairy Science 74:2277-2289

Maltz, E., S. Devir, B. Zur, O. Kroll & S.L. Spahr, 1991b. Dairy cows body weight characteristics along lactation as affected by parity, production potential and calving season. Journal of Dairy Science 74(Suppl.1):215.

Maltz, E., S. Devir, O. Kroll, B. Zur, S.L. Spahr, & R.d. Shanks, 1992. Comparative responses of lactating cows to total mixed ration or computerized individual concentrates feeding. Journal of Dairy Science 75:1588-1603.

Peiper, U. M., E. Maltz, Y. Edan, M. Babazada, H. Schon & R. Artmann, 1987. Routine automatic dairy cow's body weight measurements for the use of husbandry decisions. In: Proceedings of the third Symposium Automation In Dairying, IMAG, Wageningen, The Netherlands, p. 116-128.

Peiper, U. M., Y. Edan, S. Devir, M. Barak & E. Maltz, 1992. Automatic weighing of dairy cows. Journal of Agricultural Engineering Research (accepted for publication).

Spahr, S.L., R.D. Shanks, G.C. McCoy, E. Maltz & O. Kroll, 1992. Production potential as a criterion for total mixed ration feeding strategy for dairy cows. Journal of Dairy Science 75(Suppl.1):166.

Dairy herd lactation expert system, a program to analyze and evaluate lactation curves

R.H. Fourdraine, M.A. Tomaszewski & T.J. Cannon

Texas A&M University, Department of Animal Science, 432 Kleberg Center, College Station, Texas 77843-2471, U.S.A.

Summary

Knowledge systems may be used to assist and enhance the ability of producers to interact with data bases and decipher useful management information from production parameters. A system to interpret dairy lactation curves was developed using Prolog that runs on PC class microcomputers.

The system assists producers interpreting changes in milk, milkfat, protein, somatic cell count and body condition for dairy cattle across lactations by test period. The system automatically accesses a DHIA data base, downloads data, constructs and displays graphs and evaluates the shape and magnitude of lactation curves based upon nutritionist expertise.
Keywords: dairy, lactation curve, expert system, nutrition.

Introduction

Many factors influence the quantity, as well as the quality, of milk produced by a dairy cow. Although some factors are controlled by permanent environment, many may be controlled by the dairy manager. Through the use of quantitative analysis, these factors are identified and recommendations can be made to improve performance (Whittaker et al., 1988). Information may also be used to diagnose nutritional deficiencies and to make management recommendations. The DHIA system (Dairy Herd Improvement Association), historically a production data base, has been expanded to retain historical production information. The DHIA system provides the dairy manager with a source of information that can be used to evaluate herd and individual cow performance.

Lactation curves have been used since the 1920's to characterize and predict herd performance (Gaines, 1926; Sanders, 1923). A curve is a graphical representation of milk production, taken at regular intervals during the lactation period. It can be drawn either per cow, per group of cows or for the complete herd, and usually represents sample milk weights taken once a month for the duration of the lactation. (Fourdraine, 1988).

Milk lactation curves have been used in conjunction with milk components to diagnose a wide range of management problems. Specialists evaluate the shape of these curves visually, and from the rate of production persistency and peak features, draw inferences concerning potential nutritional, reproduction and other management problems (Fourdraine, 1988).

The Dairy Herd Lactation Expert System (DHLES) is focused toward analyzing and comparing individual herd data to production standards, DHLES extracts important features from the curves, and interprets those features based upon knowledge acquired from literature and specialists stored as rules in the program.

Objectives

The objective of the program is to enhance the usefulness of DHI data (i.e. milk production, milkfat, protein,somatic cell count, and body condition scores) to individual producers.

Modules of the program include:

- a download module to automatically obtain required data from a DHIA database;
- a graphics module to visually evaluate lactation curves;
- a expert system module containing a knowledge-based system to evaluate curves, diagnose potential causes of problems and recommend appropriate strategies to solve eventual problems.

Download Module

DHLES is a set of programs written to be used on an IBM-PC compatible computer under the MS-DOS operating system. The programs are all controlled by one main driver program. One option within the main menu of the driver program is 'Accessing DRPC (Dairy Record Processing Centre) for current data'. Upon selection of this menu item, a program is executed that automatically accesses a central data source and downloads from specified data structures the appropriate data necessary to construct lactation curves for subsequent analysis.

To download data for an individual herd, the program (LACCOM.EXE) prompts the user for a herdcode, a password, the DRPC to access, the type of telephone (pulse or tone), a phone number, the baud rate, the communication port, and the drive to store downloaded information on. These values must only be entered once, then they are stored in a file for future reference. Data concerning which herd reports to download are contained in a separate file and changed by the program. The actual communications program (DMENU.EXE) is written in BASIC and was provided by the Dairy Record Processing Centre in Raleigh, NC.

The data downloaded are on a per cow test-day basis and are put into three files (PART1, PART2, and PART3). A program written in Borland TURBO PASCAL is then executed to read the individual files and merge cow data into one TURBO PASCAL database file with appropriate index files. The resulting files are named and then stored for later analysis.

Graphing Module

The second option in the main menu will execute the graphing module of the program (LACMENU.EXE), which is written in Borland TURBO PASCAL. The graphing module allows the user to process previously downloaded herd data, and then draw and print lactation curves for the herd.

Standard lactation curves for comparison were developed in order to determine whether a particular herd's average lactation curve by parity has an appropriate shape. These curves were compiled from data representing all of the Texas DHIA herds by production classes. Production classes were based upon breed, rolling herd averages (RHA), parity and number of times the herd is milked per day. RHA is defined as the average actual lactation milk per cow production for all cows in the herd within 365 days. The data were sorted by herds into ten RHA classes with midpoints ranging from 5433.6 kg to 10 056 kg and each of approximately 480 kg intervals. A quadratic regression of test-day milk production on RHA within parity and test-day classes was used to smooth the averages. This procedure then allowed calculation of standard lactation curves by parity for RHA intervals of 120 kg rather than the approximately 480 kg intervals used in the analysis.

The standards are compared to the downloaded herd data in several different ways. These comparisons provide the information for the knowledge base as well as for several graphs. Each graph allows a different visual analysis of the data. The user can select from seven different curves:

- Milk Production;
- 3.5% Fat Corrected Milk;
- 3.5% Fat and 3.2% Protein Energy Corrected Milk;
- Butterfat and Protein Percentage;
- Somatic Cell Count;
- Body Condition Score;
- Test-day Mapping of RHA versus Potential Milk Production.

There are several types of graphs that can be drawn:

- For the downloaded herd, each curve may be drawn for first (Figure 1), second, third and greater lactation cows, or all lactations in one graph. They may also be drawn for the total consolidated herd.
- When the user is interested in analyzing seasonality, performance of individual groups of cows, or performance of individual cows, the program allows the user to select subsets of the downloaded herd and draw each curve for these subsets. For example, to analyze the performance of a specific feed group or cows freshening in January.
- Additionally, subsets of the herd can be created based on the production items and values of each item on each test-day. The user can define up to 4 subsets and draw all four lactation curves in one graph. For example, to compare production for cows which at freshening had a body condition score between 2.5 and 3 versus cows with a score between 3 and 3.5 (Figure 2).

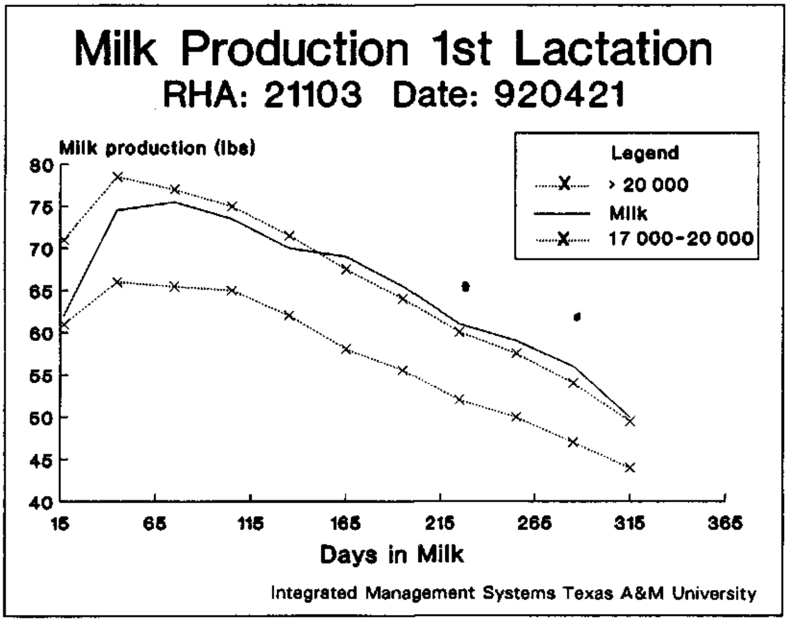


Figure 1. Milk production of first lactation cows, compared against standard milk production for Holstein cows milked three times per day.

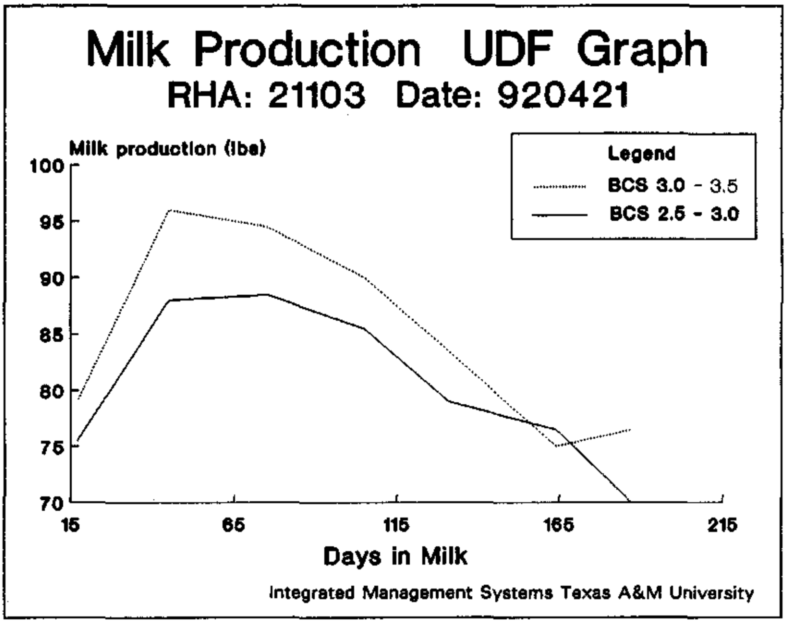


Figure 2. Comparison of cows freshening with body condition score between 2.5 and 3.0 versus cows freshening with body condition score between 3.0 and 3.5.

Expert System Module

The third option of the main menu invokes the expert system module of the program (ANALYSER.EXE). The expert system module is written in PDC PROLOG from the Prolog Development Centre.

Evaluation of a downloaded herd is performed by reading a file named KBOUTPUT.DAT into dynamic memory. In turn, the dynamic memory is consulted by the individual rules in the knowledge base. The file KBOUTPUT.DAT contains information regarding shape and absolute values of lactation curves and the selected standard lactation curves.

The knowledge base is divided into three subgroups:

1 analysis of first lactation cows;
2 second lactation cows;
3 third and greater lactation cows.

Each subgroup consists of a separate set of rules which is invoked when selected from the menu. Each individual rule consists of a number of smaller rules, so called minirules. The minirules check for specific differences between the herd's lactation curves and the standard lactation curves using threshold values which are maintained in a separate file.

Whenever all conditions in a rule are satisfied, the rule is fired and the reason for firing is displayed to the user. The program will then ask the user specific questions regarding the nature of the problem after which it will provide the user with a recommendation.

Since management can differ greatly between herds, the threshold values used in the knowledge base can be changed in the program. Changing the threshold values can have a significant impact on the way and the number of rules that will fire.

The following example is part of a rule that is used to detect sophomore burnout in second lactation cows.

```
                Rule2(5):-
1)                      fail_to_peak(2,2),
2)                      not(negative_peak(2,2)),
3)                      not(time_of_peak(2)),
4)                      not(fail_to_peak(1,2)),
5)                      not(fail_to_peak(3,2)),
6)                      shape_fat(2,2,3),
7)                      shape_prot(2,2,3),
8)                      reason(2),
                        ..,
                        ..,
                        rule2(6),!.
```

To detect sophomore burnout, there are several condition that have to be met. These conditions are described in the minirules on line 1 to line 7.

- The first minirule (line 1) checks to see if 2nd lactation cows are failing to peak on test-day 2.
- The second minirule checks to see if the milk production for second lactation cows on second test-day is not lower than the milk production on the first test-day.
- Minirule three checks if the peak production for second lactation animals does not occur after the second test-day.
- Minirules 4 and 5 check if resp. first and third and greater lactation cows peak normal.
- Finally minirules 6 and 7 check if resp. fat % and protein % drop from test-day 2 to test-day 3.

When all these conditions are met the reason for firing the rule (line 8) is displayed to the user after which the following questions are asked:

1 Is the dry period between 1st and 2nd lactation cows shorter than 60 days? (Y/N)

2 Do cows appear to be competitive for bunk space? (Y/N)

If question 1 is answered with yes, than the problem might be related to the time at which cows were bred and dried-off. Body condition at freshening might not have been restored. If question 1 is answered yes, then question 2 is asked. If the answer to question 2 is yes, then 1st lactation cows or fresh cows might have too much competition with older cows for bunk space and should be put in a separate group or provide more bunk space. If the answer is no, then the problem might be mainly due to nutrition in the latter part of the first lactation and dry period between 1st and 2nd lactation. An appropriate recommendation could be to check the ration for amount of forage versus amount of concentrates or the length of feeding time or time interval between feeding.

Conclusions

This program will allow any dairyman who participates in the DHIA to automatically download, inspect and interpret lactation curves for his herd. This capability will enhance the use of DHIA data for dairy management. Such research has motivated the collection and development of formal methods for interpreting herd lactation curves.

Future Directions

Currently the knowledge base contains 54 rules, 25 minirules and 47 recommendations. A commercial package of the program is currently available under the name DXGRAPH (Dairy eXpert system and GRAPHing program). As new technologies such as BST (Bovine Somatotropin) are introduced, dairy management will change as well as shapes and level of production for lactation curves. As more knowledge is acquired concerning lactation curves, the existing knowledge base will be expanded. Other available data from the DHIA's will be downloaded to assist in the diagnosis, such as number of days dry, days open and days to first breeding. DHLES will be integrated with other dairy management software, such as the CTAP program (Current Testday Analysis Program) that is under parallel development at Texas A&M University into an integrated dairy management system.

References

Fourdraine, R.H., 1988. Dairy herd lactation expert system. Internal report. Texas A&M University, Texas, USA.

Gaines, W.L., 1926. Interpretation of the lactation curve. Journal of General Physiology 10:27.

Sanders, H.G., 1923. The shape of the lactation curve. Journal of Agricultural Science 133:169.

Whittaker A.D., M.A. Tomaszewski, J.F. Taylor, C.J. van Overveld, R.H. Fourdraine & R. Schepers, 1988. Dairy herd nutritional analysis using knowledge systems techniques. ASAE Meeting Presentation Winter 1988, paper 88-7542.

A method for continuous automatic monitoring of accuracy of milk recording equipment

G. Wendl, X. Zenger & H. Auernhammer

Technical University of Munich, Institute of Agricultural Engineering, Vöttinger Straße 36, D-8050 Freising-Weihenstephan, Germany

Summary

To minimize the costs of milk production the daily milk yield of each cow must be known. Automatic milk recording systems have been developed for this purpose, but the accuracy of milk meters can be checked only over long periods. This paper proposes a method for continuous monitoring of milk meters that enables meter errors to be detected automatically. It is based on a comparison of expected and actual milk yields.
Keywords: milk recording equipment, error, monitoring.

Introduction

Under given economic conditions in EC successful milk production is possible only if high milk yields can be reached with low production costs. As 50% and more of the milk production costs are feeding costs (Landwirtschaftskammer Schleswig-Holstein, 1992), the nutrient supply to the single cow has to be matched to the nutrient demand as exactly as possible. The nutrient demand of a cow is extremely dependent on the milk yield. Therefore, for optimized feeding it is essential to know the daily milk yield.

Various automatic milk recording systems have been developed to measure the daily milk yield. At the moment, the number of systems installed on commercial farms in the Federal Republic of Germany is probably below 1000, but the acceptance is growing significantly. If milk meters are used for official yield recording, they have to fulfil the specifications laid down by the International Committee for Animal Recording (ICAR, 1988-1991). According to these regulations, milk meters should be checked at least once a year and recalibrated if necessary. But manual checking is very time-consuming and costly and, for this reason, it can only be done regularly at longer intervals. So there is a need for a method which can check the accuracy of milk meters continuously and signal when the accuracy of meters worsens.

Method and material

The procedure to signal milk meter errors is based on a comparison of the expected and the actual milk yield of a cow (Dufter, 1988; Zenger, 1990) and assumes that the average deviations between the actual and expected yields of several cows are not significantly different from zero if milk meters are working correctly. If the average deviation for one milk meter is significantly different from zero during a longer period, a meter error is suggested.

The monitoring method assumes that:

1. The systematic error in measurement does not worsen at the same time on all milk meters.
2. If an error in measurement occurs it will drift in one direction (directed error).
3. The other milking equipment has no defects.

The discrepancy between actual and expected milk yield is calculate from formula 1.

$$d_{ikl} = m_{ikl} - M_{ik}$$

where

d_{ikl} = deviation of expected milk yield from actual milk yield of cow k on day i and meter l

m_{ikl} = recorded actual milk yield of cow k on day i and meter l

M_{ik} = expected milk yield of cow k on day i.

The reliability of the monitoring method depends strictly on the calculation of a realistic expected value. The expected yield and its standard deviation (Hyde et al., 1981) is calculated across the previous 7 days according to formulas 2 and 3. This ensures that only amounts of milk that have been recorded on at least 3 different meters (none of them the meter which has to be tested) are used.

$$M_{ik} = \frac{m_{i-7;k} + m_{i-6;k} + m_{i-5;k} + \dots + m_{i-1;k}}{u_{ik}}$$

$$SM_{ik} = \sqrt{\frac{(m_{i-x;k} - M_{ik})^2}{u_{ik}}}$$

where

$m_{i-x;k}$ = recorded actual milk yield of cow k on day $i\text{-}x$
SM_{ik} = standard deviation of expected milk yield of cow k on day i
u_{ik} = number of available amounts of milk from cow k during the previous 7 days

To avoid possible time differences between morning and evening milk yield, an individual expected value is calculated for both yields. Since the daily amounts of milk fluctuate very stochastically (caused by external and internal influences), extreme values have to be identified and may not be used to calculate the expected value (Hyde et al., 1981; Walter, 1981). The following criteria are used to eliminate extreme values:

1. Only milk yield values from the 30th to the 300th days in lactation are used.
2. An expected value is valid only if the coefficient of variation $(SM_{ik} \times 100/M_{ik})$ is below 20%.
3. If the standard deviation of the available amounts of milk is more than 1.0, only the amounts of milk in the range $M_{ik} \pm 2 \times SM_{ik}$ (i.e. 95.45% of normal distribution) are used to calculate a new expected value.
4. Further, an expected yield is calculated only if at least 4 milk yield records are available across the previous 7 days, fulfilling the above mentioned conditions.
5. Finally, a deviation is only calculated if the actual milk yield is in the range $M_{ik} \pm 2 \times SM_{ik}$.

The calculation of average deviation per milk meter and its standard deviation is done by formulas 4 and 5 with all available deviations from the previous 30 days.

$$D_{il} = \frac{d_{i-30;k;l} + d_{i-29;k;l} + d_{i-28;k;l} + \ldots + d_{i-i;k;l}}{x_{il}}$$

$$SD_{il} = \sqrt{\frac{\Sigma\ (d_{ikl} - D_{il})^2}{x_{il} - 1}}$$

where

D_{il} = 30-day running average of deviations of meter l from the previous 30 days at time i

SD_{il} = standard deviation of deviations of meter l at time i

x_{il} = number of available deviations of all cows during the previous 30 (interval i-30 to i-1) on meter 1

Additionally, it is assumed that the calculated deviations have a normal distribution. Therefore the hypothesis H_0 ($D_{il} = 0$) can be tested against hypothesis H_1 ($D_{il} \neq 0$) by using the Student's t-statistic (level of significance 0.1%). If the hypothesis H_0 is rejected over a period of seven running days, a milk meter error is signalled.

The data base used to develop the monitoring method is described in table 1.

Table 1. Description of data base.

Investigated farm	dairy farm (34 ha)
Type of parlour	2 × 4 herringbone with identification on each stall
Number of milk meters	8
Measuring principle	volumetric, continuous, variable portions
Available data	455 days (1 March 1988 to 31 May 1989)
Number of cows	34
Available amounts of milk	
morning	10 735 kg
evening	10 585 kg

Results

Expected value for single milk yield

The monitoring method must be able to calculate the expected value. The expected yield should be as robust as possible against short-term random variations. Figure 1 shows the daily morning milk yields and the calculated expected yields for one cow.

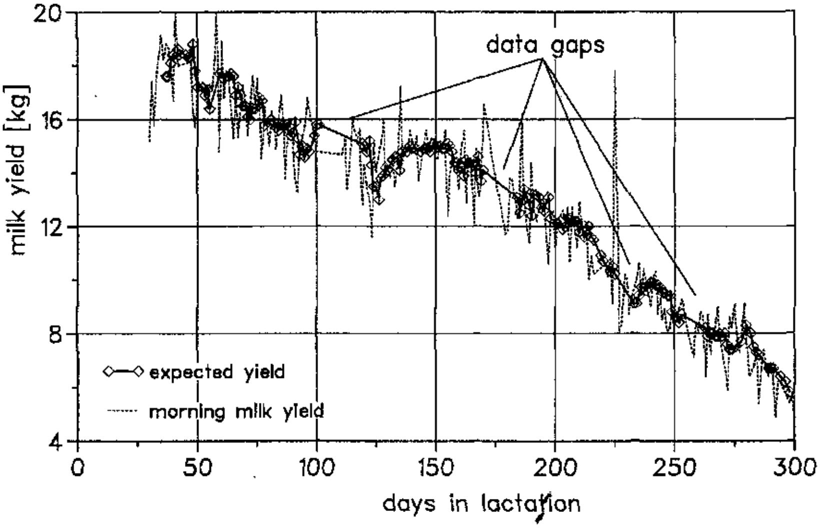


Figure 1. Lactation curve of cow no. 85 (4th lactation, morning milk yield).

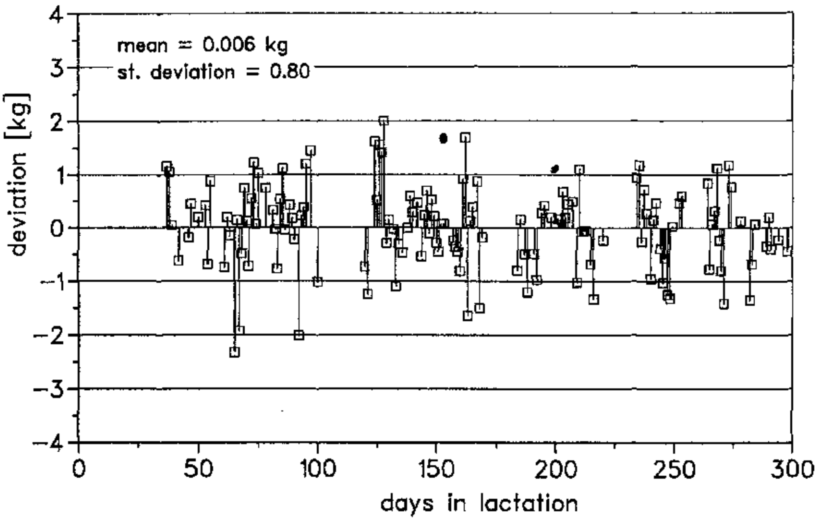


Figure 2. Deviation of the real and expected milk yield for cow no. 5 (4th lactation, morning milk yield).

Clearly, the daily milk yield varies greatly. The method for calculating the expected value has to ensure that obvious extreme values (for instance on the 225th day of lactation) are eliminated. This enables the course of the expected value to be adapted to the real lactation curve comparatively well, but it lags slightly behind the real development because it is extrapolated from the past to the future.

The discrepancy between the expected and actual milk yield for the same cow is represented in Figure 2. All deviations are below ± 2 kg except one, and vary with a standard deviation of 0.8 around zero. The size of deviations is independent of the stage of lactation.

Deviations per milk meter

If the deviations of all cows are sorted by the single milk meter and its 30-day running average is calculated, the accuracy of the meter can be estimated from the trend of the average. Figure 3 shows the single deviations and the running average for milk meter no. 5 for a period of 15 months. The deviations move symmetrically around zero during the investigation period. A significant difference from zero point cannot be determined. But on other meter devices a significant difference does appears on several periods. This signals a malfunctioning milk meter.

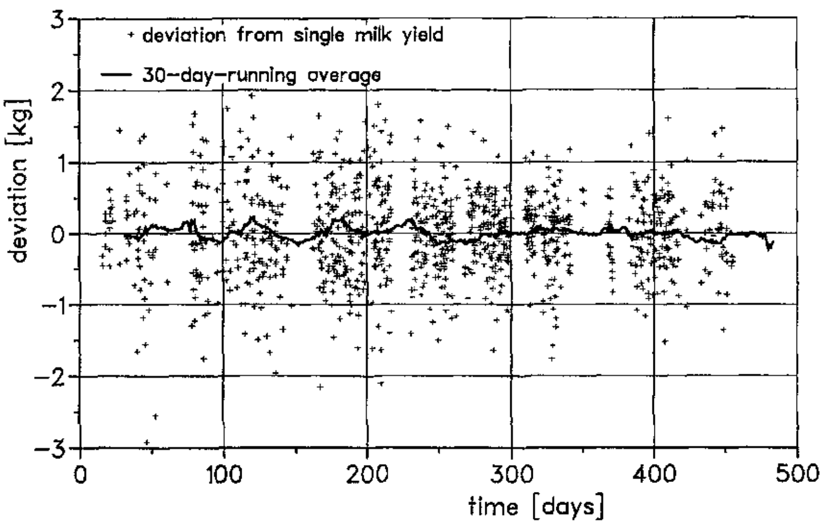


Figure 3. Deviation of real and expected milk yield for milk meter no. 5 (34 cows, 1 March 1988 to 31 May 1989).

Verification of monitoring method

The sensitivity of the monitoring method is checked by increasing the milk yield recorded at a specific milk meter. Therefore the daily milk yields recorded on milk meter no. 5 are increased by 5% between the 300th and 400th days in lactation. Doing that assumes that milk meter no. 5 has no systematic error in measurement. The change caused is shown in Figure 4. A significant difference from zero is apparent between the 316th and 418th days in lactation and this indicates that the milk meter got worse. The time lag between starting and the detection of meter error (about 2 weeks) is caused by the 30-day average. The longer this period is chosen to be, the later a meter error is detected, but the security of identifying the error increases as the risk of a wrong decision decreases.

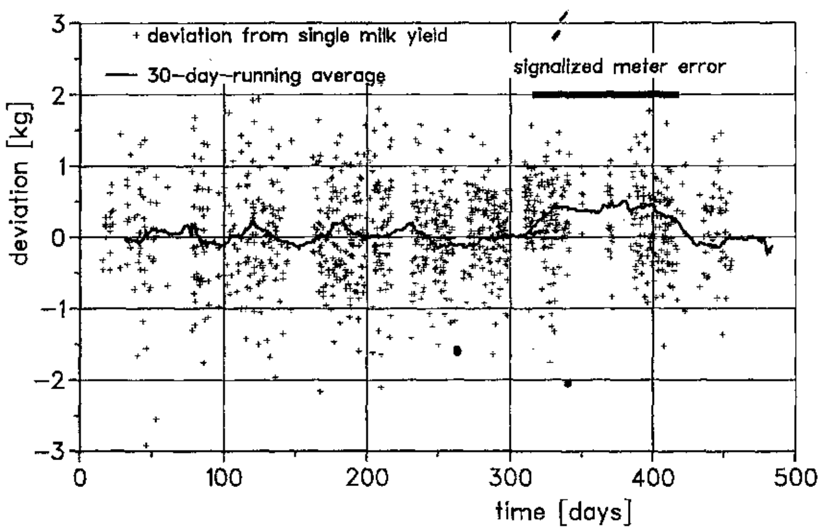


Figure 4. Deviation of actual (increased by 5% between 300 and 400 days) and expected milk yield for milk meter no. 5 (34 cows, 1 March 1988 to 31 May 1989).

Conclusion

The software-aided method developed seems to be a suitable and cost-effective procedure for monitoring the accuracy of milk meters. A very critical point of the method is the calculation of a good expected yield. Further research is necessary for optimizing and verifying:

- the method for calculating expected yield (running average or weighted running average or exponential smoothed average);
- the criteria for eliminating extreme values;
- the length of periods for making the average and
- the criteria for testing significance.

In a future practical test the software-aided monitoring method will be checked and verified by a manual monitoring. For that, the method will be implemented on the on-farm computer and it will be continuously monitored to see if deviations from the expected yield differ significantly from zero.

This method can be adapted to automatic milking if the time that has elapsed since the last milking is entered into the calculation of the expected yield. Therefore an expected yield for milk production per hour must be calculated and multiplied by the number of hours that have elapsed since the last milking. Obviously a basic requirement is that at least 2 automatic milking units are available.

References

Dufter, P., 1988. Analyse der Daten von Milchmengenmeßgeräten in Bezug auf die Einzelbucht. Diplomarbeit. Institut für Landtechnik, München, Germany.

Hyde, G.M., H.P. Pucket, H.F. Olver & K.D. Harshberger, 1981. A Step Toward Dairy Herd Management by Exception. Transactions of the ASAE 1981:202-207.

International Committee for Animal Recording (ICAR), 1988-1991. The Approval of Milk Recording Equipment.

Landwirtschaftskammer Schleswig-Holstein, 1992. Rinder-Report 1991. Betriebswirtschaftliche Mitteilungen der Landwirtschaftskammer Schleswig-Holstein, Nr. 442.

Walter, K., 1981. Die Milchleistungserfassung - eine Voraussetzung für eine leistungsgerechte Fütterung. Tierzüchter 33:163-165.

Zenger, X., 1990. Methodische Ansätze zur computergestützten Überwachung der Milchleistung in der Milchviehhaltung. Dissertation. Forschungsbericht Agrartechnik MEG-Schrift 189.

The performance of an automated dairy management data-gathering system

S. Carmi

Kibbutz Afikim, Afikim, Israel

Summary

This paper describes the performance of an automated dairy management data-gathering system in commercial dairy farms in Israel and The Netherlands. The system improves the cows' performance and the efficiency of milk production.
The data used in this report were taken from the official herd records in the two countries. Data were collected on the change in days to first service, the number of open days, the rise in milk value (price corrected milk - PCM) and the decline in the somatic cell counts (SCC).

The system enables the farmer to make decisions based on the reports supplied by the system. On farms where the system was applied correctly profits rose. There is also a great variation between individual users and despite the positive results, much importance is attached to the decisions of the user and the consequences of those decisions.
Keywords: dairy farm management, management system, price corrected milk (PCM), somatic cell counts (SCC).

Introduction

The implementation of automatic milking depends on many factors: technical, social, economic and managerial. The prerequisites are:
- the ability to gather and process data on a real-time basis;
- the ability to control health and fertility of the cows;
- the equipment to make the right decisions.

The management system tested in this study, the Afimilk system, was first presented at the symposium Automation in Dairying in 1987 (Carmi, 1987) where its operation and purposes, namely the automatic gathering of information in the milking parlour, were discussed thoroughly. The data gathering include data on milk yield and electronical conductivity as well as data on the activity level of the cow as recorded by a pedometer attached to the cow's leg.

The system applies the management principle of 'identifying the exception'. This has proven itself by identifying individual cows in heat or those presenting irregular milk production or signs of mastitis in herds of over 3000 dairy cows.

Materials and method

The minimum herd size that will benefit from an automated dairy management data-gathering system is at least 40 cows: The system has been implemented in Dutch farms with herds of that size with documented performance improvement. Even when the number of cows is limited, the farmer has other activities that must be accounted for, such as land management.

The Afimilk management system was developed by S.A.E. Afikim of Israel in the 1980's. To measure the system's performance in Israel, we compared user farms with non-user farms of the same size and from the same region (Brink). Thus the only selection criterion for the farms studied was that they employ the system. As a comparative parameter, we also list the national average of larger farms, according to the official records which contain the statistics for all kibbutzim in Israel (Anonymous, 1987-1991). This measure is intended to compensate for the relatively few number of system users in the comparison.

The data from The Netherlands used in this paper were received from individual farmers. In Israel, the herd size is 250-500 milkers, while in The Netherlands the herd size ranges from 40-150 milkers. In Israel there is a "league" for price corrected milk (PCM), for open days and several other professional parameters indicated in the figures. For details on the technical operation of the system see Carmi (1987).

Results

Per lactation per cow the milk yield (PCM) in 1991 was higher than in 1990. The average is taken from eight farms: Group 1 consists of three farms in which the system was installed in 1986, 1987 and 1988, respectively (see Figure 1 and Figure 2). During this period the PCM in Israel rose by 180 kg. Group 2 was evaluated by the same standards and comprises five farms in which the system was installed in 1990. For this group, data for 1990 (prior to installation) are compared with those for 1991. This group also shows clear and positive results. In Israel, the data for all farms is published yearly in an official report which is a reliable basis for comparison (Anonymous, 1987-1991).

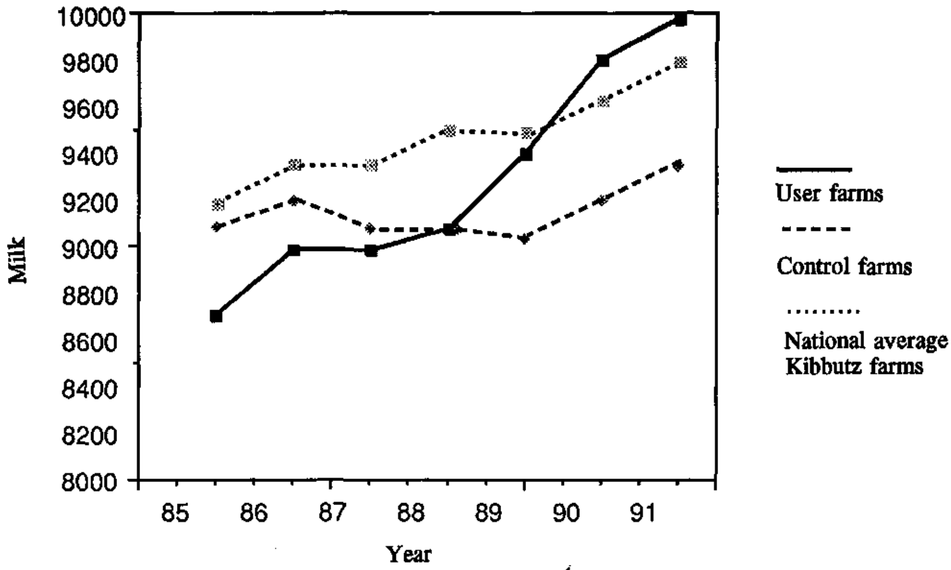


Figure 1. Average annual milk yield in Israel (user farms are the first three farms with the management system installed prior to 1990).

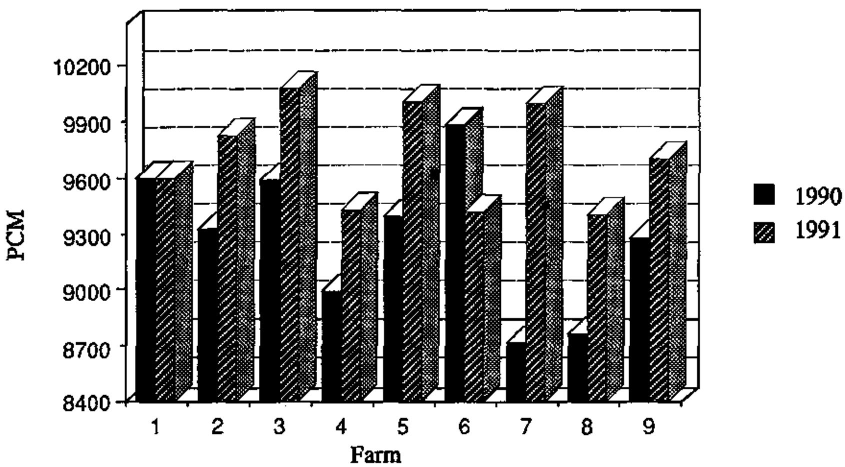


Figure 2. Price Corrected Milk of user farms in Israel (on farm no. 1, 2 and 3 the management system was installed prior to 1990).

Fertility

Clearly, each cow should bear a calf each year. But visual detection of heat discovers only 50% of heats (average for over 500 Israeli farms).

The method employed by the automated dairy management data-gathering system to reduce open days (from 115 to 100 in Israel and from 111 days to 88 in The Netherlands), clearly shows the system's advantages in detecting heat. However, the installation of the system does not necessarily improve results. One farm showed a reduction in PCM and an increase in both open days and SCC, and apparently suffers from basic management problems. The higher conception rate in The Netherlands (56% as compared to 38% for Israel), results in a greater increase in fertility (fewer open days) (see Figure 3, Figure 4 and Table 1).

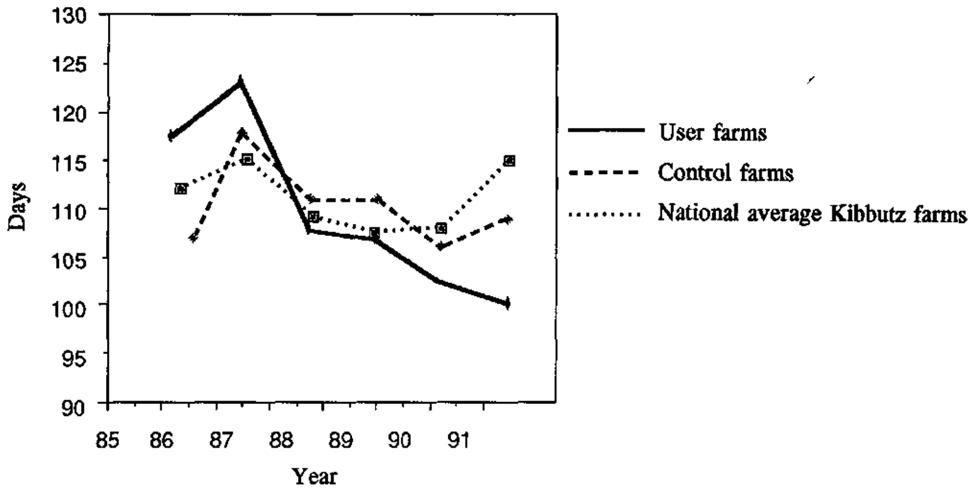


Figure 3. Days open for mature cows at the studied farms in Israel.

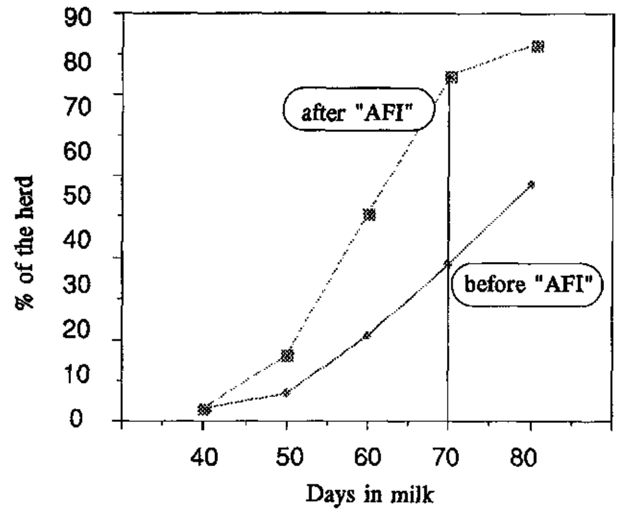


Figure 4. Days to first service at the studied farms in The Netherlands.

Table 1. Fertility for five farms in The Netherlands.

	With Afimilk	Without Afimilk
No. of cows (total for 5 farms)	275	299
Days to first insemination	67	83
Days to conception	88	111
Calving interval (days)	369	392
No. of services per conception	1.7	1.8
Conception rate - first service	60	56
Average of cycles to first service	2.3	--

Somatic Cell Count (SCC)

The decline shown by Figure 5 suggests an improvement in this area as well. The reasons for the decline are an increased milk yield and improved udder health monitoring.

It is difficult to determine which is more important, but it seems that the system's conductivity monitoring improves udder health. The results of the conductivity measurement (Shoshani & Berman) show that with the aid of the system, diseases related to the udder in a commercial farm can be detected and partly prevented. This finding is very encouraging in the light of the disappointment experienced with other methods applied (see Figure 5).

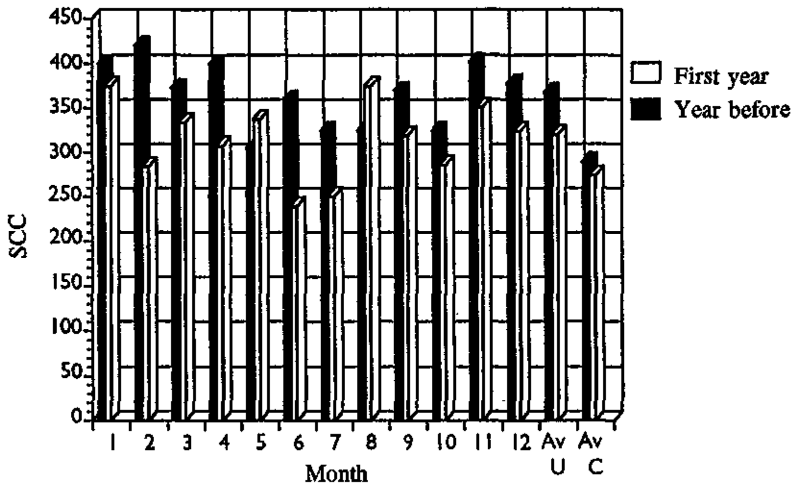


Figure 5. Somatic Cell Count (SCC) in Israel (column 1, 3, 5, 7, 9, 11: user farms; column 2, 4, 6, 8, 10, 12: control farms).

Discussion

The results from this select sample of farms in The Netherlands and Israel would seem to confirm the effectiveness of the automated dairy management data-gathering system in farm management.

It appears that the relatively high rise in milk production can be attributed to better health and culling management. The stockman is provided with a variety of tools to facilitate decision-making, instead of being forced to rely exclusively on official milk recording organizations.

The system does not automatically guarantee improved performance. One Israeli farmer (farm no. 6 in Figure 2) had poor results after installing the system, demonstrating the necessity of proper husbandry in order to achieve good results. It is the individual farmer who determines the degree of the system's success, by acting on the information it provides. We need more decision-making aids with a "thinking" system. It is important to further reduce the level of "false-positive", as the cow's activity is not solely influenced by heat, nor is mastitis the only reason for changed conductivity.

The rise in PCM of the farms where the system has been in use for a number of years seem to demonstrate the cumulative advantages of the system. For example, if the genetically related rise in PCM in Israel in 70 kg, then the organizational increase is 110 kg. The combined rise of 500 kg (minus the 180 kg) achieved as a direct result of the use of the system, clearly shows the advantage of the system for farm management.

The advantage of gathering milk yields daily rather than monthly is clear. Optimal culling requires sufficient real time data. Monthly milk recordings are mainly intended to facilitate the selection of genetically superior bulls.

Obviously, the system's effectiveness depends on its modularity. Technically speaking, this is a major improvement from the system presented at the symposium Automation in Dairying in 1987 (Carmi, 1987). The system's present modularity provides solutions to farmers according to their individual needs.

We are certainly heading in the direction of the "expert" system which will contribute greatly to the quality of decisions made on commercial farms. Undoubtedly, a reliable computerized management system is a vital part of robot milking. It is most important to continue monitoring farmers using the system in other countries in order to test the effectiveness of the system under other conditions and in greater numbers.

Acknowledgement

The author wishes to thank: S.A.E. Afikim and especially mr. Eli Peles for his important contributions to the creation of the management system Afimilk; Mr. Marco Brink for his assistance in gathering data; Prof. Aalt Dijkhuizen for permitting Mr. M. Brink to assist the author; Mr. Ehud Gelb for the statistical assistance.

References

Anonymous, 1987-1991. Summary of milk recording annual report on productivity and production, Israeli Holstein Herd Book, Israel Cattle Breeders' Association, Israel.

Brink, M. Evaluation of AFIMILK system's performance in Israel. MSc. Thesis. Wageningen Agricultural University, Department of Farm Management, Wageningen, The Netherlands.

Carmi, S., 1987. Automatic computerized herd management: heat detection, mastitis and health monitoring. Proceedings of the third Symposium Automation in Dairying, IMAG, Wageningen, The Netherlands, p. 18-27.

Shoshani, E. & A. Berman. Composite milk, electrical resistance as a means for monitoring resistance. Hebrew University Rehovot, Faculty of Agriculture, Department of Animal Science, Rehovot, Israel.

Influence of threshold values and duration of increased activity on the prediction of oestrus by pedometers

R.J. Pulvermacher* & K. Maatje**

* *Boumatic Dairy Equipment Co., P.O. Box 8050, Madison, Wisconsin 53708, USA*
** *DLO Research Institute for Animal Production 'Schoonoord' (IVO-DLO), P.O. Box 501, 3700 AM Zeist, The Netherlands*

Summary

Pedometers incorporating a microprocessor were used on 21 cows to predict oestrus at (IVO-DLO) in Zeist, The Netherlands. This study focused on the value of knowing the number of hours that the cow was active to predict an oestrus cycle. Using the criteria that four hours of elevated activity indicates an oestrus cycle, then relative increases of animal activity of 1.8, 2.0, and 2.2 indicated oestrus 45%, 55%, and 64% positively. Additional oestrus cycles were recognized using a sensitivity of only two hours of elevated activity. This indicated 86%, 78%, and 71% of the oestrus cycles using relative increases of 1.8, 2.0, and 2.2 respectively. When using a high sensitivity the number of false oestrus indications was large, requiring other calendar and visual signs to verify pedometer data. Also, as the detection threshold was lowered, the number of hours that the animal was active became more significant in predicting an oestrus condition.
Keywords: oestrus, pedometer, activity.

Introduction

Shortening calving intervals can have a big economic impact on the dairy industry. Smith et al. (1985) estimated a US$1.50 to US$3.00 loss per cow per day beyond 90-100 days postpartum. In conjunction with the need to shorten calving intervals there was a need to delay the first breeding on high production cows. High lactating cows remained in a negative energy balance longer and were often not ready to conceive before 75 days postpartum. Table 1 by Ax (1991) shows that to achieve both objectives, shorter calving intervals and increasing days until first breeding, heat detection and conception rate must be improved. Figure 1 from the same report by Ax (1991) further illustrates this point. Several researchers have done studies to predict oestrus using pedometers. Kiddy (1977), Pennington et al. (1986), Vasquez (1985) and others achieved heat detection rates that were significantly improved over the normal 50-60% visual detection that is common in industry today. The microprocessor based pedometer was also reported by Timms et al. (1991) detecting 86% of the heats and Liu & Spahr (1991) detecting 75.8% and Pulvermacher & Wiersma (1991) detecting 91%. The pedometer has a unique capability to indicate when the oestrus period begins so the dairyman can time inseminations. The objective of this study was to contrast the number of hours the cow was active with its predictive value.

Table 1. Days cows need to be inseminated for the first time after calving to achieve a 12.5 month calving interval.

Heat Detection	Conception Rate (%)			
Accuracy (%)	40	50	60	70
80	48	61	69	76
70	41	54	64	73
60	31	47	58	68
50	16	36	51	62
40	-36	20	37	52

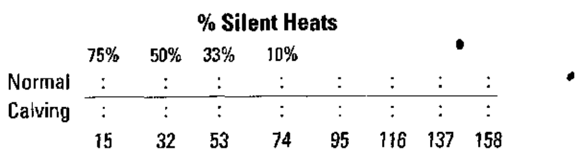


Figure 1. Expected ovulations on days after calving.

Materials and Methods

Pedometers incorporating a microprocessor with internal memory were mounted on the rear leg of cows. Every two hours, the pedometer compared the current 12 hour average activity with the sum of the two previous day's 12 hour average. All three averages were of the same time period of the day. This relative activity number was stored in memory. When the relative activity rose above the pre-programmed threshold of 2.0 (twice as active), then a light emitting diode (LED) would flash. The flashing LED normally used to alert a dairy operator was not used for the trial because a special optical interface attached to a serial port on a computer was used to collect data each week (see Figure 2). The tag memory stored 120 two-hour counter values or ten days of information. These data were later converted into a continuous record and manipulated by a custom program that mimicked the calculation done in the pedometer assembly. A five day record of the relative activity is shown in Figure 3. After an animal was confirmed pregnant, retroactively the 18-24 day interval was used to indicate the normal cycles of oestrus from the last breeding. Visual observation and two weekly milk progesterone tests were also used to determine when actual oestrus periods correlated with the tag information. Two trials were tabulated. The first involved 58 cases of oestrus on 21 cows in 1991 and the second, 25 cases of oestrus on 14 cows in 1992.

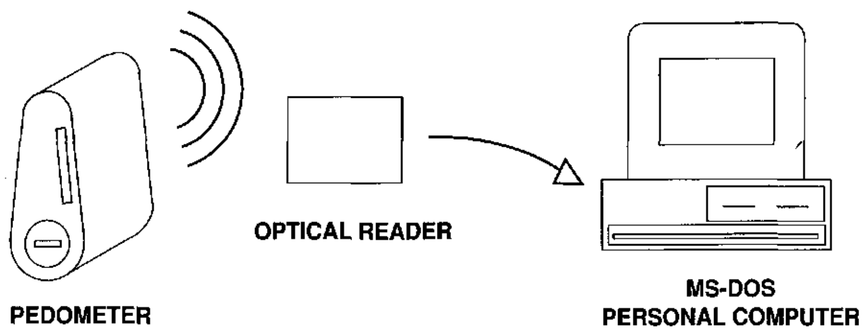


Figure 2. Pedometer reader.

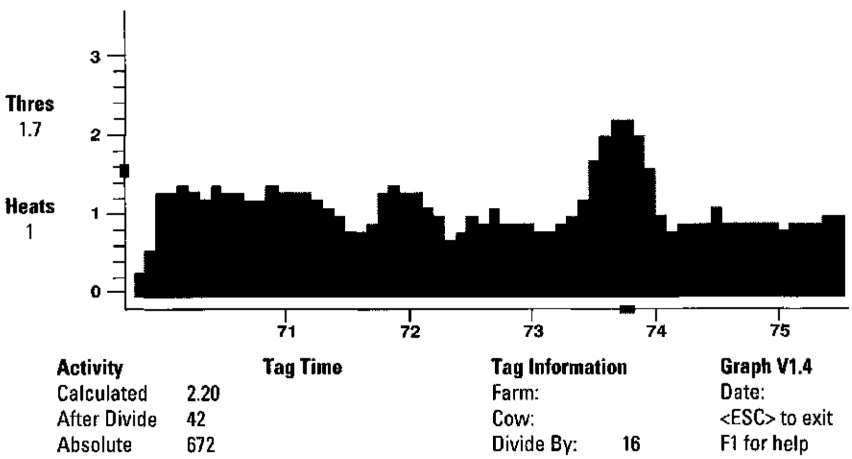


Figure 3. Rate histogram using a period of 6.

Results and discussion

Table 2 lists the data for the first trial of 58 oestrus periods, the second trial of 25 oestrus periods, and the combined results of the two trials. The threshold value in the left column indicates how active the cow was compared to the previous two days. The adjacent column indicates the number of hours that the cow exceeded the threshold. The percentage values in the other columns are explained in Figure 4.

Table 2. Data tabulations.

		n = 58		n = 25		n = 83	
Relative activity threshold value	Hours exceeding threshold	Sensitivity (in %)	Predicting value positive (in %)	Sensitivity (in %)	Predicting value positive (in %)	Sensitivity (in %)	Predicting value positive (in %)
	2	91	19	88	28	90	21
	4	84	24	88	41	86	28
1.6	6	81	29	88	50	83	33
	8	81	35	84	54	82	39
	10	76	42	80	56	77	45
	2	86	32	84	47	86	35
	4	78	41	84	57	80	45
1.8	6	69	46	80	59	72	50
	8	69	51	76	58	71	53
	10	62	55	68	61	64	56
	2	78	45	80	61	78	49
	4	71	52	76	61	72	55
2.0	6	67	57	68	68	67	60
	8	62	61	64	70	63	63
	10	52	60	60	79	54	65
	2	69	55	76	66	71	58
	4	60	60	68	74	63	64
2.2	6	53	63	64	76	57	67
	8	45	59	56	78	48	65
	10	43	64	56	82	47	70

		In Heat		
		Yes	No	
Activity	Positive	a	b	a+b
Measurement	Negative	c	d	c+d
		a+c	b+d	N

1. Sensitivity = (a/(a+c)) × 100%
2. Specificity = (d/(b+d)) × 100%
3. Predicting Value Positive = (a/(a+b)) × 100%
3. Predicting Value Negative = (d/(c+d)) × 100%

Figure 4. Diagram of possible detection results.

The most interesting results were seen when the cows became twice as active (threshold = 2.0) for two or four hours. In this area false positives were kept to a manageable level while still being sensitive enough to point out 75-80% of the animals that are possibly in oestrus. It should be noted that the second trial yielded superior results possibly due to technical disturbances during the first trial, especially with regard to predicting value positive. Figures 5 and 6 graphically show the combined results listed in rightmost columns of Table 2.

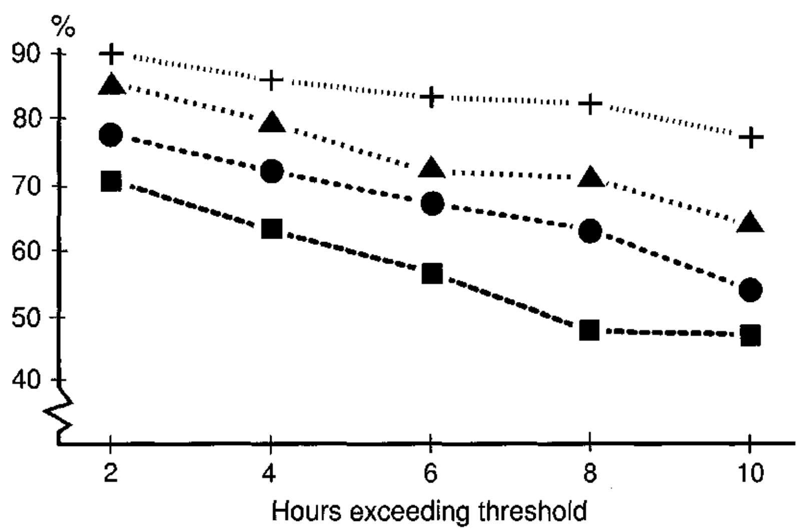


Figure 5. Sensitivity at various levels of activity.
n=83, +=1.6, ▲=1.8, ●=2.0, ■=2.2

It is interesting to observe the slopes of the curves in Figure 6. The lower the detection threshold, the greater the slope. This indicates that the number of hours that an animal was active became a more important indicator for predicting oestrus as the detection threshold was lowered. In essence, the higher the activity level or the longer the animal was active, the greater the probability that the animal was in oestrus. The results indicated that using pedometer data alone does not produce optimal results.

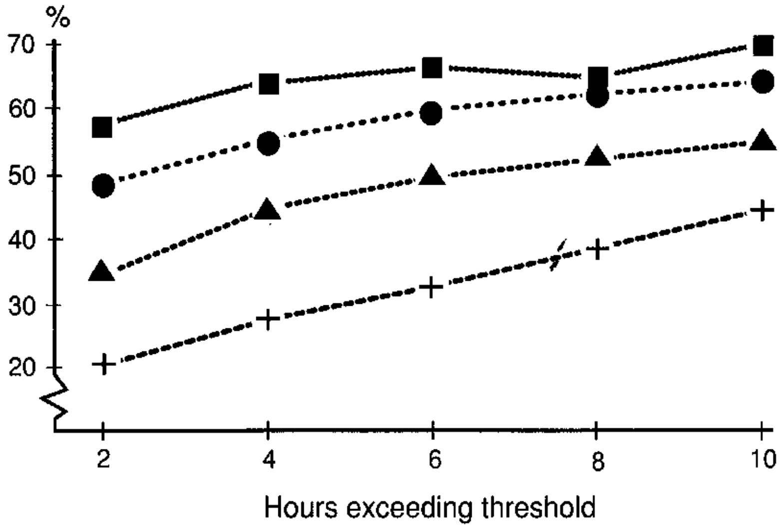


Figure 6. Oestrous predictions at various levels of activity.
n=83, +=1.6, ▲=1.8, ●=2.0, ■=2.2

However, if a medium threshold of 2.0 (twice as active) and two hours active was used to set the sensitivity, then 78% of the oestrus cycles in this study would have alerted the operator. Of those, using the criteria that four hours at 2.0 indicates an oestrus cycle, 55% would be considered a true oestrus cycle using pedometer data exclusively. The difference between 72% and 55%, or 17%, of the cases would need other information such as days since the last heat, white mucus discharge, nervousness, and/or other visual signs to provide enough information for the operator to determine if an oestrus cycle was in process. The same is true to reduce the number of false positives, and keep the number of excess breedings to a minimum.

References

Ax, R.L., 1991. Realistic goals for a dairy breeding program. Arizona Dairy Newsletter.

Kiddy, C.A., 1977. Variation in physical activity as an indication of oestrus in dairy cows. Journal of Dairy Science 60:235-243.

Liu, X. & S.L. Spahr, 1991. Increased activity ratio thresholds and time with an automated electronic system for detection of oestrus. Journal of Dairy Science 74(Supp.1):267.

Pennington, J.A., J.L. Albright & C.J. Callahan, 1986. Relationship of sexual activities in oestrus cows to different frequencies of observation and pedometer measurement. Journal of Dairy Science 69:2925-2934.

Pulvermacher, R.J. & F. Wiersma, 1991. Effectiveness of an automated oestrus detection system for dairy cows. Journal of Dairy Science 74(Supp.1):193.

Smith, R.D., P.A. Oltenacu & H.N. Erb, 1985. The economics of improved reproductive performance. Dairy Integrated Reproductive Management, Animal Science Mimeograph Series No. 88, Cornell University, USA.

Timms, L.L., P. Gauger, E. Zachary & P. Eness, 1991. Evaluation of activity monitors as a tool for heat detection in dairy cattle in a tie stall barn. Journal of Dairy Science 74(Supp.1):228.

Vasquez, L.A., 1985. Relationship between physical activity, stage of oestrus cycle, sexual behavior and plasma luteinizing hormone in dairy cattle. Thesis, Veterinary Medical Science, University of Illinois at Urbana-Champaign, USA.

Signal processing of activity data for oestrus detection in dairy cattle

W.J. Eradus, W. Rossing, P.H. Hogewerf & E. Benders

DLO-Institute of Agricultural Engineering (IMAG-DLO),
P.O. Box 43, 6700 AA Wageningen, The Netherlands

Summary

An overview of several methods for detecting oestrus in dairy cows is given. A peak detection method using the cow's activity level measured twice a day is described and validated with 165 heats. The results show the feasibility of a screening performance that can detect 9 out of 10 heats and in which 3 out of 10 alarms are correct and also the feasibility of a diagnosis test in which 6 out of 10 alarms are correct and 7 out of 10 heats can be detected. A multivalued alarm for heat estimation for better interpretation is proposed.
Keywords: oestrus detection, activity measurements, peak detection, farm management.

Introduction

Ideally, in dairy farm management the calving interval should be between 365 and 375 days. The extra arising from missed heats after this period are estimated at US$ 2 - 4 per day. For a herd of 100 dairy cows, shortening the calving interval from 390 to 380 days means an annual saving of US$ 2000 - 4000. Therefore, efficient heat detection is necessary in farm management.

A cow's heat cycle is controlled by a sequence of hormonal secretions and lasts between 18 and 24 days. Oestrogen, one of these hormones, is responsible for the typical heat behaviour and mucous secretion in the vagina. Trimberger (1944) found that the best time for insemination was 12 to 26 hours after the 'standing' oestrus or 7 to 24 hours before ovulation.

Methods of heat detection

There are many ways to detect heat. The eight most important ones are described below briefly.

- **Visual observation.** The traditional technique for detecting heats in cattle is based on observing their behaviour. The standard indicator is the cow's willingness to stand to be mounted. Other primary manifestations of heat include attempts to mount other cows, restlessness and a substantial increase in activity. Efficient detection of heat via visual observation requires time-consuming and diligent attention. Generally, the detection rate of visual observation varies between 60 and 85%, but the method is difficult, especially in large herds.
- **Cow calendar.** As heats are cyclic, time-slices can be defined during which extra attention is paid to the animals concerned. This requires daily updating of the cow's status and use of computer-generated attention lists which are based on the cow calendar.
- **Progesterone test.** 48 to 60 hours before the actual heat, the progesterone level falls sharply. When it falls below 4 ng/ml, oestrus is imminent. To achieve a good time-resolution for heat detection, the tests have to be carried out every day in a period indicated by the cow calendar. The relatively high costs and the extra labour make this method less attractive for the practical farmer.
- **Milk production.** King (1977) and other researchers found a significant decrease in milk production of between about 2 and 6 % during heats. This can be caused by an increase in restlessness and a decreased food intake.
- **Temperature.** Small changes in body temperature have been demonstrated to occur during the oestrus cycle. A few days before heat the temperature falls, reaching a minimum at two days before oestrus; on the very day of heat it tends to rise by an average of 0.6 °C, after which it returns to normal. Measuring the milk temperature is an indirect but convenient method of monitoring the body temperature. Maatje & Rossing (1976) measured milk temperatures in the claw piece twice daily during milking. The temperature rises of 0.3 °C or more that they found covered 84% of the cases of oestrus. Fordham et al. (1987) investigated what would be the best spot for temperature measurements and concluded that the short milk tube was a better place for the sensor than the claw piece. Maatje et al. (1987) achieved similar results with temperature measurements in the short milk tube during milking. The main causes of false positive responses are the influence of the ambient temperature on the actually measured milk temperature and the behaviour of the cow (Metz et al., 1987).
- **Heart rate.** Schlünsen et al. (1987) recorded the heart rate by means of an ear-mounted sensor. They ascertained that oestrus raised the pulse rate by 7% from 68.5 to 73.5 beats/min. They also found more interruptions (5, compared with 3.5) to the rest period at night (detected by sudden changes in heart rate).

- **Vaginal mucus resistance.** As a result of hormonal changes the electrical impedance (resistance) of the vaginal mucus decreases during the oestrus cycle. The minimum occurs about 25 hours before ovulation and coincides with the concentration peak of the luteinizing hormone. Heckman et al. (1979) measured the resistance in the dorsal and ventral directions of the vagina wall of 29 heifers during the oestrus cycle. Because of the strong correlation with the oestrus cycle, the impedance of the vaginal mucus turned out to be a good parameter for detecting of heat. The measurement methods so far, however, are rather inconvenient and bring the risk of inflammation. A related promising method is implanting a telemetric sensor to measure the impedance of the vaginal or vulvar tissue.
- **Activity.** It is well-known that cows in heat tend to be more active. Recording the number of steps taken in a certain time indicates the activity level. Schlünsen et al. (1987) found twice as high a step frequency during cases of oestrus in the cubicle house, compared with an increase of only 10-14% in the tied stall barn. Rossing et al. (1983), and Rossing & Eradus (1990) attached activity meters to a halter around the cows' heads to integrate the activity recording with cow identification. The increase in activity during oestrus varied between 30% and 200%.

Performance descriptors of a heat detection system

Activity, defined as the increase in pedometer count value per time unit, is a stochastic variable, with (peak) values which not only depend on the cow's heat but also on many internal and ambient factors. Therefore, the performance of a heat detection system should be described as combinations of true and false responses:

True Positive (TP) : detection of actual heat (at right time)
False Positive (FP) : detection if heat is absent
True Negative (TN) : no detection if heat is absent
False Negative (FN) : no detection of actual heat.

TP+FP gives the number of responses, and TP+FN shows the total of heats in the period of observation. The performance can now be described with the following two parameters: rate of detected heats (Detection rate, Diagnosis rate or Detectability) $D=TP/(TP+FN)$, and rate of false positive responses (False rate or Error rate) $F=FP/(TP+FP)$.

Note that in epidemiological examination in general a set of 4 (sometimes up to 6) descriptors is used: Sensitivity, Specificity, Negative Predicting Value and Positive Predicting Value (Bouten & van Dongen, 1989). The Specificity is synonymous with the Detection Rate and the Negative Predicting value is complementary to the False Rate (1-F). The other two descriptors are related to the number of true negative responses (TN) of the detection system and are necessary if it is not known what part of the population is positive (or has the specified disease). Because normally the cyclic cows are known in the management system and within this group the amount of heats is almost constant (5%), the Sensitivity and the Positive predicting value do not give significantly more information about the performance of the detection system.

Algorithms to process activity data

Many data processing algorithms have been studied in an attempt to optimize the Detection rate in combination with the inevitable False rate. Basically, they compare activity level with some form of a running mean, and a signal (alarm) is given if this ratio exceeds a threshold.

Another approach is to evaluate the actual activity data in relation to some form of a running variance (or standard deviation) of the data. Phillips (1990) used this approach, selected 12-hour intervals to determine the cow's locomotion frequency (the activity level) and processed the daytime and nocturnal data separately. He took the differences between consecutive intervals and transformed them into an averaged rms variance. If the difference between actual locomotion frequency from the former exceeds the rms variance multiplied by a sensitivity factor, oestrus has been detected. In effect, Phillips's method can be reduced to the first method, with a sensitivity level proportional to a running variance of the data.

As activity peaks due to heat normally last about 8 hours, improvements may be expected from a time base of less than 24 hours or of less than 12 hours. This will also give a better determination of the best time for insemination. Further, it is advisable to combine more sensor-based heat-related data, such as temperature and heart rate. Lake (1987) stated that the most promising parameters to monitor are temperature, activity and, possibly, heart rate.

Schlünsen et al. (1987) used the "Discriminant Analysis" method to rank the parameters for oestrus diagnosis. For oestrus detection in free stall barns the following parameters (with specified relative importance) were used: steps per day, milk yield (morning), milk temperature (evening), milk temperature (morning), milk yield (evening), el. conductivity of milk (morning), el. conductivity of milk (evening).

In the same way, Schlünsen developed a discriminant test formula for heat detection in the cubicle house. As can be expected, here the cow's activity is important. Compared with the conventional oestrus detection based solely on activity measurements, the Diagnosis rate in the cubicle house increased to 80%, with the False rate being halved to a value of 20%.

Activity measurements

At IMAG-DLO we recorded activity levels of dairy cows in a free stall barn by means of mercury-switch based pedometers (activity meters) manufactured by NEDAP. To investigate a potential combination of activity meter and neck responder used for identification, activity was measured were performed at the neck and on the foreleg. The movements registered at the neck gave far more false positive peak values than those from the foreleg, indicating that the best place for monitoring the heat-related activity is on one of the legs. Therefore registrations were henceforth done on the forelegs only. Because the counter values of the activity meters can be read every time a cow visits a concentrate-feed station or milking parlour, it seemed attractive to divide the day into more than two registration intervals. We tried to use 2, 3 and 6 hour intervals for determining activity, but because of the very irregular distribution of the interrogation events, varying between about 3 and 15 occurrences per day, we decided to use the more traditional division into day and a night. This effectively means ceasing to use data recorded at the concentrate-feed stations. The reference for determining the heat was the twice weekly measurements of progesterone level of the milk, supplemented by visual observations twice daily.

Interpretation of the activity-data

If all activity patterns were as good as those shown in Figure 1, little research would be necessary. The quality of most collected activity patterns is somewhere between that shown in this figure and the worst response as depicted in Figure 2.

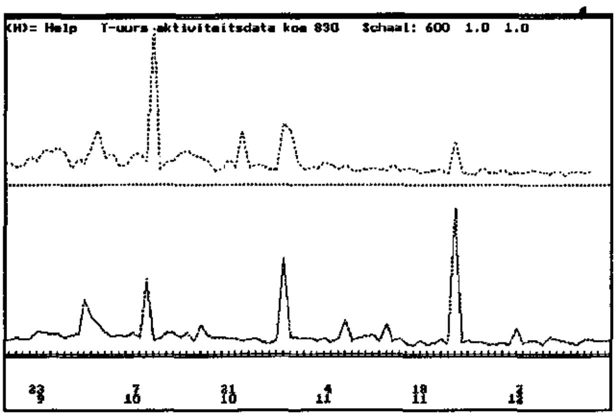


Figure 1. Cow 830 displays clear oestrus-induced activity peaks.

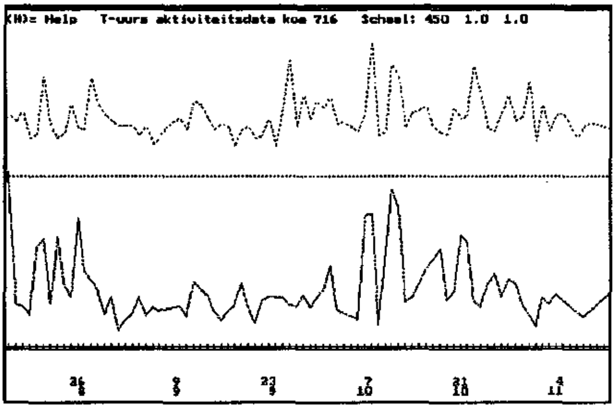


Figure 2. Cow 716 gives an unclear activity pattern.

As shown in these illustrations, we evaluated separate patterns for day and night periods, defined by the milking sessions at about 6.00 am and 4.00 pm respectively. These 12 h intervals match fairly well with the duration of the oestrus-induced increase in activity. Because it seemed reasonable to expect differences in activity level and distribution between day and night, separate peak-detecting algorithms were evaluated for both periods. In the July 1990 to July 1991 measurement period 38 cyclic cows were considered with 165 heats. The activity data were interpreted on basis of the following:

1. Only cows with two or more heats in a lactation were taken into account.
2. The period of interpretation normally started 10 days after the calving date and ended 24 days after fertilization.
3. Alarms from the detection system were assumed to be correct if their timing did not differ by more than 12 hours from the reference method of determining heat (progesterone test combined with visual observation).
4. Alarms on two consecutive days were considered as one alarm.

Peak detection algorithm

The selected peak-detecting algorithm is based on the comparison of the actual (on day n) activity level A[n] with its running mean M[n]. If the ratio of this values exceeds a threshold factor K an alarm A is given:

$A = (A[n] > K \times M[n])$ (threshold equation)
$M[n] = L \times A[n-1] + (1-L) \times M[n-1]$

where:

A = Boolean variable alarm (True/False)
A[n] = activity of day (or period) n
M[n] = running mean on day (or period) n
K = multiplication factor, determining the threshold
L = forgetfulness factor, determining the effective length of the running mean
n = number of the day on which heat should be detected

The parameters to be optimized with respect to the highest detection rate D and the lowest False rate F are the forgetfulness factor L, determining the length of the running mean, and the threshold value K. We studied the relations of K to L with D and F for separate day and night activities, expecting that this would result in different sets of optimal values for K and L. However, we found no significant differences between day and night. With the same choices for the parameters K and L for both periods Figure 3 gives the influence of the length of the running mean by varying L from 0.1 to 0.8 with K=2.0. This figure shows that with K=2.0 the sensitivity of the detection system for the choice of the effective length of the running mean is poor. A good choice here is L=0.2. This choice also proved to be optimal for K=1.4.

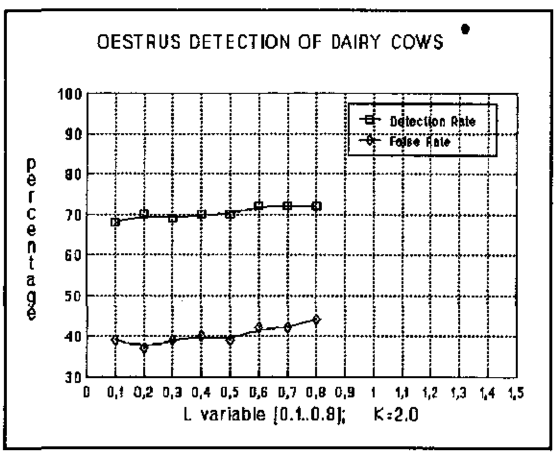


Figure 3. The influence of the choice of the running mean on D and F.

Holding L at this value the relation between the threshold value K and the performance parameters D and F is plotted in Figure 4. As can be seen, no optimal choice of the threshold value K can be made with respect to both performance parameters. Usable threshold values can be found between 1.4 and 2.0. Above 2.0 the curve of the False rate displays falls less rapidly and the Detection rate falls more rapidly. Below 1.4 the False rate increases while the Detection rate remains constant. In Table 1 three different ways of interpreting the peak-detecting algorithm are described. If maximum detection rate is important, K=1.4 is a good choice for screening purposes. In this case it has to be accepted that about one-third of the given heat alarms will be correct. On the other hand if a low False rate is required, K=2 is an appropriate choice. The penalty will be that about one-third of the heats will not be detected in this situation. For general purposes a good compromise between high Detection rate and low False rate is a threshold value K=1.7, giving a balanced False rate (about half of the given alarms is correct) combined with a good Detection rate of more than 80%.

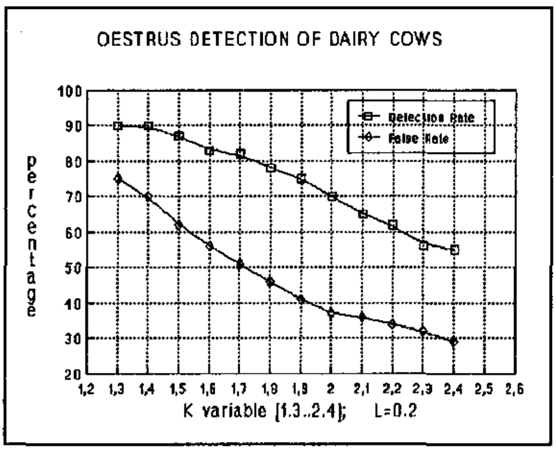


Figure 4. The influence of the threshold value on D and F.

Table 1. Summary of the results of the peak detecting algorithm.

K	L	D	F	Description
1.4	0.2	90%	70%	**Screening test** for maximum detection rate. Performance: 9 out of 10 heats will be detected, but only 3 out of 10 alarms are correct.
1.7	0.2	82%	51%	**Balanced test**: 8 out of 10 heats will be detected and half of the alarms will be correct.
2.0	0.2	70%	37%	**Diagnosis test** with emphasis on a high percentage of correct alarms. Performance: more than 6 of 10 alarms are correct and 7 out of 10 heats are detected.

In all these situations the heat detection system gives a binary alarm signal: Yes/No. Effectively the information in the activity data has been reduced to 1 bit. A better way to describe the output is to define a scale that is more or less proportional to the probability of the occurrence of heat. This has a number of advantages: the farmer has more information about the significance of the heat-alarm and can himself define at which level of alarm action has to be undertaken; and, further, this approach is more suitable for combining with other signals for combined interpretation in a fuzzy reasoning expert system.

Table 2. Examples of multiple valued output-presentations of a heat detection system.

Threshold	Screening test	Diagnosis test	Symbolic with -,*,**,***	Symbolic with other symbols	Numeric 2 bits	Numeric 3 bits
< 1.4	No	No	-	-	0	0
1.4	Yes	No	*	?	1	1
1.5	Yes	No	*	?	1	2
1.6	Yes	No	*	?	1	3
1.7	Yes	No	**	+	2	4
1.8	Yes	No	**	+	2	5
1.9	Yes	No	**	+	2	6
≥ 2.0	Yes	Yes	***	!	3	7

Rossing et al. (1989) have proposed a mastitis monitoring system where deviations in electrical milk conductivity, milk temperature and milk production are marked with one or more asterisks depending on the magnitude of the deviations. With this idea in mind, Table 2 gives some examples of how to implement a multiple-valued alarm list for heat detection. The symbols and the numeric values indicate the seriousness of the heat alarm.

Conclusion

A relatively simple heat detection system has been developed based on detecting peaks in day and night activity levels of cows. Based on 165 heats good results have been achieved. A multi-valued output seems to be a more appropriate way of give a heat alarm than the simple Yes/No response.

References

Alex, A., 1990. Automated heat and mastitis detection, Report Industrial High School Gent, Belgium.

Bouten, L.M. & M.C.J.M. van Dongen, 1989. Epidemiologic research, set up and interpretation (in Dutch), Bohn, Scheltema & Holkema, p. 230-279.

Fordham, D.P., T.T. Mc Carthy & P. Rowlinson, 1987. An evaluation of milk temperature measurements for detecting oestrus in dairy cattle. Veterinary Research Communications 11:381-391.

Heckman, G.S., L.S. Katz, & R.H. Foote, 1979. Oestrus cycle pattern in cattle, monitored by electrical resistance and milk progesterone, Journal of Dairy Science 62:64-68.

King, J.O.L., 1977. The effect of oestrus on milk production in cows, The Veterinary Record 101:107-108.

Lake, J.R.,1987. An assessment of the prospects for improved oestrus detection on the farm. In: Proceedings of the Third Symposium of Automation in Dairying, IMAG, Wageningen, The Netherlands, p. 159-165.

Maatje, K. & W. Rossing, 1976. Detecting oestrus by measuring milk temperatures of dairy cows during milking, Livestock Production Science 3:85-89.

Maatje, K., W. Rossing & F. Wiersma,1987. Temperature and activity measurements for oestrus and sickness detection in dairy cattle. In: Proceedings of the Third Symposium of Automation in Dairying, IMAG, Wageningen, The Netherlands, p. 176-184.

Metz, J., F. Wiersma, W. Rossing & V. van den Berg, 1987. First experiences with a telemetry system for measurements of body temperature by cattle cows. In: Proceedings of the Third Symposium of Automation in Dairying, IMAG, Wageningen, The Netherlands, p. 185-197.

Phillips, C.J.C., 1990. Pedometric analysis of cattle locomotion, Proceedings of the Sixth Symposium on Diseases of the Ruminant Digit, Liverpool, UK.

Rossing, W. & W.J. Eradus, 1990. Activity-meters for detecting animals in heat, Landbouwmechanisatie 3:62 (in Dutch).

Rossing, W., B. Ipema & K. Maatje, 1983. Actrons for measuring activity of dairy cows, Proceedings of the Second Symposium of Automation in Dairying, IMAG, Wageningen, The Netherlands, p. 127-134.

Rossing, W., K. Maatje, E. Benders, P.H. Hogewerf & W. Buist, 1989. Automatic mastitis detection in the milking parlour, Proceedings of the 28th Annual Meeting of the National Mastitis Council, Inc, Tampa, Florida, USA, p. 58-67.

Schlünsen, D., H. Schön & H. Roth, 1987. Automatic detection of oestrus in dairy cows Proceedings of the Third Symposium Automation in dairying, IMAG, Wageningen, The Netherlands, p. 166-174.

Trimberger, G.W., 1944. Conception rate in dairy cattle by artificial insemination at various intervals before and after ovulation, Journal of Dairy Science.

Detecting mastitis with a neural network using electrical conductivity data

M. Nielen*, M.H. Spigt** & K. Maatje***

* *Utrecht University, Department of Herd Health and Reproduction, P.O. Box 80151, 3508 TD Utrecht, The Netherlands*

** *AI-lab, Rotterdam, The Netherlands*

*** *DLO Research Institute for Animal Production 'Schoonoord' (IVO-DLO), Zeist, The Netherlands*

Summary

A standard back propagation Neural Network to classify healthy and mastitic quarters was developed as part of research aimed at producing an on-line mastitis detection system. Automatically collected quarter electrical conductivity data were used as input for the Neural Network. The network was trained with 17 healthy and 13 mastitis quarters. After training it correctly classified all the healthy quarters and 12 of the mastitis quarters. In a test set the trained network predicted all healthy quarters and 8 of 12 mastitis quarters correctly. Based on the results we concluded to continue the research using Neural Networks.

Keywords: mastitis detection, electrical conductivity, Neural Network.

Introduction

When automatic milking is introduced, automatic on-line mastitis detection will be necessary to prevent the delivery of low quality milk. The udder health of the herd needs to be known, as well as which animals need treatment. Therefore both clinical and subclinical mastitis will need to be detected. A system should be able to detect mastitis from cow data collected automatically from the milking equipment, automated concentrate feeder or pedometers.

One of the goals of 'the Milk Production Project' (Hogeveen et al., 1991) is to develop an on-line mastitis detection system based on available milking parlour data. It was decided to use a Neural Network (NN) when developing the mastitis detection system (Nielen et al., 1991). Neural Networks, developed in the field of Artificial

Intelligence, are able to detect patterns in data. A Neural Network is a model consisting of layers of highly interconnected processing units. The subsymbolic knowledge of a trained model is implicitly stored in the weights of the connections (Rumelhart & McClelland, 1986). During training, input/output patterns are presented to the model. The ultimate goal is for the model to generalize into a single set of weights that will satisfy all the input/output pairs presented to it, i.e. correctly classify all outputs.

This paper describes some results of our research aimed at producing a mastitis detection system.

Materials and methods

Data

Data collected during 1991 on a 60-cow government test farm (IVO-DLO, Zeist), were used for the research (Maatje et al., 1992). The data consisted of several automatic measurements per milking, but we only used electrical conductivity (EC) per quarter. EC measurements were collected every 5 seconds during milking. Due to differences in milking time within and between cows, the quarter EC series varied in length (Figure 1).

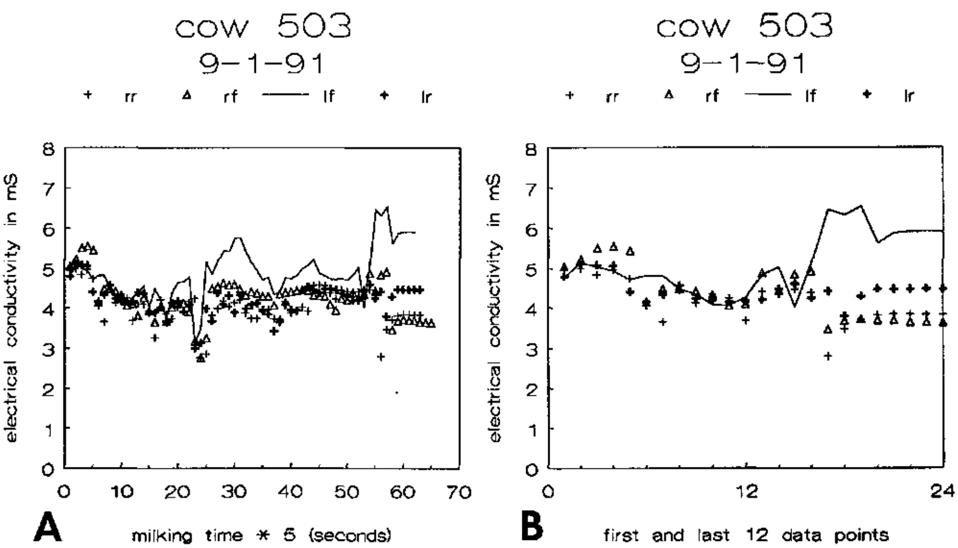


Figure 1. EC data of the morning milking of cow 503 with mastitis in the left front (lf) quarter. A: complete EC data series B: processed data. rr=right rear quarter, rf=right front quarter, lf=left front quarter, lr=left rear quarter.

Additional data included cow history and cow mastitis status. Mastitis status was based on quarter Somatic Cell Count (SCC) and quarter bacteriological culturing collected once every two months, cow SCC collected twice a week, and daily clinical observations.

Mastitis status

Mastitis status was defined at 2 levels:

- healthy quarters;
- quarters with clinical mastitis.

Healthy quarters were randomly selected from cows that had only negative quarter bacteriological culturing and no quarter SCC over 200 000 cells/ml at a sampling once every two months. In addition the twice weekly collected cow SCC between and around the samplings once every two months, had to be stable and below 250 000 cells/ml. A total of 53 healthy cow days from 18 cows with 1 to 6 samplings per cow were defined.

Quarters observed as abnormal by the milker were defined as clinical mastitis quarters.

To avoid possible influence on EC data caused by the sampling procedure once every two months, EC data from the morning milking of the sampling day were used. For the mastitis quarters, the EC data from the morning milking of the day of mastitis observation were used.

Neural Network

All research was carried out on an 80386-based PC, using the Neural Works Professional II/Plus software package (NN, 1990). Training was carried out using a standard Back Propagation algorithm, with a normalized cumulative delta learning rule with epoch size 4 and a tanh-transfer function. Weights less than 5% of the median of all weights were pruned every 500 iterations.

Because of their variable length, the EC quarter data had to be preprocessed to create an uniform input layer. The first and last 12 data points per quarter (i.e. the first and last minute of the milking procedure) were used for the analysis (Figure 1). The output was defined as 0 or 1, respectively mastitis or healthy.

The Neural Network consisted of 24 input units (1 quarter), with 5 hidden units, and 1 binary output unit. In addition, biases were added to the hidden and output units. A total of 131 weights were present in the original network. Pruning during training resulted in disabling 55 of the 131 weights.

Separate training and test sets were created for training and testing the Neural Network. Two training sets with EC data from morning milkings combined with output definitions were used (A and B). Three test sets were created. Test set I consisted of randomly selected quarter EC data from the healthy cows of the morning milking 1 day before the sampling day once every two months. For the mastitis quarters, EC data from the morning milking before the mastitis observation were used. Two other test sets consisted of quarter EC data from the previous evening (II) and evening (III) milking of the sampling day once every two months or the day of mastitis observation.

Results

The results of training sets A and B are presented in Table 1. Test set results are in Table 2.

Table 1. Results of training set A and B. H=healthy quarter, M=mastitis quarter.

		Output definition			
		Training set A		Training set B	
		H (17)	M (14)	H (17)	M (13)
Network	H	17	3	17	1
Output	M	0	11	0	12

Table 2. Results of running test set I, II and III through the trained Neural Network, which was trained with training set B. H=healthy quarter, M=mastitis quarter.

		Output definition					
		Test set I		Test set II		Test set III	
		H(12)	M(12)	H(13)	M(13)	H(13)	M(13)
Network	H	12	8	13	6	9	3
Output	M	0	4	0	7	4	10

Discussion

For our research we needed to define output for the training of the Neural Network. In mastitis research many different definitions of mastitis are used, mostly based on SCC or bacteriological culturing or both (Dodd, 1987). We decided to use two clearly defined groups to train the Neural Network. It was assumed that the difference between very healthy and clinical mastitis quarters would be the largest possible difference.

During training with training set A, 3 mastitis quarters were consistently classified as healthy by the network (Table 1). An inspection of the original clinical data revealed that quarters had been confused. Apparently the Neural Network was robust enough during training to detect the inconsistencies in the training set. Therefore training set B was constructed; it was similar to set A, except that 1 incorrect mastitis quarter had been deleted and the EC data for another mastitis quarter had been changed (see Figure 2).

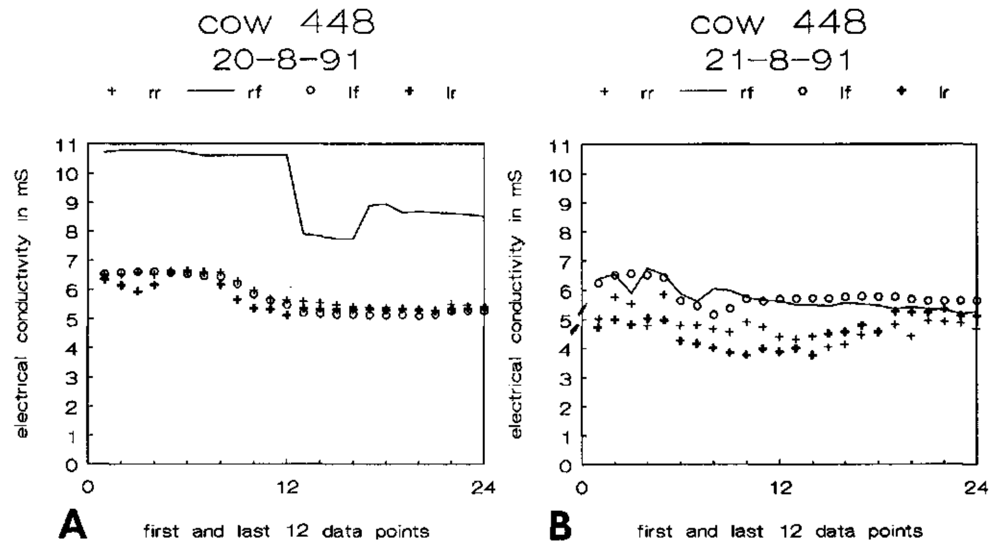


Figure 2. Processed EC data of the morning milking of cow 448 with mastitis in the right front (rf) quarter (A) and the same data the day after mastitis observation (B). In training set A, data of the right front (rf) quarter the day after observation were incorrectly used, as well as data of the right rear (rr) quarter on the mastitis observation day. lf=left front quarter, lr=left rear quarter.

Following training with training set B, 1 mastitis quarter was classified as healthy (Table 1). After inspection of the EC data it was clear that no abnormal EC values were present. However, the cow had clinical mastitis on the morning milking, with very thick and abnormal milk. The thickness of the milk may have prevented the mastitic milk from entering the EC sensor in the milk claw. We decided that based on the EC data, the Neural Network had classified this quarter correctly as healthy.

After the training with set B, the trained Neural Network was tested. No problem arose in classifying the healthy quarters in test sets I or II (Table 2). However, the mastitis quarters were mostly not classified as mastitic in the previous morning milking. In test set II (previous evening milking) more quarters were already classified as mastitic. In test set III (evening milking of mastitis observation day) most quarters were still classified as mastitic (Table 2). Of the 3 mastitis quarters that were classified as healthy, 1 belonged to a cow that was not treated.

Some healthy quarters of test set III were classified as mastitic. The effect of the sampling procedures as performed once every two months on the normal milking process could be a cause of the abnormal EC data patterns present in 3 of the 4 misclassified quarters.

It is difficult to decide whether classifying mastitis quarters as healthy in test sets I and II is biologically correct. The correctness depends on the biological variation in change of EC prior to signs of clinical mastitis signs and the alertness of the milkers in observing clinical signs. Two of the 4 mastitic quarters of test set I were classified as mastitic in all 3 test sets. Both cows had a high cow SCC before the onset of clinical mastitis.

Contrary to what is common in on-line analysis (Deluyker et al., 1989; Maatje et al., 1992), no corrections were made for cow effects on EC data. No moving averages were used and no quarter comparisons within cow were made. The high percentage of correctly classified healthy quarters in the test sets suggest a pattern common to all healthy quarters.

Differences between morning and evening EC data were expected because of an unequal milking interval. Therefore, the training set consisted of only morning milking data. The trained Neural Network was able to classify the evening milking EC data of test sets II and III (Table 2).

However, it should be noted that training and test sets were not independent. The same cows and quarters were usually used for all mastitis data, and the same cows and quarters could be present in the randomly selected healthy data sets.

Also it should be clear that the normal distribution of mastitic quarters per milking is not 50%. However, when training a Neural Network, so-called 'overtraining' can occur when certain patterns predominate. To prevent overtraining, we used an approximate 50/50 distribution for our training set.

Future research and conclusion

Because the relation between input/output is very important for the training results of a Neural Network, other EC preprocessing techniques will be tested. Another approach could be to standardize all EC curves to equal length or describe each curve. The description could include fitting lines, or include mean EC, standard deviation of EC, median EC, minimal EC, maximal EC etc.

Other output definitions will have to be tested, as well as tests on subclinical mastitis quarters, using the trained Neural Network. Independent and correctly distributed data will be needed to properly test a trained Neural Network.

In conclusion, this research strongly suggested that a Neural Network was able to differentiate between healthy and mastitic quarters, without needing corrections in the EC data.

Acknowledgements

This research was funded by the Dutch Foundation for Knowledge-Based Systems (SKBS).

References

Deluyker, H.A., L.D. Weaver, J.C. Galland & P.A. Dukas, 1989. Use of automated milk yield recording in production medicine: part II. Compendium on continuing education for the practising veterinarian, p. 1307-1310.

Dodd, F.H., 1987. Bovine mastitis. Definition and guidelines for diagnosis. Bulletin of International Dairy Federation (IDF) 211:1-24.

Hogeveen, H., E.N. Noordhuizen-Stassen, J.F. Schreinemakers & A. Brand, 1991. Development of an integrated knowledge based system for management support on dairy farms. Journal of Dairy Science 74:4377-4384.

Maatje K., P.J.M. Huijsmans, W. Rossing & P.H. Hogewerf, 1992. The efficacy of in-line measurements of quarter milk electrical conductivity, milk yield and milk temperature for the detection of clinical and subclinical mastitis. Livestock Production Science 30:239-249.

NN, 1990. Neural Works Professional II/Plus Reference Guide. NeuralWare Inc., Pittsburgh, Pennsylvania 15276, USA.

Nielen, M., H. Hogeveen, Y.H. Schukken, H.A. Deluyker & J.F. Schreinemakers, 1991. Using a connectionist model (neural network) to analyze on line milking parlour data to detect mastitis. In: Proceedings of the 6th ISVEE Symposium, Ottawa, Canada, p. 258-261.

Rumelhart, D.E. & J.L. McClelland, 1986. Parallel Distributed Processing, MIT Press, Cambridge, Massachusetts, USA.

An integrated approach to support treatment and replacement decisions in dairy cows with special attention to mastitis

E.H.P. Houben, R.B.M. Huirne & A.A. Dijkhuizen

Wageningen Agricultural University, Department of Farm Management, Hollandseweg 1, 6706 KN Wageningen, The Netherlands

Summary

An integrated dynamic programming and expert system approach was proposed to support decisions to treat and replace dairy cows, paying special attention to mastitis. In the model cows are described in terms of lactation number, stage of lactation, time of conception, milk yield during previous and present lactations, cumulative number of diagnosed clinical quarter cases in previous lactation, cumulative number of diagnosed clinical quarter cases in present lactation until current month and presence or absence of mastitis in current month of lactation.

It is impossible to include all these variables in one traditional dynamic programming model. Therefore an alternative approach was developed, using expert systems. The main reason for using expert systems was to overcome the curse of dimensionality involved with dynamic programming and to enable a more detailed definition of mastitis to be used.
Keywords: dynamic programming, hierarchic Markov process, expert system, dairy cow, mastitis, replacement, treatment

Introduction

A farmer's policy of replacing cows greatly influences profitability (Congleton & King, 1984; Renkema & Stelwagen, 1979). According to Van Arendonk (1988), the major reasons for culling cows are low production, failure to conceive, and mastitis. Mastitis has a large adverse economic impact (Schepers & Dijkhuizen, 1991). Decisions to replace cows for these reasons are based mainly on economic considerations, i.e., the farmer expects to improve profits by replacing the cow. In several studies detailed dynamic programming (DP) models have been developed to optimize decisions to replace individual animals (cows and sows) based on production capacity and reproductive state (Van Arendonk, 1985, 1986; Van Arendonk & Dijkhuizen, 1985; Kristensen, 1987, 1989; Huirne, 1990). Kennedy & Stott (1990) developed a less detailed DP model, which does include mastitis as a state variable.

In this paper we outline a detailed on-line dairy herd replacement and treatment model that pays attention to mastitis. An integrated dynamic programming and expert system approach is used to overcome the curse of dimensionality, which is the result of a large number of state variables in the DP model. An automated mastitis detection and diagnosis system is needed to give on-line support for management and treatment decisions. The research described in this paper, therefore, is part of the Milk Production Project (MPP) which is attempting to automate mastitis detection and diagnosis and to advise a farmer on feed and grassland management (for a more detailed description of the MPP as a whole, see Hogeveen et al., 1991).

In this paper we begin by defining the state of clinical mastitis state. Then, the curse of dimensionality is explained by an example, after which the alternative DP structure is described. Finally, the role of expert systems in the modular DP model and for further refining is outlined.

Definition of the state of clinical mastitis

Three variables which together describe the clinical mastitis state of an individual cow are introduced in the DP model: *PQlac* is the cumulative number of diagnosed clinical quarter cases in previous lactation (four levels: 0, 1, 2 and 3+), *CQuart* is the cumulative number of diagnosed clinical quarter cases in the present lactation from beginning of lactation (t=0) up to and including month t-1 (four levels: 0, 1, 2 and 3+), and *DQuart* is the binary variable which indicates that clinical mastitis was diagnosed in at least one quarter (1+) or in none of the quarters (0) in the current month t of present lactation. Figure 1 depicts the mastitis states graphically.

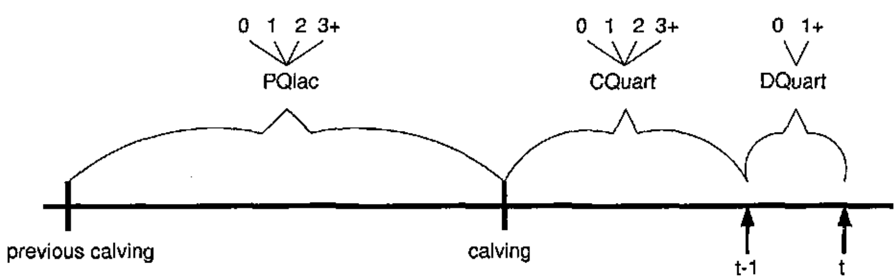


Figure 1. Graphical representation of the states of clinical mastitis and possible levels for each state variable.

A data set of 5313 lactations of 2477 Black-and-White cows was analysed using this definition of mastitis states. The main results are described in Houben et al. (1992). They include estimated production parameters and state transition probabilities with regard to clinical mastitis needed in the DP model. Clinical mastitis was found to reduce milk production by 2.3-6.2%, and also appeared to be repetitive across lactation, therefore it has important economic implications which affect decision-making.

Curse of dimensionality

Dynamic programming (DP) can be used to determine the replacement policy that maximizes the present value of expected net returns over a given planning horizon (Huirne, 1990). DP uses the principle of optimality (Bellman, 1957) to calculate in a very efficient way the optimal decision for each combination of state variables. Problems will occur if there are many state variables. The following example illustrates the resulting curse of dimensionality. In the DP model presented by Van Arendonk & Dijkhuizen (1985) cows are described in terms of the following state variables (probable levels are given in brackets; time-step is 1 month): lactation (12), month in lactation (16), time of conception (2-7), production in present lactation (15) and in previous lactation (15). Month in lactation and time of conception are described in 70 mutually exclusive combinations, since lactation cannot last longer than time of conception plus 9 months (6×9 states) and all empty cows produce relatively the same in each month of the lactation (16 states). In the first lactation there is no previous production. This means a cow can be in any one of a total of 11×70×15×15 + 70×15 = 174 300 states. If clinical mastitis were included by the three additional variables *PQlac* (4), *CQuart* (4) and *DQuart* (2) then the number of states would be 11×70×15×15×4× 4×2 + 70×15×4×2 = 5 552 400, which is a factor 32 higher. If month of calving were also included (seasonal effect) the model would become 12 times larger (i.e. 66 628 800 states). Even with the most powerful computers of today, it is impossible to find optimal solutions for such a model within an acceptable computation time.

Hierarchic Markov process

One of the reasons that replacement models, formulated as a traditional Markov decision process (i.e. a DP model; for an introduction to Markov decision processes, see Howard, 1960 and to White & White, 1989), are usually very large is that the age of the animal in question is included as a state variable (Kristensen, 1988). As a result, most elements of the transition matrix equal zero, because these transitions are not feasible (e.g. the transition from lactation 2 to lactation 5 is not possible). Kristensen (1988) developed an alternative structure of a Markov process, called the hierarchic

Markov process (HMP). The idea behind the HMP is to take advantage of the fact that when a replacement takes place, not just a regular state transition occurs, but the process (life cycle of the replacement animal) is restarted. In the traditional Markov decision model a replacement is represented as a transition just like all others from one state to another. In an HMP the Markov decision process (MDP) is split into a main process and subprocesses. Each stage in the main process represents a separate Markov decision process (a subprocess) with a finite number of stages, i.e. the maximum lifespan of a cow (Figure 2).

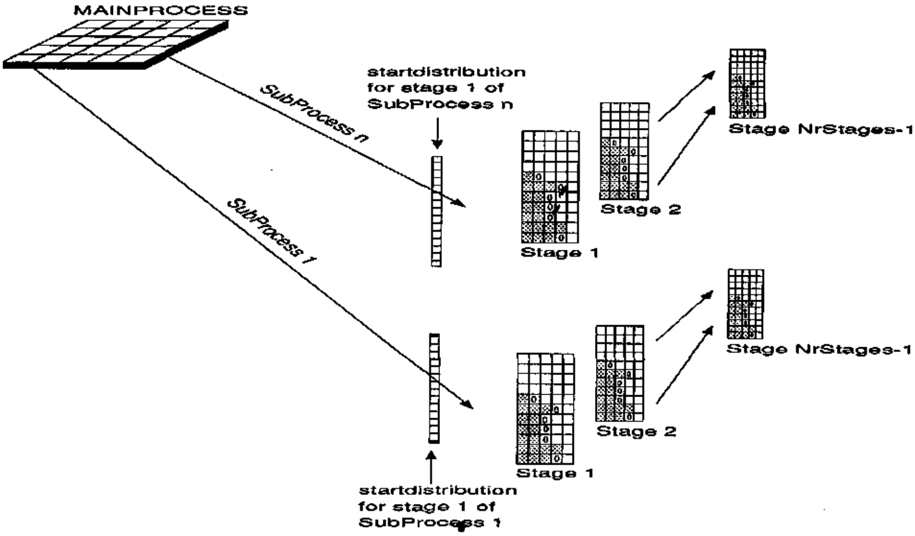


Figure 2. Transition probability structure of a hierarchic Markov process (NrStages is maximum age of a cow).

The number of subprocesses is equal to the number of states in the main process. State variables of the main process concern states of the cow which do not change during its life time (e.g. age at first calving). The rewards (net revenue from a single stage) in the main process are calculated from the rewards of the subprocesses. The time-step (stage duration) in the main process is equal to the total length of the corresponding subprocess (Kristensen, 1987). For a more detailed description, see Kristensen (1989).

The transition matrix of a regular MDP is a square matrix of size s×s (s = number of states). In an HMP the transition matrix of the main process is a small square matrix of size m×m (m = number of subprocesses). The transition matrix of the subprocesses includes: A-1 not necessarily square matrices of size $s_a \times s_{a+1}$ (s_a = number of states for age a, A = maximum age of the cow). The structure of the transition matrix of an HMP is also shown in Figure 2.

An advantage of an HMP over an MDP is that the number of transition probabilities is reduced by a factor of the number of ageing states. If, for instance, 12 lactations and 16 lactation states are included in the model, the number of transition probabilities is reduced by a factor of 192. On the other hand this is not really a reduction of the number of transition probabilities, since these probabilities are all zero in an MDP. In other words, the HMP especially refers to the non-zero part of the transition matrix of an MDP. So, if an MDP is implemented in an optimal way (i.e. ignoring the zero blocks) the reduction of model size should actually not be considered as an advantage of the HMP.

The main advantage of the HMP is directly related to its structure. A subprocess has a well defined finite planning horizon (lifespan of cow). This, together with its large state space, makes value iteration the ideal optimization method to use. Value iteration focuses on changing the value function until it becomes sufficiently close to the maximum point of the criterion value (Howard, 1960; White & White, 1989). The main process has a small state space and an infinite planning horizon, therefore policy iteration can be applied without computation problems. Policy iteration focuses on changing the policy until an optimal policy is attained (Howard 1960; White & White, 1989). Policy iteration is an efficient and exact optimizing method for small models under infinite planning horizon. In terms of theory, policy iteration should be preferred since it is exact and very efficient in the sense that it converts rapidly to a solution (Van der Wal & Wessels, 1985). It can be proven mathematically that the complete HMP should be regarded as a regular MDP optimized with policy iteration (Kristensen, 1989). Applying the value iteration method in the subprocesses with a finite planning horizon and policy iteration in the main process with an infinite planning horizon results in a sound optimization technique which is also fast, exact and able to handle very large models (Kristensen, 1988).

Modular optimization model

Another reason that replacement models are usually very large, is that it is assumed that the interactions between all state variables have a significant influence on the optimal policy. In many cases, however, this assumption does not hold. So, it should be possible to split the whole state space into several, sufficiently small models (DP modules), which can be optimized using an HMP. The results obtained can be as valid as optimizing the entire model as a whole. If it is known that there is interaction with a certain state variable, then this state variable can be included in such a DP module with less detail (i.e. with fewer possible levels). Note that ageing state variables (i.e. stage variables) are included in each DP module, since the expected net returns are optimized over a given planning horizon. Examples of the state variables of such DP modules, refering to the dairy herd treatment and replacement model, are:

fertility module:	lactation (12), month of lactation (16), month of conception (6), production (5) number of states: 4 200
production module:	lactation (12), month of lactation (16), production (15), production in previous lactation (15) number of states: 39 840
mastitis module:	lactation (12), month of lactation (16), production (15), *PQlac* (4), *CQuart* (4), *DQuart* (2) number of states: 86 400
season module:	lactation (12), month of lactation (16), production (3), month of calving (12) number of states: 6 912

If interaction is not absent, expert systems (ES) can play an important role. For this kind of treatment and replacement models it seems probable that the information which is concealed in these interactions can be implemented in an ES. Some of this information can be made available by the HMP system itself, since there is some overlap in the state variables of the various DP modules from which interactions can be interpolated, and some information can be obtained by interviewing experts.

We intend to test this approach by comparing the results of a large DP model with results based on a modular approach.

Using expert system for further refining

A mathematical model is usually a simplification of the real world. DP models are no exception. In the example used in this paper, this is especially true for the definition of state of mastitis. The definition makes no distinction between the bacterial cause of the clinical mastitis, ignores sub-clinical mastitis and assumes that detection and diagnosis have an accuracy of 100%. However, using expert systems it is possible to estimate expected losses resulting from mastitis more precisely if, for instance, bacterial cause is known and the expected losses of an average mastitis case are also known from the DP results. These expected losses can then be weighted by the probabilities of detecting a certain type of mastitis.

Another field in which expert systems can be used is for reasoning about replacement decisions based on subjective, farm-specific circumstances, such as amount of milk necessary to satisfy yearly milk quotas, or on unquantifiable cow characteristics such as having other diseases, and inferior exterior.

Discussion and outlook

Current systems to support replacement decisions in livestock are mainly based on productive and reproductive characteristics of animals. In dairy cows these characteristics may include: lactation number, stage of lactation, milk production level, time of conception, and month of calving (see for instance Van Arendonk, 1985). Research done by Huirne (1990) showed that extending a dynamic programming model with expert systems can make it more valuable and appropriate for making decisions about replacement. The objective of the integration is to combine the strong points of both the dynamic programming model and the expert systems. In this way the integration has the advantage of yielding synergetic results.

In The Netherlands the main reasons for culling cows are poor yield and appearance (35%), poor fertility (20%) and mastitis (8%) (Van de Venne, 1987). When these factors are successfully included in the replacement model, the system will support about 63% of all treatment and replacement decisions in dairy cattle management. Thus the model is a promising tool to help farmers in management.

The usefulness of integrating state of clinical mastitis into this type of replacement model largely depends on the ability to classify cows according state of mastitis. In the 'Health Manager' module of the Milk Production Project, an effort is being made to automate this classification. In the current HMP approach, which is part of the 'Production Manager' module, it was assumed that it is possible to correctly classify cows with mastitis. On-line practical use of the Production Manager module thus depends on the results of the Health Manager module. However, for research purposes, these two modules being operated completely independently. The ultimate goal of the Milk Production Project is to build a complete, integrated knowledge-based system to be used to give on-line advice on mastitis.

Acknowledgement

This research is part of one of the projects funded by the Foundation for Knowledge Based Systems (SKBS), a Dutch foundation that stimulates research in the field of KBS and technology transfers between universities and industry.

References

Bellman, R.E., 1957. Dynamic programming. The Princeton University Press. Princeton, NJ, USA.

Congleton, W.R. & L.W. King, 1984. Profitability of dairy cow herd life. Journal of Dairy Science 67:661.

Hogeveen, H., E.N. Noordhuizen-Stassen, J.F. Schreinemakers & A. Brand, 1991. Development of an integrated knowledge-based system for management support on dairy farms. Journal of Dairy Science. Accepted for publication.

Houben, E.H.P., A.A. Dijkhuizen & R.B.M. Huirne, 1992. Knowledge based support of treatment and replacement decisions in dairy cows with special attention to mastitis. Proceedings of the SKBS/MPP symposium, Zeist. The Netherlands.

Howard, R.A., 1960, Dynamic programming and Markov processes. MIT Press. Cambridge, MA, USA, 136 pp.

Huirne, R.B.M., 1990. Computerized management support for swine breeding farms. Ph.D. Thesis, Department of Farm Management, Wageningen Agricultural University, The Netherlands.

Kennedy, J.O.S. & A.W. Stott, 1990. An adaptive decision-making aid for dairy cow replacement. Proceedings of 6th EAAE Congress, The Hague, The Netherlands.

Kristensen, A.R., 1987. Optimal replacement and ranking of dairy cows determined by a hierarchic Markov process. Livestock Production Science 16:131-144.

Kristensen, A.R., 1988. Optimization techniques in replacement models. In: S. Korver & J.A.M. Van Arendonk (Eds.): Modelling of livestock production systems. Kluwer Academic Publishers, Brussels, Belgium, p. 97-104.

Kristensen, A.R., 1989. Hierarchic Markov processes and their applications in replacement models. European Journal of Operational Research 35:207-215.

Renkema, J.A. & J. Stelwagen, 1979. Economic evaluation of replacement rates in dairy herds. I. Reduction of replacement rates through improved health. Livestock Production Science 6:15.

Schepers, J.A. & A.A. Dijkhuizen, 1991. The economics of mastitis and mastitis control in dairy cattle: a critical analysis of estimates published since 1970. Preventive Veterinary Medicine 10:213-224.

Van Arendonk, J.A.M., 1985. Studies on the replacement policies in dairy cattle. II. Optimum policy and influence of changes in production and prices. Livestock Production Science 13:101-121.

Van Arendonk, J.A.M., 1986. Studies on the replacement policies in dairy cattle. IV. Influence of seasonal variation in performance and prices. Livestock Production Science 14:15-28.

Van Arendonk, J.A.M., 1988. Management guides for insemination and replacement decisions. Journal of Dairy Science 71:1050-1057.

Van Arendonk, J.A.M. & A.A. Dijkhuizen, 1985. Studies on the replacement policies in dairy cattle. III. Influences of variation in reproduction and production. Livestock Production Science 13:333-349.

Van de Venne, 1987. The influence of milk levy system at the age at replacement and reasons for replacement of dairy cows. Department of Animal Breeding. Wageningen Agricultural University. The Netherlands. Publication nr. 6, 32 pp. (in Dutch).

Van der Wal, J. & J. Wessels, 1985. Markov decision processes. Statistica Neerlandica 39:219-233.

White, C.C. & D.J. White, 1989. Markov decision processes. European Journal of Operational Research 39:1-16.

Development of a knowledge-based system describing the relations between mastitis and milking machines

H. Hogeveen, J. van Vliet, E.N. Noordhuizen-Stassen & A. Brand

Utrecht University, Department of Herd Health and Reproduction, Yalelaan 7, 3584 CL Utrecht, The Netherlands

Summary

Much specialist knowledge on the relationship between milking machines and mastitis is necessary to diagnose a mastitis problem on a farm. If a knowledge-based system must perform the mastitis diagnosis, it should include a subsystem dealing with milking machines. This paper describes the development of a multilayer conditional causal model on the relationship between milking machines and mastitis. The top level of the model gives an overview of the general process of udder infection. During reasoning the user can zoom into submodels which give more detail. The top level, a second level submodel on impacts and a third level submodel on liner slip are described.
Keywords: mastitis, milking machines, knowledge-based systems, conditional causal models.

Introduction

In The Netherlands several universities and institutes are collaborating to develop a large-scale knowledge-based system for integrated management support on dairy farms. This project, known as the Milk Production Project (MPP), pays attention to the health and production of a dairy herd, and to their financial consequences (Hogeveen et al., 1992a). Because of the great economic impact of mastitis (Schakenraad & Dijkhuizen, 1990), the health module of the MPP focuses on mastitis (Hogeveen et al., 1992a). There are many cow, environmental and management factors related to the induction and outcome of an udder infection. Much specialist knowledge in various domains is necessary to diagnose a mastitis problem on a farm. A veterinarian or farm advisor does not have all that specialist knowledge. Therefore a knowledge-based system can help a farm advisor or veterinarian when diagnosing a mastitis problem on a farm.

The milking machine may influence udder health in various ways (Williams & Mein, 1985; Grindal, 1988; Østerås & Lund, 1988; Spencer, 1989). Thus, when creating a knowledge-based system to diagnose a mastitis problem, an important part of the system deals with the influence of a milking machine on udder health.

This paper describes how a knowledge-based system on the relations between milking machines and mastitis is being developed. Parts of the system will be described in detail.

Material and methods

Knowledge representation scheme

There are various knowledge representation schemes. One technique is to use models which explicitly describe the structure of a particular domain and thus represent the structural mechanisms of a system. Using models to represent knowledge has various advantages above using the more traditional "IF-THEN" rules, which represent heuristic symptom/cause associations (Iwasaki, 1989; Plant & Loomis, 1991).

In this study the knowledge representation scheme used is a conditional causal model. The basic elements of a conditional causal model are shown in Figure 1.

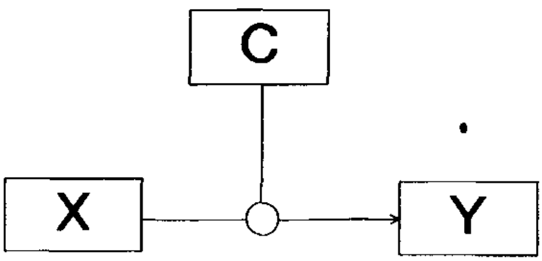


Figure 1. Graphical representation of the basic elements of a conditional causal model.

The conditional causal model consists of a set of nodes describing a domain. The nodes are connected by unidirectional links (arrows) which represent a causal dependence of a node on another node. The magnitude of a relation between two nodes can be influenced by zero or more conditions (Schreinemakers, 1991). In Figure 1 node *Y* is causally dependent on node *X*, while this relation is influenced by node *C* (Hogeveen et al., 1992a). When using conditional causal models, forward and backward reasoning is possible.

When a model becomes large the clarity can be enhanced by using multiple levels. There are two methods of creating multiple levels: by compartmentalization and by depth (Hogeveen et al., 1992b). In the models on the relationship between milking machines and mastitis, compartmentalization is used, which means that a node in a model represents a group of nodes at a lower level.

Conditional causal models can be created using the CAMEL tool (Tepp & Schreinemakers, 1991).

Knowledge acquisition

A knowledge engineer and a domain expert collaborated to create the models. Initial models were developed on the basis of interviews with the domain expert. These models gave only a graphical representation of the domain and the relations between the variables were not qualified. The initial models were adjusted after discussions with the domain expert. This cycle was repeated until the domain expert considered the models to be correct. At that point the relations between variables were qualified.

Results

The overview level

The top level of the system is also referred to as the overview level. It gives an overview of the general process of a mastitis infection and how this interacts with a number of mechanisms. The general process of mastitis infection is given in the middle part of Figure 2. This process, however, is not complete, it focuses on the milking machine and contains only those parts of the mastitis infection process that interfere with the milking machine. The sources of bacteria leading to a mastitis infection can be:

1. the (barn) environment;
2. an infected quarter of the same cow;
3. an infected quarter of another cow.

Through various pathways, bacteria can enter the milk collected in the milking cluster (Figure 2). Bacteria in the cluster milk can lead to infection through two mechanisms:

1. bacteria can attach to and colonize the teat skin (in Figure 2 represented by the loop arrow), which can ultimately result in an infection;
2. a reverse pressure gradient or an impact can force bacteria directly into the teat cistern, which can lead to mastitis.

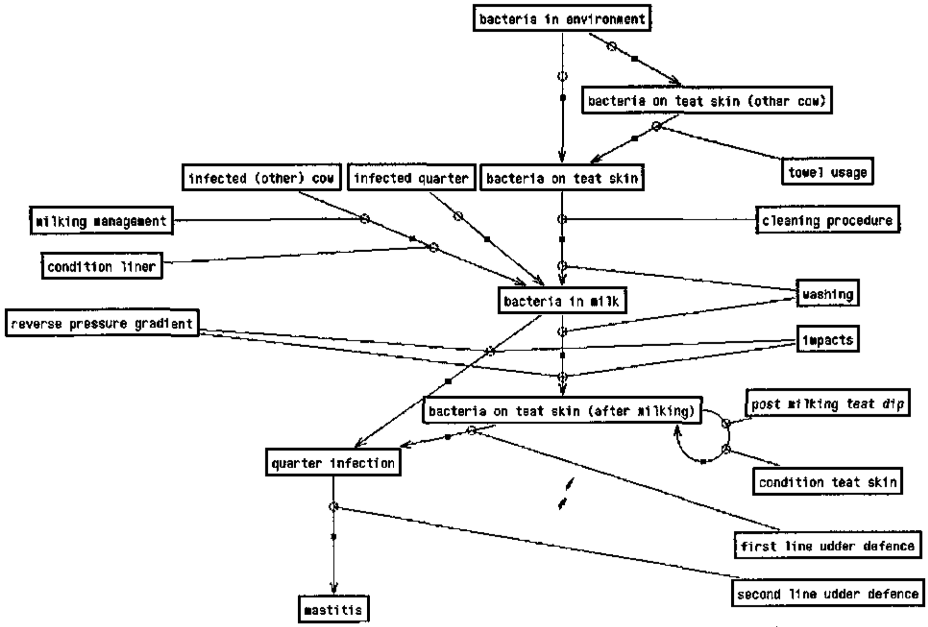


Figure 2. CAMEL screendump of the overview level.

The nodes on the right and left side of Figure 2 are conditions. The value of these conditions can be manipulated by the farm management. The nodes *washing*, *impacts*, *reverse pressure gradient*, *condition teat skin*, *first line of udder defence* and *second line udder defence* are representations of lower level submodels. The nodes *impact*, *reverse pressure gradient* and *washing* are strongly related to the milking machine. Milking machines are also an important part of the submodel under the node *first line udder defence*, through their effect on the condition of the teat sphincter.

It is impossible to describe here all lower level submodels on the relationships between milking machines and mastitis, therefore the submodel represented by the node *impact* will be used as an example.

The submodels on impact

Impacts are caused by irregular fluctuations of vacuum and are conditioned by the reserve capacity of the vacuum pump, total volume of the milking system and the type of milking claw. These relations are represented in Figure 3 and are part of the second layer of the total model.

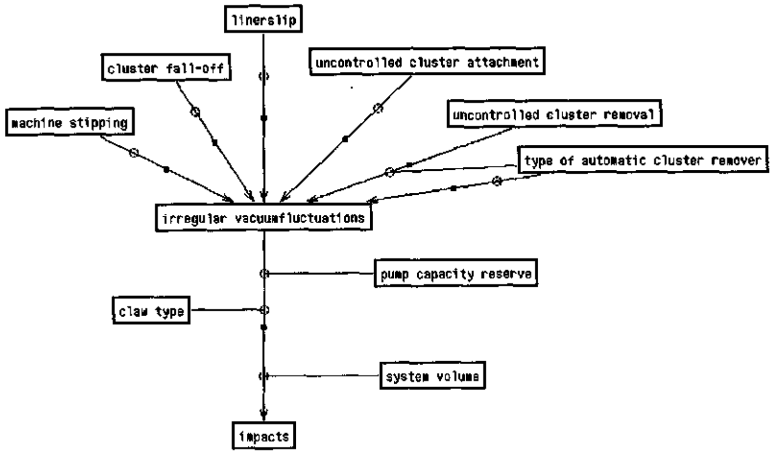


Figure 3. CAMEL *screendump of the impact submodel.*

The various mechanisms resulting in irregular fluctuations of vacuum are also given in Figure 3. The nodes *system volume*, *pump capacity reserve*, *cluster fall-off* and *liner slip* represent underlying submodels and are part of the third layer of the model.

The conditional causal model for liner slip is given in Figure 4. Liner slip can be caused by a wrong weight distribution of the milking cluster or by the wrong type of liner. The relation between the nodes *liner slip* and *claw weight distribution* is influenced by the condition *udder type*. The relation between the nodes *liner slip* and *liner type* is influenced by the conditions *teat type* and *liner condition.* There is no fourth layer under the liner slip model.

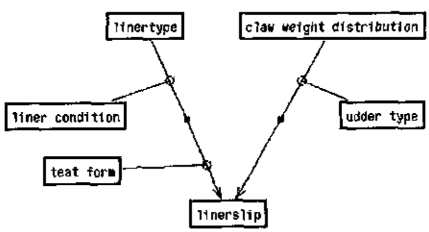


Figure 4. CAMEL *screendump of the liner slip submodel.*

Reasoning and interaction with the user

When diagnosing a mastitis problem on a farm, the method of backward reasoning will be used. This means that the reasoning process is started with a change in the value of the last node in the model. In our case this is node *mastitis* in Figure 2. During the reasoning process possible causes for the mastitis problem will be given. The user can check the solution and if it is rejected as possible solution, the reasoning process will continue.

When the value of the node *mastitis* is changed, the model starts reasoning using predefined preferences of search paths. The farm's database and information given by the user are used to find possible situations that can lead to the given value of node *mastitis*. When the model finds as possible cause "too many impacts" the user can zoom into the node *impact* and the submodel given in Figure 3 appears on the screen. Reasoning continues within the impact model. If the reasoning process determines that "too many liner slips" can be the cause of the impact problem, the user can zoom into the node *liner slip* and reasoning will continue within the liner slip submodel.

The reasoning process continues until a satisfactory solution is found or until all possibilities have been checked.

Discussion

The overview level described in this paper is not complete. It focuses on the relationship between milking machine and mastitis. Other infection mechanisms (e.g. infection through contaminated bedding material) are not modelled in the overview level described in this paper. The conditional causal models on the other infection mechanisms will be developed in the near future. A conditional causal model for first line of udder defence has already been developed (Hogeveen et al., 1992b), and a model on the second line of defence is currently being developed. Norwegian researchers found that 16-45% of the inter-herd variation in udder health was explained by milking machine defects and faulty milking management (Østerås & Lund, 1988). Other models are therefore also important to explain a mastitis problem on a farm. However, the working of the milking machine on a farm can be better controlled by management measures than the working of a cow's second line of defence.

The working of the milking machine can affect the mastitis situation of a farm in two ways:

1. as a vector by actively transporting bacteria to and sometimes into an udder quarter;
2. by affecting the condition of the teat and therefore the functioning of the first line of udder defence (Spencer, 1989).

Despite all research effort to define the relations between milking machine and mastitis, the relations are still not precisely known. There is still discussion on how certain mechanisms are modelled in our knowledge-based system. However, our knowledge-based system is intended to be used by farm advisors. It will not be used as a "black box", but will allow the farm advisor to interact with the reasoning process. It is more important that the system gives all possible causes in the right context than that the relations are modelled exactly. In The Netherlands a standardized scheme is used to measure milking machine performance during milking. The variables collected in this milking machine performance report can be used by the knowledge-based system described in this paper.

The knowledge-based system presented here is still in a development stage. The preliminary results indicate that it is possible to detect milking machine defects as a cause of a mastitis problem. In addition to its possible use as problem solver by farm advisors, the multilayer conditional causal model presented here gives a good schematic overview of the relations between milking machines and mastitis. It can also be used as knowledge source for research and for teaching purposes.

Acknowledgements

This research was made possible by the Foundation for Knowledge Based Systems (SKBS), a Dutch foundation that stimulates research in the field of knowledge-based systems and technology transfer between universities and industry in the development of knowledge-based systems.

The authors thanks Kees de Koning for his critical review of the milking machine model.

References

Grindal, R.J., 1988. The role of the milking machine in mastitis. British Veterinary Journal 144:524-533.

Hogeveen, H., J.F. Schreinemakers & E.N. Noordhuizen-Stassen, 1992a. Application of conditional causal models in an integrated knowledge-based system for dairy farms. AI Applications (in press).

Hogeveen, H., J.F. Schreinemakers & E.N. Noordhuizen-Stassen, 1992b. A multilayer conditional causal model for udder defence (in Dutch). Submitted to: Dutch Artificial Intelligence Conference (NAIC), Delft, The Netherlands.

Iwasaki, Y., 1989. Qualitative physics. In: A. Barr, P.R. Cohen & E.A. Feigenbaum (Eds.): The handbook of artificial intelligence Vol. IV. Addison wesley Publishing company, Reading, Massachusetts, USA, p. 323-413.

Østerås, O. & A. Lund, 1988. Epidemiological analyses of the associations between bovine udder health and milking machine and milking management. Preventive Veterinary Medicine 6:91-108.

Plant, R.E. & R.S. Loomis, 1991. Model-based reasoning for agricultural expert systems. AI Applications 5(4):17-28.

Schakenraad, M.H.W. & A.A. Dijkhuizen, 1990. Economic losses due to bovine mastitis in Dutch dairy herds. Netherlands Journal of Agricultural Science 31(1):89-92.

Schreinemakers, J.F., 1991. Pattern recognition and symbolic approaches to diagnosis. Dissertation, Erasmus University Rotterdam, The Netherlands.

Spencer, S.B., 1989. Recent research and developments in machine milking - A review. Journal of Dairy Science 72(7):1907-1917.

Tepp, D.M. & J.F. Schreinemakers, 1991. CAMEL: Causal model environment and laboratory. Management Report Series No. 97, Erasmus University Rotterdam, The Netherlands.

Williams, D.M. & G.A. Mein, 1985. The role of machine milking in the invasion of mastitis organisms and implications for maintaining low infection rates. Kieler Milchwirtschaftliche Forschungsberichte 37(4):415-425.

5. General assessments

Automatic milking and animal breeding

H.O. Gravert

Federal Dairy Research Centre, P.O. Box 6069, D-2300 Kiel 14, Germany

Summary

Animal breeding is a part of domestication and can be regarded as adjusting the genotype to a given environment. It includes identification of cows, recording production figures as well as indirect traits like fertility, udder health and feed efficiency. In automated milking only the B method in milk recording (owner-sampling) is applicable and automated milk-meters are required to measure the daily milk yields. Daily recording will cancel out random deviations much more effectively than monthly recording in the traditional A4 method.

So far no reliable data are available to estimate genetic parameters under automated milking conditions. Naturally the genotype of the cow has to be adjusted to the new system, mainly with respect to udder shape and teat placement as well as temperament. Changing udder shape will not be a major problem, but selection of cows reacting positively to the new system will take several generations.
Keywords: individual identification, milk recording, automatic milking, breeding, cow adaptation.

Introduction

Animal breeding can be seen a part of domestication. In prehistoric times when cows were used primarily for milk production, selection was mainly directed towards calmness of cows, temperament and let-down effect of milk ejection. Even today, local indigenous breeds require the presence of the calf when the cow is milked. Milk ejection from the alveolate into the cistern is caused by the contraction of the myoepithelial basket cells which surround the alveolate. This contraction is regulated by oxytocin, a hormone stored in the posterior lobe of the pituitary gland and released by nervous stimulation. Therefore let-down of milk can be blocked, e.g. when cows are frightened during milking, by releasing adrenaline from the adrenal medulla. Insofar as it is normal, the let-down of milk is a combined effect of genotype and environment where cows have been selected for robustness to fright and the environment has been adjusted to avoid any unusual noise, tactile or other disturbances. In this sense breeding for automated milking will become a new challenge.

Breeding the right animals includes accurate identification and recording, estimating genetic parameters for recorded and desired traits as well as mating the "best" animals. Here, "best" means cows with the highest marginal profit under systems of automated milking.

Identification and recording

Electronic identification of dairy cows has proved successful under practical conditions for about 20 years. Implants may be cheaper than transponders round the neck, but there may be some constraints when culled cows have to be slaughtered. Electronic identification does not seem to be a major problem for automated milking. The equipment will open the respective gates and routes. Information on the teat position of each cow can be stored in the computer, and the amount of concentrates can be adjusted to the liveweight and milk yield of each individual cow.

Milk yield

In milk recording in automated systems the traditional A4 method of the International Committee of Animal Recording (ICAR) is not applicable. A4 means that an independent person from the recording organization measures the milk yield during milking times on one day every 4 weeks or once a month (Gravert, 1987). This person has to be present on the farm when the cow is milked, which seems impossible with automated milking.

Therefore only the B method is applicable, in which the farmer or stockman takes the records and samples. This method, also known as owner-sampling, is widespread in areas with low cow density and high labour cost, as in Scandinavia. Many breeding organizations in other countries, however, require the A method for registering cows in the herdbook. Registration is a prerequisite for selling breeding stock which might be a significant source of income for leading dairy farms. For example, in Germany about 300 000 animals are sold annually as breeding stock, with a value of about 600 million DM. This is equivalent to 4 per cent of the total milk sales (ADR, 1991).

Though in the B method the farmer himself records milk yield and takes samples, its accuracy seems to be comparable to the A method. Less accuracy of the B method in relation to the A method could be caused by intentional bias and larger random errors. Therefore any incentive to manipulate records should be avoided. This can be achieved if absolute production figures are replaced by estimated breeding values which are based on pedigree, half and full sibs and offspring when available. However, even in such an estimated breeding value, calculated by an Animal Model, the own performance of a cow is included, and the breeding value might also be biased.

An "Animal Model" means that the breeding value, which is defined as the additive genotype of an animal, is estimated as Best Linear Unbiased Prediction (BLUP) from production records of related animals (Henderson, 1975). Any opportunity to manipulate records has to be prevented as far as possible. In automated milking this can be done by automated recording of each milk yield of each milking within 24 hours.

With regard to random errors the problems seem less severe. When recording by the A4 method ICAR requires that the devices to measure the milk yield must have a standard deviation of the differences between true and measured yields of less than 250 g for milk yields up to 10 kg and less than 2.5% for milk yields above 10 kg. This would mean that the maximum standard error deviation of a mean of 10 test days with morning and evening records per annum is about $2.5 : \sqrt{20} = 0.6\%$. If we measure the milk yields in automated milking, the total number of records per cow and lactation will be nearly 1000 instead of 20. So the records are much more accurate with automated milking, even if the milk meters work with a larger random error. Theoretically the random error could be $0.6 \times \sqrt{1000} = 19\%$ of the single record.

With respect to the ICAR requirements regarding bias, the milk meters for automated milking have to be the same as conventional milk recording. If there is a bias, e.g. of + 1%, then the annual production of a cow is overestimated by 1%, independent of the number of measurements.

With daily recording the actual annual milk yield or lactation yield is measured. In conventional systems, however, samples are taken just once a month. As a rule 9 to 11 test days are used as a sample and each record is multiplied by the number of days between two test days. Therefore the true annual or lactation record of a cow is estimated from these test days. Because there is a random day-to-day fluctuation in milk yields from a cow, the estimates are connected with a further random variation. This day-to-day variation is about 5% of the average daily yield.

Milk composition

Another problem arises when sampling milk for fat and protein content as well as for cell counts. Though technical solutions for daily sampling seem feasible, practical installation will not be worthwhile. So I would recommend taking samples once a month from all milkings on a day and mixing them proportionally to the respective milk yields so that one sample per cow and per 24 hours is made. Then take another sample from the bulk milk for a cross-check. Clearly, proportional sampling is extremely important in automated milking, since the fat content - and to a lesser extent the protein content - depends on the interval between milkings.

In automated milking devices are foreseen to monitor the health status of each quarter permanently (Ordolff, 1989). So cell count numbers in milk samples may be of less value than they are in traditional milking. As far as fat content of milk is used as indicator of correct feeding, the fat content of the bulk milk gives more information than that for the milk of individual cows. The same will be true for the protein content. If there is an energy deficit in high-yielding cows, their acetone content in milk might serve as a reliable indicator. It is rather stable during the day and taking one sample to measure acetone would be sufficient.

Breeding for automated milking

So far, no reliable data are available to investigate genetic parameters with regard to automated milking. From the experience with general introduction of milking machines in the middle of this century it is clear that the suitability of cows for automated milking will be different and that this difference also has a genetic background.

Udder conformation

For good machine milking the teats had to be shorter and thinner than for hand milking. For automated milking the correct placement and direction of the teats will be important. With automated milking the udder capacity can be less than it needs to be nowadays, and each cow can be milked when about 5 to 10 kg milk have been synthesized in the alveolae. Therefore, the ideal udder shape might differ from the ideal form of today. Both traits, teat position and udder shape, are very heritable. In most breeding associations cows are inspected and judged according to a "linear description" of 10-12 body traits (Diers, 1986). The heritabilities of different traits in different populations depend on real differences in genetic variances between populations as well as on different accuracies and experience of the classifiers. Most estimates for udder shape and teat placements vary around h^2 = 0.2 and 0.3 respectively (Legates, 1970, Thompson et al., 1981, Christensen, 1982, Meyer et al., 1987, Swalve & Flock, 1990). This enables the breeding values of AI bulls to be estimated reliably by evaluating about 30 daughters per bull. This would make it possible to select bulls which can change udder shape and teat positions into the desired direction. These traits can be changed significantly within 2-3 generations, which will take about 10-15 years.

Cow behaviour

It might be more difficult to change the nervous system of the cow. Every stockman knows that cows are very sensitive animals and that smooth or rough treatment affects the let-down effect of milk, and this causes significant differences in milk flow rate and milk yield. Nevertheless the cow is a creature of habit like other animals. By training it can be adjusted to unusual conditions. However, the degree to which behaviour can be changed will also have some genetic background, as demonstrated by wild and domesticated animals (Meyn & Wilkins, 1974). In total, however, the selection response to change nervous reactions and behaviour pattern will be rather small because these traits are difficult to measure and the number of cows for selection is limited to those which are really milked automatically. So most selection for good temperament will be just phenotypic selection with little genetic consequences.

Breeding for milk yield

For practical breeding the question arises: to what extent are cows that are good for conventional milking also good for automated milking? Theoretically the breeding value of a cow could consist of two parts: one is the general ability to produce milk under both systems and the other part is specific to each system. Therefore the relative importance of the general part can be quantified by the correlation coefficient between production figures for the same cows in both systems. If the ranking of cows in conventional and automated milking is identical, then the expected correlation is 1. A correlation of 0 would mean that all information about production ability under conventional milking is useless for automated milking. In our experiment with 55 cows we found a correlation of $r = 0.72$, which means that in general the ranking of cows under conventional milking was the same as under automated milking, but with some exceptions (Kremer, 1992: personal communication). Of course, due to random sampling the correlation between averages of 50 days in a sample of 55 cows even within the same milking system will be less than 1. We simulated such a trial from our experimental herd with daily milk recording and calculated 50-day averages for 55 cows within a conventional twice per day milking. The correlation between these averages was $r = 0.78$ which is the "repeatability" of a 50-day yield. Therefore the selection response in herds with automated milking will be about the same as in the conventional system. Since it is generally agreed that frequent milking does improve milk production, the question may arise whether the records should be corrected when used to estimate breeding values. This is done with 3× milking instead of 2× (USDA, 1980). In my opinion this correction is not necessary, because automated milking is applied to all cows and during the whole lactation within a herd. Therefore the effect of automated milking acts as a herd effect like good management and is removed by incorporating the herd effect into the model.

Conclusion

Summing up we see the need to develop milk meters for automated milking and to negotiate the milk recording procedure with the respective organizations. With regard to breeding, no major change from the conventional systems seems necessary.

References

ADR, 1991. Rinderproduktion in der Bundesrepublik Deutschland 1990, 225 pp.

Christensen, L.G., 1982. Type evaluation of dairy cattle in Denmark. National Institute for Dairy Science, Kopenhagen, Denmark.

Diers, H., 1986. Nachkommenschaftsuntersuchungen zur linearen Exterieurbeschreibung in der Schwarzbuntzucht Niedersachsens. Dissertation. Göttingen, Germany.

Gravert, H.O., 1987. Dairy Cattle Production. World Animal Science C 3. Elsevier, 309 p.

Henderson, C.R., 1975. Use of all relatives in intraherd prediction of breeding values and producting abilities. Journal of Dairy Science 58:1910-1916.

Legates, J.E., 1970. Components of variance for descriptive type classification of Holstein-Friesian cows. Journal of Dairy Science 54:775-781.

Meyer, K., S. Brotherstone & H. Hill, 1987. Inheritance of linear type traits in Dairy cattle and correlations with milk production. Animal Production 44:534-543

Meyn, K. & J.V. Wilkins, 1974. Breeding for milk in Kenya with particular reference to the Sahiwal Stud. World Animal Review, p. 24-30.

Ordolff, D., 1989. Voraussetzungen und Grundlagen automatischer Milchgewinnung. Habilitationschaft, Hohenheim, Germany, 188 pp.

Swalve, J.J. & D. Flock, 1990. Berücksichtigung von Beurteilermittelwert und -standardabweichung als wichtige Einflußgrößen bei der Analyse von Daten der linearen Exterieurbeschreibung. Züchtungskunde 61:367-383.

Thompson, J.R., A.E. Freeman, D.J. Wilson, C.A. Chapin & P.J. Berger, 1981. Evaluation of linear type traits program in Holsteins. Journal of Dairy Science 64:1610-1617.

USDA, 1980. Dairy Herd Improvement Letter 56, No. 4.

Ethology and technology: the role of ethology in automation of animal production processes

J.F. Hurnik

University of Guelph, Department of Animal and Poultry Science, Guelph, Ontario, Canada N1G 2W1

Summary

Strongly emerging ethical concerns for the quality of life of farm animals demands serious attention of the designers of contemporary production systems. The milking parlour itself, and all aspects of the milking process, should be comfortable and positively reinforcing to the animals involved. Milking frequencies or voluntary entries must be monitored continuously and deviation investigated in order to minimize potential development of negative conditioning to the milking unit. The designers of automatic milking systems could consider increasing the number of milking compartments to accommodate computer-controlled preset entries of more animals simultaneously.
Keywords: milking cows, animal welfare, behaviour, automatic milking systems.

Introduction

It is always easier to adjust newly-developing animal production technologies to the biological requirements of animals, rather than animals to the technology. It is therefore surprising how often this simple rule has been ignored in our search for new animal production systems.

The design of animal facilities and management systems has traditionally been dominated by economic considerations, often only short-term economic considerations. Scientists in animal agriculture have not, in the past, very systematically utilized the potential benefits of ethological information to improve the productivity of farm operations and better the wellbeing of farm animals. Strongly emerging ethical concerns for the quality of life of farm animals demands serious attention of the designers of contemporary production systems to psychological propensities and social tendencies of farm animals. Particularly in our time when the search for new animal production systems has become much more dependent on the expertise in technical fields of mechanics and automatization, it is very important to remind ourselves that successful animal husbandry technologies must respect all the basic biological requirements of animals involved.

The concept of harmony between animals and their surroundings

In order to minimize misunderstanding, let me first briefly qualify that, in my presentation, behaviourial response is defined as any observable action of the organism that results from stimulation, regardless if such stimulation has its origin within or outside the organism, and regardless of whether or not the observed response is influenced or uninfluenced by conditioning process (i.e. if the response is instinctive or acquired by experience).

Optimal biological functioning of an organism occurs only when it lives in the most appropriate surroundings. Let us call such an ideal blend between the organism and its surroundings a state of harmony and assume that, under such conditions, and only under such conditions, the best overall biological functioning of the organism is assured and the maximum quality of its life is reached. Optimal biological functioning does not necessarily mean the highest performance, such as the fastest speed, the most powerful response, or the strongest reproduction. Highest performance may lead to lower quality of life by weakening the organism through exhaustion and greater susceptibility to infection or injury, or linked to early mortality. In relation to animal quality of life, i.e. wellbeing or suffering, the concept of biological functioning must be based on the organism's overall capacity to interact with its surroundings and successfully adjust to changes as they occur during its life. The concept of harmony rests on optimal convergence - the best possible blend - between the organism and its environment, achievable only through adjustment of surroundings to the genetic and ontogenic predisposition of the organism, or full adaptation of the organism to its surroundings. The term harmony should, thus, be understood as a theoretical framework, an abstract notion of optimal biological state of the organism.

Farm animals, as do all other animals, possess a range of behaviourial expectations regarding their surroundings in order to live as physically and psychologically healthy individuals. If the opportunity to exercise these expectations is frustrated, harmony will be seriously violated and the quality of life reduced. To assure essential welfare standards, farm animals in all production systems should have the benefit of:

- adequate air, water and feed supply according to their biological requirements for normal growth and development;
- safe housing and a sufficient amount of space to prevent injuries or atrophies;
- appropriate level of environmental complexity to prevent harmful deprivation and boredom, or aversive stimulation and fear;

- regular daily supervision and effective health care to minimize undetected accidents and initiate prompt assistance;
- sensible handling in all stages of their life to avoid unnecessary suffering.

In the context of agricultural ethics, discussion of such a concept does not, in itself, fully define our obligations toward farm animals. Moral acceptability of a given production system depends on joint consideration of the animal's quality of life, achieved productivity, and ecological consequences. In this presentation, I intend to deal only with one segment of this complex assessment, by focusing on behaviourial information relevant to the development and management of automatized milking parlours.

Innate and learned behaviours

As indicated earlier, the development of any sophisticated, new technology for animal production systems requires solid technical and biological expertise. The technical expertise includes material choice, mechanics, design engineering, electronics, computer programming, economics and other related fields. The biological expertise incorporates familiarity with animal requirements for space, air supply, thermal protection, nutrition, and behaviour. Familiarity with behaviourial characteristics requires not only a knowledge of the inventory of animal actions, but also an understanding of the underlying psychology for these actions. This means familiarity with animal sensory capacities, learning ability, and motor skills or, in other words, the animal's ability to detect events in their surroundings, memorize the specific significance, and act accordingly. Events to which animals respond are stimuli for their action. Such action might be innate or acquired through experience (Figure 1). Controlling any behaviour requires a clear understanding of which of the above categories the particular action belongs.

Innate action, consisting typically of involuntary reflexes and genetically fixed instincts, control the organism's homeostasis (e.g. the maintenance of metabolic balance, immunobiological defence, posture coordination) and other important survival-related functions of the organism. As a result of the genetic fixation, they show no, or relatively little, variability among individuals of a given species and thus are difficult to modify by experience or training. Learned responses, characterized as behaviourial actions acquired through experience, are much more plastic and the variability from individual to individual of the same species is often distinct. The learning success of individual animals depends on their sensory capacity to identify stimuli, memorize their effects (i.e. to detect associations between stimuli), and their ability to execute the appropriate response. In contrast to a relatively consistent inventory of innate behaviours, differences in learning skills generate adaptive variability among individual organisms of the same species. Learning, therefore, provides opportunity to alter the behaviourial inventory of animals, and thus develop skills necessary for harmonization of animal behaviour with the proposed technology. Such adaptability, however, is limited by the psychological and physiological predispositions of each individual animal.

Innate behaviour:

STIMULUS

• sense datum	sensory capacity	stimulus occurrence
• afferent transmission		
• efferent transmission		
• motor action	motor capacity	fixed action performed

RESPONSE

Learned behaviour:

STIMULUS

• sense datum	sensory capacity	
• afferent transmission		stimulus perception
• association	learning ability	
• efferent transmission		learned action performed
• motor action	motor capacity	

RESPONSE

Figure 1. Operational schemes of reflexive and learned behaviour (reflexive behaviour is considered to be the simplest form of innate behaviour).

Animal learning can be divided into four types:

- habituation learning;
- latent learning;
- motor skill learning;
- problems solving learning.

All four types play a role in an animal's adaptation to production technology and, therefore, deserve the attention of both designers and managers of animal facilities.

Habituation Learning is an extinction form of learning, related to stimuli perceived originally as aversive or attractive but, by experience, proven to be neutral. A dairy cow, for example, may be at first very reluctant to enter a new or renovated area of the barn or an unfamiliar walking passage. However, after experiencing its safety, the signs of fear disappear.

Latent learning refers to situations wherein the formation of new associations can be enhanced with better familiarity of the animal with its overall surroundings, or with the device the animal is expected to enter or operate. Heifers which have an opportunity to freely investigate a milking parlour before the beginning of lactation learn the milking routine much faster.

Motor skill learning refers to the acquisition of new skills or the enhancement of existing motor skills. Success of this type of learning depends on how well the new facilities or technology concord with normal motor actions of the animal. Actions which are difficult or in conflict with natural postures and/or movements of the animals are perceived as aversive and the animal will tend to avoid them. The effective use of a new type of feeder or waterer may require a period of practise if its use is conditional on animal ability to operate them, or if special motor skills are required to reach these devices. Mutual mounting of cows can be seriously inhibited if the floor has inadequate traction or if the ceiling of the building is low and the animals (particularly older cows) are unable to develop skills to overcome this handicap.

Problem solving learning usually refers to circumstances when the correct response depends on the capacity of the animal to utilize experience from other learning trials, or by observing other animals act. This is the most demanding form of learning in which progress reflects closely the cognitive abilities of the responding organism. Animal cognitive capacities which depend on abstractions or logical deduction appear to be limited in comparison to humans. Nevertheless, animals are able to solve situations if they do not exceed their sensory modes, memorizing capabilities and motor skills. It is known to farmers that some cows, in order to reach better pastures and to satisfy their exploratory curiosity, may learn to neutralize an electric fence by pushing down on its holding sticks, or opening apparently safe gate locks.

Cattle will more readily learn to perform tasks or operate devices that are easily detectible by animals. Designers of dairy housing and milking facilities, designers should also, therefore, be familiar with the sensory capacities of dairy cattle.

The visual field of cattle is about 340°, but their vision is, for the most part, monocular. Binocular vision is relatively narrow. This means that cows can visually monitor their entire surroundings, yet to accurately assess distances outside their field of binocular vision, they must turn their heads. This explains why a cow's movement forward is interrupted if she must turn her head sideways to assess a novel or distracting object.

Scotopic vision in cattle is well developed, and therefore they can see relatively well at low light intensity and at night. Their chromatic vision, however, appears to be limited. Contrasting edges or borders are highly noticeable to cattle and, if unfamiliar, will always cause animals to stop and investigate before proceeding. This investigation is initially visual, followed by proximate olfactory investigation of the object, and finally licking or contacting it with the nose. Efficient movement of cattle through handling areas requires uniform illumination with a minimal of visual or other distractions. This is of particular economic importance in the movement of cattle to and from the milking parlour.

The auditory capacity of cattle is well developed, and sensitivity to unfamiliar noises is high. Olfaction (smell) in cattle is excellent and plays an important role in any close examination of new stimuli. Cows have a relatively high tolerance for acid taste, and a distinct preference for sweetness.

Behaviour and milking parlour

The milking parlour itself, and all aspects of the milking process, should be comfortable and positively reinforcing to the animals involved. Healthy cows with healthy udders seem to enjoy being milked, and for the best yield and efficiency, nothing should interfere with this enjoyment. The milking parlour must therefore never be used for other purposes, particularly treatments perceived as aversive or painful. In traditional milking systems, cows should also never be moved into the parlour except at regular milking times. It is in the best interests of the dairy person that all milking-related activities be performed in a very consistent manner over time.

Milking represents a very complex sequence of conditioning processes. Cows, like most animals, are readily conditioned to events that are consistent in time and form, and can rather precisely anticipate forthcoming events. With experience, the very first cues indicating approaching milking (noise of milking machine being turned on, release of cows from stanchions, etc.) set into motion the complex series of psycho-physiological processes that prepare the cow for milk let-down. Consistent timing leads to full and easy synchronization of these processes with the milking routine, culminating in almost instant milk let-down after the udder is washed and the teat cups attached. For this reason, any change in the order of, or in the time interval between these conditioned cues will disturb the cow's preparation, resulting in sub-optimally timed milk let down. In addition to ensuring efficient milking on the part of the cow, consistent milking routines also serve to streamline workers efforts and maximize labour productivity.

Automatic milking systems

The progress in automatization of animal production will depend, more than any other technological advancements in agriculture, on sensible integration of biological and technical knowledge. By eliminating the need for direct supervisory presence of humans, successful automatization is determined by its operational reliability and best possible adjustment of the technology to the psychophysiological characteristics of animals involved. Automatization demands synchrony between the mechanical systems and each animal in the group (i.e. fast and slow learners, skilful and less skilful animals). It also necessitates a high degree of predictability of animal reactions to the crucial elements of the technology. Furthermore, all of the above critical requirements must be designed to be simple and non-confusing to the cow. This means that cues or signals to which the animals are expected to respond must be easily recognizable and, if possible, instinctively generate attraction.

Approach routes and entrances to the milking unit should be clearly visible and distinguishable from their surroundings. Walkways, holding units and the operation of the milking device itself must be comfortable and non-aversive to the cow. Automatization of teat cup attachments requires a high degree of uniformity in the position of the udder and hind legs. The configuration of the floor under the hind legs to standardize the position of the udder must not cause any discomfort to the milked cow. Such discomfort would certainly interfere with the cow's appreciation of milking and correspondingly reduce motivation for re-entries.

After entry into the milking unit, the identification of teat position and attachment of cups should be consistent in time. Similarly, the time lag between washing and drying of the udder and attachment of the cups should be uniform from milking to milking since these factors are part of the conditioning process influencing milk let-down. As mentioned earlier, cows' behaviourial signs during milking indicate positive reinforcing properties of the milking process. Nevertheless, the motivation for milking cannot be expected to be of such predictable nature and such strength as those observed for drinking and eating. Voluntary approach can be inhibited in the case of illness or injury of the udder. Early detection of problems, particularly precise detection of the first signs of mastitis, must be therefore an integral part of any automatic milking system. Milking frequencies or voluntary entries must be monitored continuously and deviation investigated immediately in order to minimize potential development of negative conditioning to the milking unit. It should be realized that a strong aversive experience (e.g. pain) very often leads to so-called "one trial avoidance learning", usually with long-lasting effects on the animal's behaviour.

Introductory training of cows to the automated milking parlour should start with familiarization with the milking device (latent learning) prior to its use. Learning by observing other cows could also enhance the efficiency of the training process. The use of highly palatable feed in the milking unit may increase motivation for entry. However, extended or continued use of highly palatable feed as a reinforcer could also have negative consequences by increasing competition for entry and rewarding aggressive behaviour of cows.

The concept of regular voluntary entry into automatic milking units is conditional on a stable and effective motivational desire of cows over time. As outlined above, this may not necessarily always be the case if the cow's experience with the device is not positively reinforcing. Additionally, the concept tends to underestimate the factor of social facilitation of animal behaviour. Animals within a herd do not act independent of each other but, more typically, as a coordinated social unit. They eat, rest and prefer to perform many other activities in a synchronized fashion. To expect them to act in a sequence or line, one after the other, would be an overly mechanistic concept for such a social species. Frustration of the important biological phenomena of social facilitation reduces social tolerance among group members. Even if the cows accommodate sequential individual entries into the automatic milking system, this arrangement may reduce the time of socially synchronized resting and be a source of physical disturbance. For these, and several other, important reasons, the designers of automatic milking systems could consider increasing the number of milking compartments to accommodate computer-controlled preset entries of more animals simultaneously - ideally, the whole group. Using microchip implants as reference points for teat positions, all compartments could, perhaps, be served by a single fast-operating sensing unit for accurate teat cup attachment. Such an arrangement would simplify and shorten the training period, extend the capacity of the parlour, and be applicable to conventional tie stall housing systems. In addition, and perhaps most importantly, this design would harmonize with the psychological and social tendencies of dairy cows.

The perception by stockpersons of the effect on their esteem, self-concept and satisfaction of the incorporation of automatic milking into their herds

M.F. Seabrook

University of Nottingham, Rural Business Research Unit, Sutton Bonington Campus, Loughborough LE12 5RD, United Kingdom

Summary

An established group of dairy stockpersons were investigated in order to gain an insight into their perceptions of automatic milking. While age and education level appear to have some influence on attitudes it is the person's self-concept (self-image) which is most crucial. Those stockpersons with a cognised self of being livestock orientated appeared more demeaned by the prospects of automatic milking than those who had a cognised self of being machinery orientated. Similarly those who perceive themselves as progressive see greater opportunities than those who perceive themselves as traditional.

Keywords: stockpersons, self-concept.

Introduction

As part of an on-going research programme the author has drawn together a panel of stockpersons. The technique follows a paradigm widely used in consumer research and enables an in depth understanding to be obtained and enables deeply held views to be expressed. The operation of the panel enables the development of an understanding of the psychological factors that influence the behaviour, attitudes and motivation of those people working with dairy cattle. The panel consist of 24 stockpersons, 12 of whom are employees and 12 are employers or family members of employers who milk cow on the family business. Approximately 50% are over the age of 40 years. Each stock-person is involved in the regular practical task of machine milking about 120 cows through herringbone-type milking parlours. While the panel is not a random sample it does contain representative types of dairy stockpersons and because of the nature of the interaction with the researcher it is possible to obtain a far more accurate picture of true feelings and deep perceptions than is possible with a freshly drawn random sample. The panel have confidence to express their feelings and reservations knowing that their position or employment is not affected in any way.

The panel were introduced to the concept of automatic milking and their views and perceptions gathered. These were then related to known social and psychological parameters of each of the stockpersons.

Perceived attributes of automatic milking

The stockpersons will at this stage only have perceptions of the effects of automatic milking and no real experience, although they will be familiar with automatic feeders and cluster removal. While they are making assessments on the basis of perception their expressed attitudes are important in ensuring that any incorporation of a system of automatic milking into dairy production will be effective.

The experimental procedure followed consisted of two stages. Firstly the individual members were asked to express their feelings both positive and negative about automatic milking. Secondly these expressed views of individuals were then compiled into a list of positive and negative attributes and the importance of each of these were then assessed by each member. An example of positive attributes include "removal of drudgery/routine of milking", and of negative attributes being "loss of interaction with cows", particularly at milking. It must be recognised that some attributes seen as positive by one group may be seen as negative by another.

Table 1. A summary of the perceived positive attributes of automatic milking of dairy cows.

Employees' "positive" attibutes	Employers'/family of employers "positive" attributes
removal of drudgery/routine of milking	removal of drudgery/routine of milking
more sociable and betters hours of work	opportunity to reduce labour on the farm
a new challenge and opportunity	less weekend working
opportunity to develop new skills in electronics	opportunity for innovation and development
opportunity to develop new skills in observing cattle, away from milking parlour	could save costs

For example potential cost saving may be seen as positive by the employers and their family members but negative by employees who may fear for the security of their employment position. Each of the attributes and implications were scored by semantic differential. This enables the study to consider the level of overall balance of positive perception about automatic milking.

The positive attributes as defined are summarised in Table 1, this shows the five key points.

The negative attributes as defined are summarised in Table 2, this shows the five key points.

Table 2. A summary of the perceived negative attributes of automatic milking of dairy cows.

Employees' "negative" attributes	Employers'/family of employers "negative" attributes
loss of interaction with cows	loss of interaction with cows
loss of skill/personal esteem	los of skill/personal esteem
loss of my job	might in practice be very high cost
not likely to be reliable, will go wrong	not likely to be reliable, will go wrong
cow welfare will be compromised, especially high yielders	cow welfare will be compromised, especially high yielders

Results

Employment status

Employers had a distinctly more favourable perception of the process, seeing the opportunity "to reduce labour" as being a very beneficial attribute.

Age

Younger employees and younger employers or younger members of employer families have a more positive perception of the benefits of automatic milking. The main advantage being the opportunity to be relieved of the routine of milking. Older stockpersons appeared more jealous of their skills and appear very sceptical and say that "automatic milking can not really work in practice on a wet and cold winter's day".

Education and training

The higher the level of education and training of the stockpersons the more positive attitude they had to automatic milking. Those with an understanding of computers and electronics in particular saw the opportunity "for new challenges" and the opportunity to "develop new skills".

Self-concept

Seabrook & Higgins (1988) have discussed in detail the crucial role of the self-concept in determining behaviour. Each and every individual person has a view of themselves and a view about how other people see them. These views and images about the self can be termed the self-concept. The images defined by the self-concept, the way a person sees themselves in their world, generate a frame of reference by which an individual recognises themselves and can preselect the goals, attitudes and behaviours adopted from an array of alternatives. The cognised self is the evaluative measure of how a person sees himself/herself. Within the context of automatic milking the crucial component of the self-concept, as evaluated by the cognised self, appears to be the *livestock orientated - machinery orientated* dimension. Those stockpersons with images of themselves as *machinery orientated* consider that automatic milking will not demean their self image. Those who consider themselves as *livestock orientated* see automatic milking at conflict with their self image. Similarly an important component of the self-concept appears to be the *traditional - progressive* dimension. Those stockpersons with considered images of themselves as *progressive* consider that automatic milking will not be at dissonance with their self image. For those who consider themselves as *traditional* then they perceive automatic milking at conflict with their self image.

The self-concept also involves the necessity to evaluate the effect of the individual's reflection of how they are seen by other people, the other self. The limited exposure of the panel to electronics means this aspect and role of automatic milking is not yet highly evolved or developed sufficiently to enable formative images to be held. Initial expressions suggest that *livestock orientated* stockpersons are happy to be considered "reluctant to be an innovator and user of electronics" by other people, on the other hand the *machinery orientated* stockpersons do not feel their other self is likely to be affected whether or not the are involved in the adoption of automatic milking. In other words automatic milking is not perceived by them to be crucial to their self-image.

Empathetic interaction

Seabrook (1991) has highlighted the importance of the Empathetic Interaction Component in ensuring good welfare conditions for livestock. Those stockpersons scoring high on this component did see the opportunity "to develop new skills in observation of their cows away from the milking parlour" as a very positive attribute of automatic milking. However they expressed severe reservations at the "loss of opportunity to interact and handle the cows at milking".

Personality

Those stockpersons with higher extraversion scores perceived the process more positively than those with higher introversion scores. Seabrook (1991) has suggested that personality and some empathetic components are related and thus the introvert may be unhappy at the lack of opportunity for interaction at milking,

Conclusion

While the stockpersons are making assessments on the basis of perception their current attitudes are important in ensuring that any incorporation of the systems in dairy production will be effective. Those stockpersons with a cognised self of being livestock orientated appeared more demeaned by the prospects of automatic milking than those who had a cognised self of being machinery orientated. Similarly those who perceive themselves as progressive see greater opportunities than those who perceive themselves as traditional. Projection of automatic milking in terms of "enabling better stockmanship and care for cows" might create less dissonance for those whose self-concept would otherwise be compromised.

References

Seabrook, M.F. & C.B.R. Higgins, 1988. The Role of the Farmer's Self-Concept in Determining Farmer Behaviour. Agricultural Adminstration and Extension 30:99-108.

Seabrook, M.F., 1991. The human factor - the benefits of humane and skilled stockmanship. In: S.P. Carruthers (Ed.): Farm Animals: it pays to be humane. Centre for Agricultural Strategy, Reading, UK, p. 60-72.

Human aspects in automatic milking

P. Lundqvist

Swedish University of Agricultural Sciences, Department of Farm Buildings, Division of Ergonomics & Safety, P.O. Box 945, S-220 09 Lund, Sweden

Summary

The use of automatic milking systems might prevent musculoskeletal injuries and occupational accidents from occurring during the milking operations. On the other hand, it is well known from other industries with automatic production that work operations with adjustment and repair work involve high risks of accidents. While developing the process of automatic milking it is very important to consider the human aspects, to prevent new types of serious injuries in milk production. Human aspects in automatic milking are discussed from a Swedish point of view.
Keywords: automatic milking, robotic workplace, occupational accidents.

Introduction

Work in agriculture has been considered to be highly demanding. The number of occupational accidents and diseases is quite high, compared to other industries (Lundqvist & Gustafsson, 1992). Stueland et al. (1990) concluded that agriculture is among the most dangerous occupations in the United States. According to the report of the Health Risks Study Group to the Swedish Commission on Working Conditions (Anonymous, 1990), female agricultural workers demonstrated a raised frequency of serious accidents, including loss of limb and disorder of the musculoskeletal system. Male agricultural workers had an increased risk of fatal accidents. A study by Lindén (1986) showed that 58% of the occupational diseases in agriculture were related to the locomotive system, compared to 49% for all industries in Sweden.

Dairy farming is one of the most burdensome activities within the agricultural industry. A study of farmers involved in the daily milking of dairy cows, found a high incidence of problems in the locomotor organs. More than 70% stated that they had had difficulties in some part of their bodies during the past 12 months. Females reported a higher incidence of such problems in most body parts than males . In comparison with those in other occupations, milk producers had a notably high incidence of difficulties in the elbows, lower back, hips and knees, with males reporting difficulties in the shoulder joints and females difficulties in the hands and hand joints (Gustafsson, 1989).

According to official statistics (Hansson et al., 1989) more than one-fourth of the occupational accidents in Swedish agriculture occurred in connection with milking and handling of animals within the farm buildings. Of the various work operations in dairy farming, milking was responsible for most of the near-accidents, in absolute numbers as well as in per cent of all near-accidents (Gustafsson et al., 1991). In a study of the psychosocial factors in the working environment of young Swedish milk producers (Lundqvist, 1988), a series of other problems were registered. The young dairy farmers in the study felt that the job was hectic, tiring and risky. They also felt dissatisfied about the few vacation opportunities and the long working hours.These findings show that milking cows in traditional milking systems is one of the most risky and burdensome work operations in the primary agricultural industry.

The high level of occupational injuries within the agricultural industry and particularly within dairy farming is worrying. What measures ought to be taken to improve working conditions on dairy farms? My findings (Lundqvist, 1988) suggest that the milkers should learn more about animal behaviour. It is also important to protect the milkers when they are working close to the animals, during operations such as milking, moving animals, checking animal health and artificial insemination. One way to improve the situation might be to develop automatic milking systems.

The aim of this paper is to discuss the human aspects of automatic milking systems from a Swedish point of view, i.e. considering our present laws and regulations regarding animal welfare, working conditions, hygiene and the like.

Automatic milking systems

Automatic milking techniques are now being developed in a number of countries. Other types of automation techniques have been applied and are now being developed within milk production. Dairy management systems such as cow identification systems, milk yield recording, milk temperature measurements, activity recording and detection of mastitis are examples of sensor technique. Automatic identification systems are being used to feed the concentrate outside the milking parlour. Automatic cluster removal has been in use since the 1960s and was developed to increase the number of animals milked per operator per hour without overmilking.

In journal articles on automatic milking systems very little has been mentioned about what risks the worker might be exposed to during the normal use of the milking robot or during jobs such as adjustment and testing activities, repair work or in situations when the robot becomes defective.

Are robots safe?

An interesting answer to this question has been given by Chen & Tayyari (1990): "No matter how safely a robotic system is designed and implemented, it cannot be 100 per cent foolproof and the accident risks still exist for workers neglecting safety precautions and rules".

Industrial robots can work around the clock on repetitive and/or hazardous tasks in different environments without requiring pauses, vacations or sick leave. Occupational injuries, however, could occur everyday in any type of workplace, even in fully automatically operated ones. Reports of robot fatalities can easily be found in the literature (e.g. Anonymous, 1987; Etherton, 1988; Järvinen et al., 1992). Etherton (1988) has pointed out the following two commonly hazardous zones and corresponding typical accidents around industrial robots:

1. The Robot-Movement Zone. This zone is often called robot work envelope or danger zone. If an individual stands in this zone when the robot is powered, he/she is exposed to risk of crushing, shearing and impact injury.
2. The Approach Zone. The area just outside the robot-movement zone is the approach zone. The personnel in this zone could be exposed to thrown objects, electrical hazards or mechanical hazards of associated equipment. Passing from the approach zone to the movement zone should be limited.

According to Swedish statistics it is the fingers and hands which are the most likely parts of the body to be injured if an accident occurs at work with industrial robots (ISA, 1988). These facts about industrial robots show that the industry has not solved the safety problems.

Many countries have developed standards or guidelines for industrial robot safety, including recommendations on matters such as safeguarding, emergency stops and other working conditions. Jiang & Cheng (1990) have presented a procedure analysing for robot system safety. The analysis covers safety measures that should be taken, risks of not taking them, causes of the risks, and corrective or preventive measures. They emphasize that safety should be considered from the very beginning of robot application, and throughout the installation and operation of a robot. Are these thoughts being applied in the process of developing milking robots? Are the research institutes and the firms dealing with the milking robot sure about the safety aspects for the farm workers . . . and the cows? Is it possible to make a milking robot foolproof for people and cows?

How much can be replaced by automation?

This question was asked by Messer (1982). He wrote about the French architect, Le Corbusier, who once defined a house as "a machine to live in". Messer then went on with: "few can disagree that buildings used for livestock production are machines. Like other machines they have an outer shell, the roof and walls, to protect the specialised machinery that performs the functions previously performed by man". Even if we do not fully agree with Messer, it is true that the development of automatic systems for keeping livestock has been very rapid for the last couple of decades. We also know that the working environment in livestock buildings is more complicated than in most industrial buildings, due to the special requirements of other living creatures - the animals (Figure 1).

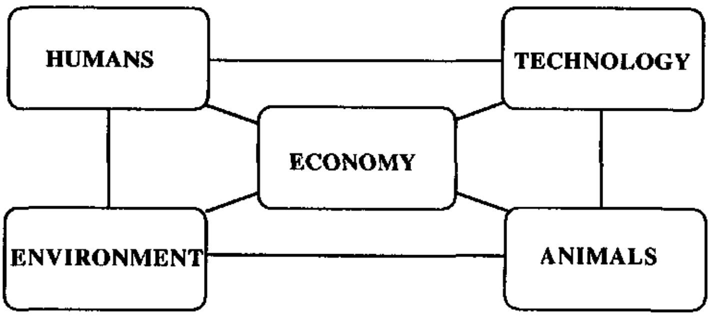


Figure 1. The working environment in livestock buildings is more complex than in other industries due to the special requirements of the animals.

Regulations for both humans and animals have to be considered in livestock buildings.

The current Swedish Work Environment Act (Anonymous, 1991) applies in principle to all fields in which employees are active. The Act's protective provisions concerning technical equipment and hazardous substances apply to self-employed persons such as farmers.

The National Board of Agriculture (Anonymous, 1989) has issued regulations and general recommendations concerning animal management in Swedish agriculture.The regulations state that animals shall be managed in such a way that persons responsible for the animals can attend to them without difficulty. Further it is stated that the animals shall be housed and treated in a good animal environment and in such a way that their health is furthered and natural behaviour is possible. The Swedish requirement that "cattle which are kept for milk production and which are older than six months shall graze in the summer" may require special arrangements and layouts for the optimal utilization of an automatic milking system.

In the statutory order on animal protection (Anonymous, 1989) it is stated that new technical systems and technical equipment for animal housing must have been approved from the point of view of animal health and protection before being taken into use. In order to facilitate and speed up the introduction of automated milking on commercial farms it seems important to initiate such tests and evaluations as soon as possible. They should be administered by government testing stations or university departments. It also seems urgent to coordinate and integrate the design of new milking systems with the present trends towards "low cost" dairy barns (uninsulated, natural ventilation, TMR-feeding), new animal welfare regulations and the like, that characterize development in many major milk producing countries. So if automatic milking is to be introduced in Sweden and other countries with similar animal welfare regulations it also has to be tested and examined before it is approved.

Will automation of milking improve human health?

If or when the automation of milking is implemented on dairy farms, will the health of farmers and farm workers improve?

- Musculoskeletal complaints and injuries represent a problem of today's milkers and would certainly be helped by the automation of milking, which considerably reduces strenuous and repetitive work.
- Occupational accidents are quite common on dairy farms today and most of them occur during the milking operation. If the milking robot is foolproof, there will be a substantial possibility of reducing the number of accidents during milking. But if the level of risk is the same as in the use of industrial robots, then there might be more severe accidents during inspection, testing, adjusting or repair work. Automated milking also reduces the contacts between the farmer/farm worker and the cows. This might lead to higher risks in situations like treating or moving cows when the operator does have to interact with the animal.
- Hectic work with long working hours and few vacation opportunities, are common problems today among dairy farmers. Will this situation improve? It will depend on how reliable this system will be and how the farmers will use their saved working hours.They may have to spend a lot of time controlling and adjusting the robot, or they might spend the time saved taking better care of the animals or spending more time with their families. It is obvious that many farmers would like to increase herd size, to afford this new investment. In that case the working situation may not be much better.
- A working life with high quality, interesting and stimulating work operations is the goal for most people. Will this be possible with automated milking? Some people think that the working conditions with automatic milking will be safer, cleaner, less tied to certain working hours and in some ways of better quality. Others disagree and point out that the work will not be that interesting any longer and that there will be more stress due to more dependence on outside help when there are computer failures, programming problems, electrical or mechanical breakdowns etc. What about the farmers' and the workers' qualifications and skills with respect to

animals? When a man/woman no longer works closely and directly with his/her animals, but through and via the computers and other technical systems, is that a working life with high quality?

Conclusion and some priorities for research

The use of automatic milking systems might prevent musculoskeletal injuries and occupational accidents during the milking operations. On the other hand it is well known from other industries with automatic production that work operations with adjustment and repair work involve high risks of accidents. In the process of developing automatic milking it is very important to consider the human aspects at every stage, to prevent new types of serious injuries in the milk production.

In an article on industrial robots Helander (1990) presented six research needs which also seem to be relevant in most cases for milking robots:

1. the establishment of a databank for accident analysis;
2. field studies of design requirements of robotic workplaces;
3. perception of robot arm movement;
4. the design of teach pendants (tools used for programming robots);
5. function allocations between humans and robots;
6. development of a transponder safety sensor (a safety sensor that can be placed on the worker).

These are problems that need to be solved and the list for milking robots can be extended with aspects like:

- what knowledge will be required by the operator (about robots/animals - technology or biology?);
- how will a farmer cope with a technical breakdown of the milking robot during Christmas Eve or New Year's Eve . . . . ?

References

Anonymous, 1987. Robot safety. A manual on the art of creating safe, practical workplaces in FMS-systems. The Swedish Work Environment Fund, Stockholm, Sweden.

Anonymous, 1989. Regulation and general recommendations concerning animal management in agriculture etc. The National Board of Agriculture, Jönköping, Sweden.

Anonymous, 1990. A survey of jobs posing special risks to health. The report to the Swedish Commission on Working Conditions. The Health Risks Study Group, Ministry of Labour, Stockholm, Sweden.

Anonymous, 1991. Arbetsmiljölagstiftningen. Arbetarskyddsstyrelsen, Solna, Sweden. Handbok H8 (in Swedish).

Chen, F.F. & F. Tayyari, 1990. Safe industrial robot operations. In: Das, B. (Eds.): Advances in Industrial Ergonomics and Safety II, Taylor & Francis, New York, USA, p. 789-794.

Etherton, J.R., 1988. Safe maintenance guide for robotic workstations. NIOSH technical report, NIOSH, Division of Safety Research, Morgantown, West Virginia, USA, No. 88-108.

Gustafsson, B., 1989. Ergonomics and safety in milk production. Paper presented at the 11th International Congress on Agricultural Engineering. Dublin, Ireland, 4-8 September 1989.

Gustafsson, B., G. Lindgren & P. Lundqvist, 1991. Near-accidents in agriculture. A survey of Swedish studies. Swedish Joural of Agricultural Research 21:85-93.

Hansson, R., E. Broberg, A. Johansson, U. Jorner, R. Selander & B. Karlberg- Nilsson, 1989. Undersökning av olycksfallen i jord- och skogsbruket 1987. Lantbrukshälsan, Stockholm, Sweden. Rapport 28. (in Swedish with English summary).

Helander, M.G., 1990. Ergonomics and safety considerations in the design of robotics work-places: A review and some priorities for research. International Journal of Industrial Ergonomics 6:127-149.

ISA, 1988. Risker vid arbete med industrirobotar. Arbetarskyddsstyrelsen. Solna, Sweden, Riskdatablad 1988:1 (in Swedish).

Jiang, B.C. & O.S.H. Cheng, 1990. A procedure analysis for robot system safety. International Journal of Industrial Ergonomics 6:95-117.

Järvinen, J., W. Karwowski, J. Lepistö & M. Rahimi, 1992. Industrial robot-related accidents in Finland. In: Rahimi, M. & W. Karwowski (Eds.): Human-Robot Interaction, Taylor & Francis, London, UK, p. 108-120.

Lindén, A., 1986. Arbetsskador i jordbruket år 1982. Arbetarskyddsstyrelsen. Information om arbetsskador. Solna, Sweden 1986:2 (in Swedish).

Lundqvist, P., 1988. Working environment in farm buildings; Results of studies in livestock buildings and greenhouses. Dissertation. Sveriges lantbruksuniversitet. Institutionen för lantbrukets byggnadsteknik, Lund, Sweden. Rapport 58.

Lundqvist, P. & B. Gustafsson, 1992. Accidents and accident prevention in agriculture; A review of selected studies. International Journal of Industrial Ergonomics (accepted for publication).

Messer, H.J.M., 1982. How much can be replaced by automation. Agricultural Manpower 4:18-24.

Stueland, D., T. Zoch, P. Stamas, G. Krieg & W. Boulet, 1990. The spectrum of emergency care of agricultural trauma in central Wisconsin. American Journal of Emergency Medicin 8:528-530.

Short and long term economic aspects of automatic milking systems

S.B. Harsh*, R.B.M. Huirne**, A.A. Dijkhuizen** & R.W. Gardner*

* *Michigan State University, Department of Agricultural Economics, East Lansing, Michigan 48824-1039, U.S.A.*
** *Wageningen Agricultural University, Department of Farm Management, Wageningen, The Netherlands*

Summary

Automatic milking systems is a new technology recently developed for the dairy industry. This paper examined the economic consequence of using this technology in place of a conventional parlour system on a medium sized dairy farm in the U.S.A. and in The Netherlands.

The base analysis indicates that in both countries the break-even level of the automatic system is nearly double that of the parlour system. The sensitivity analysis indicates that the results can change fairly significantly when some assumptions are changed. This is particularly apparent with changes in wage rates. Lastly, with any new technology there may be some effects on the industry. Because of the nature of this technology, the industry effects will likely be fairly significant, particular with respect to changes in the structure of the industry.

Keywords: economics, milking systems, automatic milking systems.

Introduction

Agriculture is an industry that has witnessed many new technological innovations in recent years. Each of these innovations needs to be carefully evaluated before it is adopted by individual firms, and, in a broader sense, the industry itself. This is true of the new technologies being developed to automate the milking of dairy cows. Whenever a new technology emerges, many factors exist that will influence the scope and speed of adoption. One of the key factors influencing the adoption process is the perceived economic gains that producers will reap from new technology. Without knowing the economic consequences of adopting a new technology, managers will be extremely reluctant to employ them. However, the economic consequence is not the only factor that will influence the adoption process. Other influential factors include the degree in which the mix of resources (e.g. labour and capital) utilized in the production process is changed, the level of management skills needed to make effective use of the technology, the riskiness associated with the technology, institutional constraints such as government regulations, and the motivation and goals of the producer.

Of particular concern and interest to producers and others is what impact the new technology will have on the industry itself. How will it change the industry structure, affect the competitive position of the industry and influence the long-term income level of the industry? Also, how will these changes influence other related business sectors.

This paper will focus on evaluating the economic consequences of using automatic milking systems on dairy operations in both the U.S.A. and The Netherlands. It will also address some of the implications for the overall dairy industry as well.

To address the economic issues related to automatic milking, it is important to define the framework that will be used to conduct the analysis, and to clearly state the assumptions used in making the analysis. The major economic concern is whether the new technology of automatic milking systems is a more economical investment in comparison to a conventional modern milking system such as a herringbone milking parlour. Milking systems involve major capital investments that are utilized over several years. Thus, capital budgeting procedures will be utilized in the analysis. These procedures are well defined in several management textbooks (Harsh et al., 1981). The traditional approach is to compare the two investments, and the one with the greatest (smallest) discounted income (expense) stream would be the preferred investment. In this analysis, however, the approach will be slightly varied due to the uncertainty of the investment level required for the automatic system since they are not yet commercial products. To address this concern, and to allow for a more meaningful sensitivity analysis, the discounted income streams of the two investment options will be equated by adjusting the investment cost of the automatic system. This figure can then be compared to the actual investment cost when it is introduced as a commercial product.

The analysis that will be used in this paper will consist of two parts. The first part will be a base analysis which will be used to compare the two systems under U.S. conditions and conditions in The Netherlands. The second part will test the sensitivity of the results obtained in the base analysis by adjusting some of the key assumptions used in this analysis.

Base analysis

The base analysis will assume that a producer must choose between a traditional milking system and an automatic milking system. This implies that the producer is at a point where the existing milking system either needs replacing, or requires a major modernization with one of the two proposed systems. The base analysis addresses the economic issues related to this selection process. However, for the producer that has recently installed a new milking system, the base analysis is not appropriate. In this situation, the producer has a large amount of sunk costs and thus the relative investment costs are greatly altered.

Base assumptions

As a starting point, it is necessary to state some assumptions with respect to size of operation, general costs, and tax rates that will reflect the representative farms used in the analysis. It is assumed that the U.S.A. representative farm has a milking herd of 125 cows. This size of operation is comparable to that of a medium size U.S. lake states dairy farm. Additional information regarding the characteristics of the U.S.A. farm can be found in the publication by Nott (1991). In order to make the international comparisons more meaningful, the Dutch representative herd size is assumed to be the same as the representative herd size of the U.S.A. This herd size is commonly found in The Netherlands. A 125 cow dairy herd reflects a situation where a full-time worker is employed on the farm, with seasonal labour hired as necessary. Thus, there is an opportunity to save labour costs by the utilization of the automatic system. It is also an operation that has sufficient size to justify full utilization of a automatic milking systems.

Other characteristics of the U.S.A. and the Dutch representative farms that will have a bearing on the economics of these investments are the cost of capital and the marginal tax rate. The cost of capital is assumed to be 8 percent. It should be noted, in this base analysis if a single value is given for an assumption, then it should be assumed that the value is appropriate for both countries. The assumed marginal tax rates for the U.S.A. and The Netherlands is 44% and 50%, respectfully. When making conversions from the U.S. dollar (US$) to the Dutch guilder (NLG), US$ 1 is assumed to be equal to NLG 1.70.

Investment costs

One of the major components in deciding between the two milking systems will be the investment costs to install the two systems. For the traditional milking system, a double eight herringbone parlour with a crowd gate and automatic detachers will be assumed. Based on the 'Dairy Housing and Equipment Handbook' (Anonymous, 1989) this parlour can be operated by a single person. Also included in the parlour system will be electronic milk meters connected to a milking computer. An integrated information system is part of the automatic milking system, and, to make the two systems as comparable as possible, the information system is also included in the parlour system. With some renovation, it is assumed that this new system can be installed in an existing milking facility. The cost for this parlour, including installation costs, is assumed to be US$ 90 000 in the U.S.A. and NLG 165 000 in The Netherlands.

For the automatic milking system, no assumption is made regarding the level of investment costs for the system. As stated earlier, the analysis will define the investment level of the automatic milking system that will equate the annualized net incomes of the two systems.

Salvage value in both systems at the end of the useful life is assumed to be five percent for both systems.

Life of investment

Length of time these two systems will perform reliably and/or not become technologically obsolete will influence the relative cost of the systems. For the traditional system, the life of the investment is assumed to be 12 years. Since the automatic milking system technology is more complex, a shorter expected life of seven years is assumed. The life of the automatic system is difficult to estimate because there are not adequate on-farm experiences with these systems.

Maintenance costs

The cost of maintenance between these two systems should vary because of the different levels of complexity. For the traditional parlour system it is assumed to be three percent of the investment cost per year and for the automatic milking system it is assumed to be six percent of the investment cost per year. The value used for the traditional parlour system is one that is commonly used for livestock equipment. However, for the newer automatic milking system, there is not enough on-farm experience with these systems to estimate a value with full accuracy.

Milk production

With the traditional parlour system it is assumed that only two milkings per day will occur. This is fairly typical of most medium size dairy operations located in the U.S.A. With the automatic milking system, multiple milkings (three to four per day) can be easily accomplished. With a higher number of milkings, higher milk production can be achieved. There have been many studies indicating an increase in milk production with multiple milking (Amos et al., 1985; Hillerton et al., 1990; Ipema et al., 1987). However, these studies indicate the production increase because of multiple milkings can have a fair amount of variance. The production increase found in these studies ranged from 10% to 15%. In this analysis, it is assumed that milk production will increase by 12% with the automatic system over the parlour system.

Milk price

The net base milk price (gross milk price less deductions such as hauling and marketing) is assumed to be US$ 0.2756 per kg for the U.S.A. and NLG 0.75 for The Netherlands. This price will need to be adjusted to reflect milk quality differences between the two milking systems. Research indicates that when milk production increases from 7000 to 8000 kg/cow because of increasing the number of daily milking from two to three or four milkings, both the protein and butterfat percentage levels decline (Van Scheppingen et al., 1992). The butterfat level will decline by 0.15% and the protein level by 0.05%. If milk is priced on a component basis, then there would be a decrease in the milk price received because of the higher milk production. Using the current price premium for butterfat in the U.S.A., this results in a 0.72% lower price. In The Netherlands where there is both a butterfat and protein premium, it would amount to a 2.6% decrease in the milk price.

Labour costs

One of the biggest advantages of the automatic milking system would be a reduction in labour used for milking. For the standard parlour system it is assumed that twice daily milking and related activities will take 3.8 hours per day. Included in this figure is time allocated for checking the herd for health problems and oestrus, preparing the herd and equipment for milking and post milking activities. This figure is based upon the milking rate stated in the 'Dairy Housing and Equipment Handbook' (Anonymous, 1989). It has been adjusted upward to reflect the other non-milking activities indicated above.

For the automatic milking system, labour will still be needed to check the system for mechanical flaws and proper functioning. Time will also be needed to observe the herd for diseases and other problems, conduct oestrus checking, and handle cows with mastitis and other health problems. It is assumed that these activities will take longer since the cows will not be observed in the milking parlour. For the automatic system, the daily labour requirement is assumed to be 1.2 hours. For both systems, a labour cost of US$ 7.60 per hour is assumed for the U.S.A. and NLG 28 for The Netherlands.

Feed costs

As a result of higher milk production related to the automatic milking system, feed costs for each kilogram increase in milk production is assumed to be US$ 0.12 per kg and NLG 0.20 per kg, U.S. and The Netherlands, respectively. The U.S.A. figure is derived from the published enterprise cost budgets for dairy animals (Nott et al., 1992).

Depreciation recovery

To capture the tax effects on the cash flows of the investment in equipment and facilities, the straight line tax depreciation method will be used for both systems. Depreciation is assumed to be 5 years with a zero percent salvage value. Since both systems will have a positive market salvage value, the difference between the tax depreciated value and the market salvage value will be taxed at the marginal tax rate.

Milk quota cost

In The Netherlands the amount of milk that can be sold is limited by the quota system. Thus, if the automatic system results in an per cow increase in milk production the dairy farm has two choices:

- purchase additional milk quota;
- reduce the number of animals in the herd.

In the base analysis, it is assumed that additional quota will be purchased at a cost of NLG 4.5 per kg. This quota will be totally depreciated over a 5 year period. Thus, there will be some positive tax effects. It is also assumed that at the end of the life of the investment, the milk quota can be sold at the original purchase price. The difference between the tax depreciated value and the end of investment value will be taxed at the marginal tax rate.

Inflation rates

Most of the costs and returns incorporated in the analysis will trend upward because of inflation. The annual percentage inflation rates used in the analysis are as follows: milk price = 4.1, feed cost = 3.6; other costs = 4.5. These figures were generated by the AGMOD econometric model for agriculture (Ferris, 1989).

Other assumptions

There are some factors that have not been included in the analysis. One consideration of importance is the impact on herd health. It is assumed that the automatic system relative to the conventional parlour system will not alter the level of health problems experienced in the milking herd. Also, it assumes the dairy operation as having adequate sources of capital to purchase either system.

Analytical model

As indicated earlier, the economics of the two systems will be analyzed using the capital budgeting procedures. The equations used in the analysis are as follows:

$$NPV_k = -IC_k + \sum_{m=1}^{n} \frac{NR_{m,k}}{(1+i)^m} - \frac{SV_k}{(1+i)^n}$$

where:

NPV_k = Sum of the discounted net after tax net present value stream for system k;

k = Type of system (1 = traditional parlour, 2 = automatic system);

IC_k = Investment cost of system k. It includes both the purchase cost of milking system and the milk quota cost (if required);

$NR_{m,k}$ = After tax net return in year m for system k. It is the increase in after tax revenue (milk income) less after tax expenses (maintenance cost, labour costs, increase feed costs related to higher milk production) plus the after tax depreciation allowance;

SV_k = Salvage value for system k. This includes both the equipment salvage value and the milk quota salvage value (if required);

n = Number of years investment k will be utilized; and

i = After tax discount rate.

Since the investment life of the two investments will generally not be equal, the following equation is used to standardize the NPV_k of the two milking systems:

$$ANI_k = NPV_k \times \frac{i}{1-(1+i)^{-n}}$$

where:

ANI_k = Annualized after tax net income for investment k.

Results of the Base Analysis

Based upon the assumptions discussed above, the break-even level of investment in the automatic milking system in the U.S.A. would be US$ 175 000. This is nearly two times the investment cost of the conventional parlour milking system. Thus, if the actual cost of the automatic system was less than this amount, then it would be economically advantageous to invest in the automatic system. On the other hand, if the automatic system costs more than this, then the parlour system would be more economical.

The break-even investment level for The Netherlands is NLG 310 000. This is 1.9 times greater than the cost of the parlour system. With the higher milk price and labour costs in The Netherlands, the ratio is anticipated to be higher. However, the cost of acquiring milk quota has the effect of lowering the ratio.

Other considerations

The base analysis identifies the equivalent level of investment to make the automatic milking system as profitable as a conventional milking parlour system. This should not be the only factor taken into consideration in making the investment. The automatic system, when contrasted with the parlour system, greatly alters the labour to capital ratio. The automatic system will eliminate the need for 946 hours of labour annually and greatly increase the capital requirements. For the farm that has trouble acquiring labour for milking or feels that the existing labour force is working too many hours, adoption of the automatic system has strong appeal. On the other hand, if the farm is already carrying a large debt load and additional debt may put the business at risk financially, then the automatic system with its high capital requirement may be less attractive.

The automatic system may also affect herd management procedures because there will not be the opportunity to observe the cows in the parlour. This will place a premium on addressing herd health and other problems outside the parlour environment. If this is poorly performed, the relative economics of the two systems would change.

In a similar vein, the automatic system is much more complex and thus subject to more problems. This either demands a reliable local source for maintenance and support services or the farm should have its own capacity to maintain complex systems. If this is not the case, then the automatic system becomes less advantageous.

Sensitivity analysis

In conducting the base analysis several assumptions were made with regard to factors that will influence the economics of the two investment alternatives, the conventional milking parlour and the automatic milking system. Of particular interest is how sensitive the results are when alternative assumptions are made. This part of the paper examines the effects when certain assumptions are altered.

The effect of wage rates on the maximum investment level

One of the major advantages of the automatic milking system is the saving of labour costs. Figure 1 illustrates the change in the break-even investment level for the automatic system. As it can be observed, the break-even investment level is fairly sensitive to wage rates in both countries. The break-even level is higher in the U.S.A. because there is no need to purchase milk quota as is the case in The Netherlands.

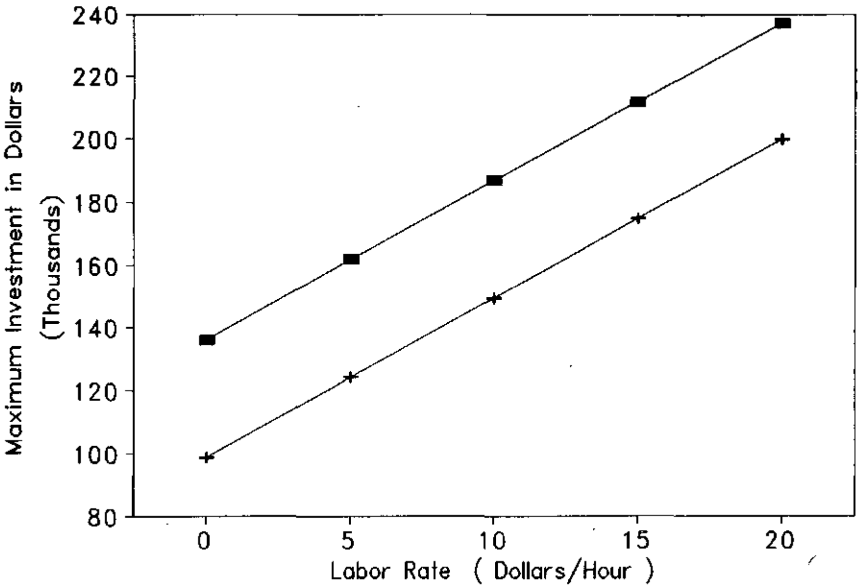


Figure 1. Effect of wage rates on maximum recommended investment in automatic milking system (■ = U.S.A.; + = The Netherlands).

The effect of milk production response on the maximum investment level

There is some uncertainty to the level of milk production response achieved from the multiple milking associated with the automatic system. This response level has a major influence on the relative economics of the two milking systems. In the base analysis, a 12% increase was assumed. If this increase was as low as 8%, then the break-even investment level for the automatic system would decline by 17% in the U.S.A. and 15% in The Netherlands. On the other hand, if the production response was 16%, the break-even investment level would increase by same percentage levels.

Three milkings per day

One of the advantages of the automatic system is the higher milk production related to increase frequency of milking. Since the labour rate in the U.S.A. is relatively lower than that in The Netherlands, it might be possible to obtain the same increase in the U.S.A. with three milkings per day with the conventional milking parlour. To analyze this situation with the conventional parlour, the daily labour requirement was raised to 5.6 hours, the annual maintenance costs were raised by 1%, the useful life of the investment reduced by 2 years and a 10% milk response was assumed with a

0.72% price decline. This reduced the break-even investment level of the automatic system by 21%. If the base analysis break-even investment of the automatic system is used, then the net after tax annual returns would increase by US$ 5141.

Purchase milk quota or reduce herd size

As an alternative to purchasing quota to address the increased milk production with the automatic system, in The Netherlands farms could reduce the number of cows to hold the quantity of milk sold at the same level. This would result in reduction in cow carrying costs (all cost not related to production of milk) of NLG 3500 and a smaller investment in dairy cows (NLG 2800 per cow eliminated) The funds from the eliminated cows can be used to offset the cost of the automatic system. Under these assumptions, the break-even investment level of the automatic system level increased by 31%. If the base analysis break-even investment level of the automatic system is used, this would increase the annual after tax returns to the farm by NLG 11 700. Thus, reducing the herd size is a better alternative than purchasing milk quota at a price of NLG 4.5 per kg.

Impact on the dairy industry

If there is widespread adoption of automatic milking systems, there will likely be some significant changes in the dairy industry. One anticipated change is the upward shift in the size of dairy farms. To effectively utilize this technology, a dairy farm will need to have enough cows to benefit from the labour savings and to make it worthwhile to acquire the management skills for successfully utilization of the technology.

Another change will be a reduction of labour employed in the dairy industry and an increase in the use of capital. Will this labour outflow from the industry occur by normal attrition or will it create some unemployment problems? Also, the dairy industry will become more capital intensive, thereby making it more difficult for new farms to enter the industry.

As automatic milking systems are complex from both a technological and managerial viewpoint, there will be a need to enhance the management skills on dairy operations. Thus, dairy farms will need to acquire new skills and expertise if they are going to make effective use of this technology.

The issue of the income effects on the industry also needs to be addressed. This is technology that has the effect of lowering the marginal cost of production and, thus, the supply curve of the industry will be shifted outward. Without a growth in demand, this will result in lower prices. Furthermore, when the price of the product is inelastic (which is the case with milk), the relative price decline will exceed the relative increase in supply. Therefore, the overall income to the industry will decline. To maintain the same income levels, a farm will need to expand. The more competitive farms will undertake the expansion process and the less competitive farms will exit from the industry. With the milk quota system, the same process will occur through the sale and purchase of quotas.

The point at which a farm adopts the technology will also have an impact. The early adopters will reap the greatest economic benefit from the use of the technology. Late adopters will be forced to utilize the new technology just to remain competitive.

Lastly, a new support industry will be needed to service the more complex automatic milking systems. Without adequate support, these systems can be a liability rather than an asset.

References

Amos, H.E., T. Kiser & M. Lowenstein, 1985. Influence of milking frequency on production and reproductive efficiency of dairy cows. Journal of Dairy Science 68:685-732.

Anonymous, 1989. Dairy Housing and Equipment Handbook. Midwest Plan Service, Iowa State University, Ames, Iowa, USA.

Ferris, J., 1989. A description of AGMOD - An econometric model of U.S. and world agriculture. Department of Agricultural Economics, Michigan State University, East Lansing, Michigan, USA, Staff Paper No. 89-19.

Harsh, S.B., L.J. Connor & G.D. Schwab, 1981. Managing the farm business. Prentice-Hall, Inc., Englewood Cliffs, New Jersey, USA, chapter 9.

Hillerton, J.E., C.H. Knight, A. Turvey, S.D. Wheatley & C.J. Wilde, 1990. Milk yields and mammary function in dairy cows milked four times daily. Journal of Dairy Research 57(3):285-299.

Ipema, A.H., E. Benders & W. Rossing, 1987. Effect of more frequent milking on production and health of dairy cattle. Proceedings of the Third Symposium on Automation in Dairying. IMAG, Wageningen, The Netherlands, p. 283-293.

Nott, S.B., 1991. Business analysis summary for specialized Michigan dairy farms. Michigan State University, East Lansing, Michigan, USA Agricultural Economics Report No. 562.

Nott, S.B., G.D. Schwab, A.E. Shapley, M.P. Kelsey, J.H. Hilker & L.O. Copeland, 1992. 1992 Crops and livestock budgets estimates for Michigan. Michigan State University, East Lansing, Michigan, USA, Agricultural Economics Report No. 556.

Van Scheppingen, A.T.J., P.B. de Boer, A.H. Ipema, A.P.J. Subnel & J. Visch, 1992. Dairy Farming and Automated Milking. Research Institute of Dairy Farming, Lelystad, The Netherlands, Research Report 74.

Analysis of capital investment in robotic milking systems for U.S. dairy farms

D.V. Armstrong*, L.S. Daugherty**, D.M. Galton*** & W.A. Knoblauch****

* *The University of Arizona, Department of Animal Sciences, 205 Shantz Building, Tucson, Arizona 85721, U.S.A.*

** *The University of Arizona, Department of Agricultural Economics, Tucson, Arizona, U.S.A.*

*** *Cornell University, Department of Animal Science, Ithaca, New York, U.S.A.*

**** *Cornell University, Department of Agricultural Economics, Ithaca, New York, U.S.A.*

Summary

Engineers have developed an automatic milking system that features robotic installation of the milking machine on the cow's udder. Transition from a labour intensive milking system to a capital intensive system is an opportunity for increased profitability for dairymen in Europe. This analysis is to evaluate the economic feasibility of the 'robotic' automatic milking system(s) as a replacement for the production line milking systems currently in use in the U.S.A. The breakeven cash outflow is calculated for four production line milking systems in use in the U.S.A. The systems are projected to milk three-times-a-day. The systems are two that typify the Northeast temperate areas (the double-4 herringbone milking 120 cows and the double-16 herringbone milking 800 cows); and, two that typify the Southwest desert areas (the double-10 herringbone milking 500 cows and the double-30 parallel milking 1,500 cows daily). The breakeven cash outflows, for a fifteen year planning period, revealed that the automatic milking systems would need an annual cash outflow under US$ 30 000 to cover capital investment, capital replacement of components and annual labour, repairs, taxes and insurance. It is unlikely that the capital intensive 'robotic' automatic milking system will soon be a viable alternative to a large scale, efficient production line milking system in the U.S.A.

Keywords: milking systems, robotics, present value, capital investment.

Introduction

For European dairy farms, the future introduction of a fully automatic milking system is seen as a possible opportunity for increased profitability through increased milk yield and lower labour input. The majority of dairy cattle in the United Kingdom and Europe are milked by the dairyman who sees the automatic milking system as a possibility for a more relaxed lifestyle, which would reduce the unsocial hours required with dairy farming.

The developers and manufacturers of automatic milking systems forecast that the system may have an influence on dairy farms larger than 50 cows in the U.S.A. (Robot Milking, 1988)

Total labour cost on the majority of U.S. dairy farms is usually 8-15% of the gross income. Fifty percent of the labour cost is associated with the milking operations. During the last thirty years, new equipment such as automatic detachers, crowd gates, and rapid exit parlours, coupled with higher milk production per cow, has decreased the percent of gross income spent on milking labour. Costs for milking labour, depreciation of milking parlour and equipment, and repairs account for 6-10% of gross income. So, any system that would lower these costs, relative to the capital investment required for new technology, and maintain milk quality or increase milk production, would be adopted by the U.S. dairy industry.

Most dairy cows in the U.S.A. are milked twice-a-day, although the practice of three times-a-day milking has increased in recent years with a few herds being milked four times-a-day. The practice of milking cows three times-a-day increases milk production by 14-18% over twice-a-day milking (Armstrong et al., 1985). Eighteen of the top twenty Arizona herds in May 1992, for fat corrected milk per cow, were herds milked three times-a-day (Armstrong & Smith, 1992).

Research in Holland (Ipema et al., 1987) has shown that a cow milked with an automatic milking system would produce 14% more milk (with an average of 3.9 times milked per day) when compared to a group of cows being milked twice-a-day. Since the milk produced response with an automatic milking system is approximately the same as that experienced in the U.S.A. by herds which change from twice-a-day to three times-a-day, changes in production with different milking systems are not discussed herein.

This research examined the economic feasibility of replacing the production line milking systems, currently in use in the U.S.A., with 'robotic' automatic milking systems. Four production line milking systems are described herein. Two of these (the double-4 and double-16 herringbone types) are typical with confined housing for cattle in the Northeast temperate climates. Two (the double-10 herringbone and the double-30 parallel) are typical with dairy operations in the arid Southwest. A direct comparison was not possible due to the inability to acquire the physical and cost data for the automatic milking system(s). Instead, the cash outflows (capital investment, capital replacement and pertinent costs) are developed for the four production line milking systems, for a fifteen (15) year planning period. This process generates a maximum annual cash flow for the automatic milking systems to be competitive. By identifying this cash flow, dairymen and allied industry personnel can decide whether an automatic milking system is a feasible alternative to the current production line milking technology. A similar study in 1988 showed that automatic milking systems would increase the cost of the milking operation. (Daugherty & Armstrong, 1988)

Results and discussion

The operating and ownership costs that are normally projected to evaluate an investment in a milking system are labour, utilities, repairs, taxes, housing, insurance and interest. Ideally, a comparison of an automatic milking system with a production line system would compare all of these costs. However, this comparison cannot be made at this time due to the unknown costs of robotic milking technology. Instead, the pertinent costs for each production line milking system were used for a breakeven analysis, with the following assumptions:

1. As stated earlier, the milk production response with an automatic milking system in Holland and three-times-a-day milking with a production line system in the U.S.A. are the same.
2. The utility cost of energy is a function of the volume of milk that is cooled and stored. Since the milk production for the systems are the same, the utility costs for either system is assumed to be the same.
3. Housing costs would be the costs of building and maintaining the structure to protect the milking system(s) from the elements; and, to comply with state and interstate requirements. These costs are assumed the same for the automatic milking system and the production line system.
4. Repair costs are estimated using a percentage of component costs.
5. Insurance is estimated using a percentage of the average annual investment in components.
6. Property taxes are estimated using a typical tax rate applied to the agricultural value of the components.
7. The estimated costs of the automatic milking system to the industry (March 1992):
   (a) US$ 155 000 for a double stall one robot unit which would accommodate 80 cows;
   (b) US$ 80 000 - 100 000 for a one stall one robot unit which would accommodate 20 cows;
   (c) US$ 94 000 - 125 000 for a one stall one robot unit which would accommodate 20 cows.

With these assumptions, the pertinent costs for this analysis are labour, repairs, taxes and insurance. The calculation of the labour costs is shown in Table 1. These annual labour costs are the annual milking hours expended at US$ 9.00 per hour.

Table 1. Calculation of labour costs.

Type	Total milking cows	Cows /hour (grp)	Milking hrs /day	Group change @15	Total[1] daily use	Milkers /shift	Annual labour hrs	Annual labour costs US$ 9
NE								
D-4 Herringbone	120	40	9	2.25	14.25	1	5 206	46 856
D-16 Herringbone	800	160	15	3.75	21.75	2	15 893	143 035
SW								
D-10 Herringbone	500	100	15	3.75	21.75	1	7 946	71 517
D-30 Parallel	1500	300	15	3.75	21.75	3	23 839	214 552

[1] includes 3 hours daily cleanup and setup.

The capital investment cash outflow is the initial cash outlay to purchase the system (Table 2). The capital replacement cash flows are the net cash outlay for replacing those system components that wear out, or become unserviceable, during the planning period. The net cash outlay is the replacement cost minus the salvage value. The salvage value is the projected future market value of the item being replaced. The component's expected life and salvage value are estimated using equations or procedures developed by agricultural engineers.

The annual cash outflows are the sum of the initial investment, or the capital replacement net cash flow, plus the pertinent costs for each year of the 15 year planning period. The annual cash outflows were calculated for the Double-4, Double-16, Double-10 and Double-30 milking parlours. Table 3 shows these calculations for the Double-30 parallel milking parlour.

Table 2. Milking parlour costs (in U.S. dollars).

Item	D-4 Herring-bone	D-16 Herring-bone	D-10 Herring-bone	D-30 Parallel
Stalls/rapid exit	9 000	32 000	24 000	66 000
Pipe fence & galv. curb	2 800	8 640	8 600	31 980
Crowd gate	8 000	12 000	12 000	12 000
Cow wash system	none	none	15 000	30 000
Milking equipment	21 000	50 000		
Pulsators/claw/shells/wash system	included	included	24 000	72 000
Automatic detacher	12 800	51 200	32 000	54 000
Double loop milk line	included	included	20 000	24 000
Balance tank with line	included	included	2 500	2 400
Vacuum pump	included	8 000	7 000	16 500
Milk storage & equipment	25 000	76 000		
Tube precooler	included	included	8 000	4 500
Thermalstores	1 875	3 750	3 750	5 625
Chiller	none	none	10 000	7 500
Precool evap. combo system	none	none	none	6 000
Bulk tank 6000 gallon	included	included	25 000	75 000
Plate cooler, 2 stage	3 000	6 000	4 500	8 000
Sink, stainless w\comp.	300	1 600	800	2 400
Milk transfer pump (5 hp)	included	1 800	1 800	1 800
Water heater	600	1 000	1 000	2 200
Water generator	none	5 000	none	8 000
Compressor	none	none	12 000	36 000
Air compressor & air dryer	none	none	3 000	4 500
Press tank w\pump	none	none	4 000	5 000
Jet wash pump	none	none	2 000	6 000
Clean up water pump	500	500	500	500
Main entrance electrical service	2 500	3 000	3 000	3 000
Milk barn electrical service	10 000	30 000	20 000	50 000
Generator, standby	4 000	24 000	24 000	32 000
Total cost	101 375	314 490	268 450	566 905

Table 3. Southwest D-30 parallel (costs in U.S. dollars).

End year	Labor	Repairs	Property taxes & insurance	Sum cash costs	Salvage income	Capital outflow	Before tax ownership cashflow
0						566 905	566 905
1	214 552	24 033	8 516	247 101			247 101
2	214 552	24 033	8 516	247 101			247 101
3	214 552	24 033	8 516	247 101			247 101
4	214 552	24 033	8 516	247 101			247 101
5	214 552	24 033	8 516	247 101			247 101
6	214 552	24 033	8 516	247 101			247 101
7	214 552	24 033	8 516	247 101	60 310	213 125	399 916
8	214 552	24 033	8 516	247 101			247 101
9	214 552	24 033	8 516	247 101			247 101
10	214 552	24 033	8 516	247 101	10 757	68 000	304 344
11	214 552	24 033	8 516	247 101			247 101
12	214 552	24 033	8 516	247 101			247 101
13	214 552	24 033	8 516	247 101			247 101
14	214 552	24 033	8 516	247 101	60 310	213 125	399 916
15	214 552	24 033	8 516	247 101	301 701		54 600

The net present value (NPV) of the cost stream @10% = (US$ 2 514 879).
The annual payment equivalent to this NPV is @10% = (US$ 17 402).

The net present value of the annual cash outflows for the 15 year period is calculated.

$$NPV = \sum_{n=1}^{K} \frac{I_n}{(1+d)^n} - O$$

where:
NPV = net present value
n = the time period, with
K = the last time period
I = annual cash flow
d = discount rate
O = initial cash outlay

The net present value of the cash outflow is used as the principal to calculate the average annual cash outflow or 'payment' that will equate to a particular production line system.

$$P = NPV \times \left[\frac{d}{1 - (1 + d)^{-K}} \right]$$

where:

P = annual payment
NPV = present value of investment
d = discount rate
K = number of time periods

This 'payment' is then divided by the number of automatic milking units needed to replace the particular production line system. In Table 4 the results are presented for two different discount rates, 10% and 20%. At 10% discount rate the present value of the cash outflow is US$ 516 387 for the double-4 herringbone milking system typically used in the Northeast temperate area of the U.S.A. The annual annuity equivalent for the 15 year planning period is US$ 67 891. Since 2 dual automatic milking units would be required to replace the double-4 herringbone, US$ 67 891/2 equals US$ 33 946. This means that the capital investment, capital replacement of components and annual labour, repairs, taxes and insurance for the automatic milking system would have to be at or below US$ 33 946 per year for 15 years to be an economically feasible alternative to the double-4 herringbone.

With the double-16 herringbone the net present value of the cash outflows is US$ 1 578 124 using a 10% discount rate; and, US$ 1 092 361 using a 20% discount rate. The annual annuity equivalents are US$ 207 482 and US$ 233 637 respectively. These estimated annual cash outflows are then divided by ten (10 automatic units are required to replace the double-16) and the breakeven annual cash outflow would have to be US$ 20 748 and US$ 23 364 respectively. This indicates that the cash outflows for the 'robotic' automatic milking system units would have to be quite low to compete with the larger double-16 herringbone production line milking system. The cash outflow per 'robotic' automatic milking system unit would need to be under US$ 21 000 and to compete with the double-10 herringbone. The maximum breakeven annual cash outflow would need to be under US$ 17 000 to compete with the double-30 parallel system.

Table 4. Summary of present value of 15 year cost streams (in U.S. dollars).

Number of robotic units @80 cows/unit	Type	Net present value @10%	Annual annuity to equal NPV @10%	Annual cost per automatic unit
		10% DISCOUNT RATE		
	NE			
2	D-4 Herringbone	516 317	67 891	33 946
10	D-16 Herringbone	1 578 124	207 842	20 748
	SW			
6	D-10 Herringbone	960 543	126 286	21 048
19	D-30 Parallel	2 514 879	330 641	17 402
		20% DISCOUNT RATE		
	NE			
2	D-4 Herringbone	356 402	76 228	38 114
10	D-16 Herringbone	1 092 361	233 637	23 364
	SW			
6	D-10 Herringbone	696 116	148 887	24 814
19	D-30 Parallel	1 766 432	377 808	19 885

The net present value(NPV) of the cost stream @10% = (US$ 873 220).
The annual payment equivalent to this NPV is @10% = (US$ 19 134).

References

Armstrong, D.V., D.L. Bath & R. Selley, 1985. Three times-a-day milking. National Cooperative Dairy Herd Improvement Handbook Fact Sheet I-2.

Armstrong, D.V. & J. Smith, 1992. Top fifty percent of herds for fat corrected milk. Arizona-New Mexico Dairy Newsletter, May, p. 4.

Daugherty, L.S. & D.V. Armstrong, 1988. Credit purchase of robotic milking stalls for typical Arizona dairy farm. Arizona Dairy Newsletter, June 1988, p. 3.

Ipema, A.H., E. Benders & W. Rossing, 1987. Effects of more frequent daily milking on production and health of dairy cattle. In: Proceedings of the Third Symposium Automation in Dairying IMAG, Wageningen, The Netherlands, p. 183-293.

Robot Milking, 1988. Newsletter Irish Farmers Weekly, June 4, 1988, p. 16.

Automatic milking in Italy: implementation on the dairy farm and economic aspects

F. Sangiorgi & G. Provolo

Institute of Agricultural Engineering, Via G. Celoria 2, 20133 Milan, Italy

Summary

First of all the farm size and husbandry techniques adopted in Italy are examined. By considering the most common dairy farm sizes, changes in the current lay-out (milking parlour) are hypothesized in order to allow milking robots to be installed, while taking into consideration the influence on feeding techniques. An economic comparison between an automatic milking system (AMS) installation in a farm and a standard tandem parlour (STP) is presented. The actual state of the art in the technical development is that an AMS works on two stalls, whereas a robot installed in an STP is able to control up to 4 stalls. By comparison with an AMS, this system allows greater flexibility under Italian conditions, without any need to alter the current layout. A survey of Italian dairy farmers from important dairying areas, with respect to acceptability and affordability, showed a slight preference for the adoption of a robot in a standard parlour. However the technological developments in future can change this preference.

Introduction

The steady decrease in the agricultural workforce in the last twenty years is a sign of technological progress, yet it has brought a lack of manpower in certain jobs (the heaviest and least skilled). Dairy farming too has been hit by this problem, especially in those areas where it has to compete with industry and services. Labour-intensive dairy farms have been particulary badly hit. On these farms the owner is used to managing the herd and delegates milking to hired labourers, even though this may be expensive. This attitude has led to a general increase in the size of the herd and in milk production in order to justify the use of hired labour. In order to maximize labour productivity, heavy investments have been made in the milking parlour (e.g. automatic teat cup removal and automatic door opening).

In Italy about 3 million cows are kept in over 300 000 farms. Yet it must be remembered that more than 30% of total Italian milk production is concentrated in only a few provinces (Milan, Cremona, Piacenza, Brescia, Mantua, Reggio Emilia, Parma, Modena). Therefore it is in these areas that complete automation of the milking process can be introduced.

Current farming is based on loose-housing with cubicles or deep litter. The yard, often paved, divides both the feeding area and the lying area. Animals are kept in groups and fed on a total mixed ration throughout the year. Few farms use automatic feeders to give extra concentrate to high-yielding cows.

Automation of milking and simulation of robotized milking

The main reason for automating milking is to replace the milking attendant with a robot that performs the udder preparation and attaches the teat cups. This means that milking parlour can be used as it is with all the existing equipment, but milking must be done at regular intervals. The attendant's job is to collect the cows, see to the correct running of the machine, identify the sick cows and look after the milk flow and storage.

Alternatively, a robot can be placed in a stall so that cows can freely enter it throughout the day. In this case the feeding system must be automated. This robot system, which has been the subject of many reports (Rossing et al., 1985; Sangiorgi, 1990), implies a complete re-arranging of buildings and management. Labour is still necessary in order to perform some operations (feed preparation, mucking out, checking, etc.) and, in any case, it must be available for at least 20 hours a day.

Some problems have not yet been solved, such as monitoring the health of the herd. Moreover the availability of a traditional milking parlour seems absolutely necessary as a back-up.

The performance of the AMS has been widely discussed (Rossing et al., 1989), but the possibility of adopting an automatic system that only attaches teat cups has not yet been fully investigated. At present, only standard tandem parlours (STP) can be automated because:

- unlike herringbone and rotary parlours, important delays do not arise from slow operating robots.
- they make it easier for the stall to be adapted to the animal and, therefore, improve the robot's performance.
- they allow cows which are not milked or which need inspection by the veterinary surgeon or simply need to be kept on stand-by position, to be kept back without delaying the whole milking operation.

In this type of parlour, the robot must be able to move from one stall to another to attach teat cups. The cow's entrances and exits are checked by means of the computer already being used for the STP.

The milking attendant only needs to collect and channel the cows to the milking parlour two, three or four times a day. He looks after the animals and the equipment. The performance of this system depends on many factors, some of which are connected to the cows (milking speed), some to the robot (movement speed etc.) some to the milking parlour itself (entrance and exit time of the cows).

We devised a simulation model in order to assess the possible performances of a robot working in an STP. In this model the robot is assumed to work in one row only (Figure 1).

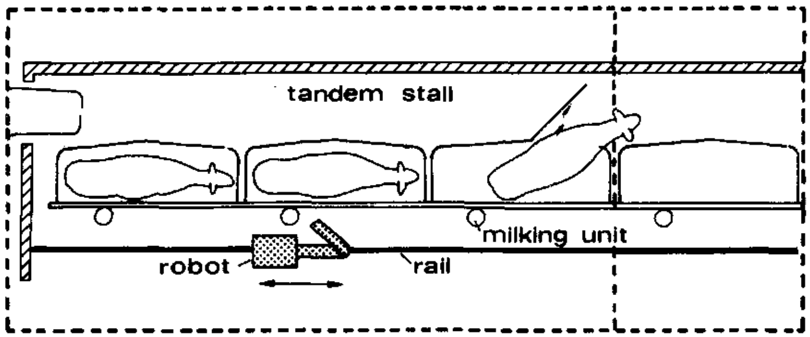


Figure 1. Standard tandem parlour (STP) with robot as used in the model.

Materials and method

The model takes the following operations into account:

- entrance of a cow from the holding area to a milking stall.
- attaching of teat cups, including udder stimulation.
- milking (including automatic removal of teat cups and teat disinfection).
- exit of a cow from the parlour.
- movement of the robot from one stall to another.

The simulation model is time based: at every stage time is increased by a fixed time step while, for every operation, the model analyses the various stalls according to established priorities. The time necessary to perform each operation for each cow is calculated on the basis of an average value and from a variability. The time taken by the robot to move depends solely on the distance to be covered. The input value is the time taken to move from one stall to another. The working time of the robot coincides with the operation of attaching teat cups including udder preparation. The variability depends solely on the difficulty the robot has in attaching teat cups on to different cows.

Results of the simulation model

An example of the output of the model which shows the differences obtained when the number of stalls varies and with two different speeds of robot movements (0.1 and 0.05 m/s) is shown in Figure 2A. The results clearly show that the robot is fully exploited when it handles three to four stalls. Given the robot's working capacity, the best parlour dimension is 4 stalls (less than what is considered standard for a milking attendant, which is 6 stalls in 2 rows). This can be explained by the fact that the model considers only one row for each robot. Figure 2B clearly shows that with four units the idle time is less; this means that having more units does not permit better performances, because of the hypothesized movement speed.

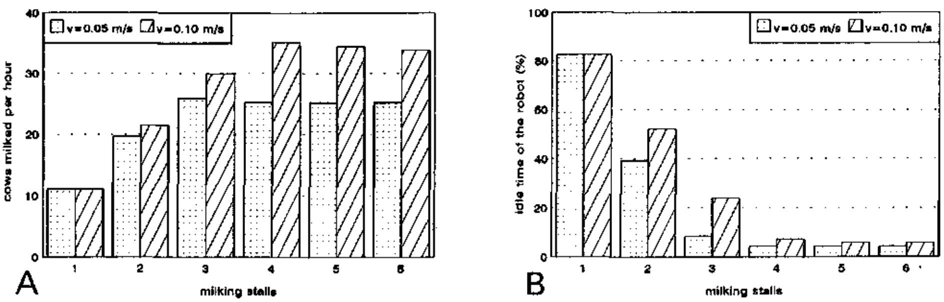


Figure 2. Performance (A) and idle time (B) of an STP with robot, considering two movement speeds of the robot.

Discussion

The automatic milking system (AMS) has been proposed in modules in which a robotized unit controls two stalls. In that case it is possible to handle 80 lactating cows. Although this figure must be verified in practice, the number of cows handled must be considered as the highest unchangeable figure. In fact it is not possible to increase the number of cows and, if that number is reduced, the costs will increase dramatically (or the cost of the robot must be reduced).

Using a robot in the milking parlour would allow a working capacity of 25-35 cows per hour per robot. In this case, the number of cows that could be handled is more flexible and adaptable to the needs of the farmer. In fact, by varying the milking time from 1.5 to 3 hours, it is possible to envisage the number of cows increasing from 37-52 to 75-105 for each module (robot working on four stalls in an STP).

Economic comparison of different technical solutions

We did an economic comparison with the aim of finding out to what extent investment and running cost can influence the cost of milk production in various farming conditions. This can provide a further means evaluating the feasibility of Italian dairy farmers adopting the various types of robots.

Materials and method

In the comparison we assumed the following farming conditions:

- current labour and productivity costs in a traditional loose housing system with cubicles and a standard milking parlour (STP) in which a robot can easily be adopted.
- in the same traditional dairy farm, the attendant is replaced by a robot in the STP, all other structural and management components remain unchanged.
- a traditional loose-housing system with cubicles but with the adoption of a automatic milking system (AMS) and automatic feeding. A back-up milking parlour (an STP type) is also envisaged since it is unlikely that a robot will be operating continuously, considering the current state of the art of this technology.

In order to carry out the economic comparison, a mathematical model was devised. Its main input data are reported in Table 1.

It must be remembered that:

- the milking parlour is always a tandem one in the three dairy farms considered.
- the working times concerning the milking procedure have been considered in a different way than with the current farming system, since the attendant can perform various jobs (e.g. feeding calves) while the robot (whether an STP robot or an AMS one) is operating.
- the labour needs for feeding in an AMS are reduced thanks to the automatic dispensing system. The feed preparation is manually assisted.

In any case it should be remembered that whereas data concerning the current farming system refer to practical conditions, those concerning the use of an STP or AMS robot tend to be optimistic.

Table 1. Main input data used in the economic evaluation.

	STP	STP with robot	AMS	AMS & parlour
Robot cost (mln. ITL)		200	280	280
Investment (mln. ITL/cow)				
lying area	0.9	0.9	0.9	0.9
yard	0.4	0.4	0.4	0.4
feeding area	1.2	1.2	1.6	1.6
milking parlour	2.2	2.2		2.2
Labour (s/cow/day)				
mucking out	120	120	120	120
feeding	240	240	180	180
milking	240	120	60	60
management	60	60	60	60
Total	660	540	420	420

The economic comparison was carried out considering an interest rate of 3% and a variable useful life of the various building and equipment (20 years for buildings, 10 years for equipment, 5 years for the robot and the automatic feeding system). The number of robotized units to be installed is obtained by assuming an output of 100 cows for a robot in an STP and 80 cows for an AMS. The cost of labour was assumed to be 15 000 ITL/h (normal time) and 22 500 ITL/h (overtime). The number of attendants is calculated on the basis of 1920 h/year per person and 1 h/day overtime.

No other items of the production cost were considered, however important they may be, because they are common to all types of dairy farm. The cost of feed was not considered even though it may be higher in robotized parlours due to the need to increase the milk yield.

Results of the economic comparison

The results of the economic comparison can be summarized as follows:

- in Figure 3 are reported the milk yield increments that are necessary in order to keep the percentage incidence of costs per kg milk the same as on traditional farms. The figure shows the herd size and the average total milk production in the most important dairying provinces in Italy. Its purpose is to point out that in certain cases it is almost impossible to meet the target because of current average high yield levels (Milan, Cremona, Brescia) and because of the particular use of *milk* (Parma, Modena, Mantua, Reggio Emilia, Piacenza), that is the production of Parmesan cheese. Figure 3 also shows the herd size range in which the different proposed solutions (STP & robot or AMS) can be applied by considering a production increase of 30%.

- for each proposed solution, the figures concerning the mean incidence values of investment and running costs per kg milk are reported in Figure 4. The values must be compared to the size of dairy farms in the main provinces of the Po Valley reported in Table 2.

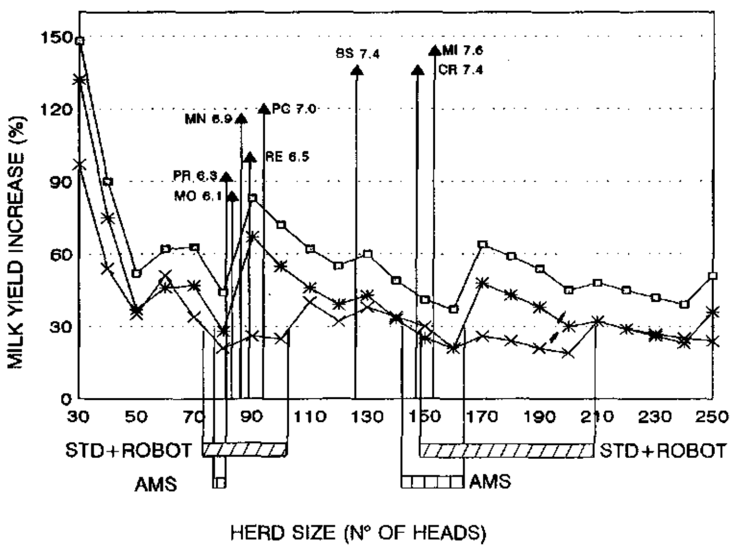


Figure 3. Milk yield increase necessary for the adoption of an STP with robot (×), AMS (⋇) and AMS & parlour (-■-). Actual milk yield in selected provinces in t/lactation (▲) and range of herd sizes for application of a robot. See table 2 for explanation of the province codes.

Discussion

The results of the economic comparison show that, at least for the Italian situation, it is necessary to increase the current milk production. This can create technical (the yields are already high) and quota problems for farmers.

The range of application of the two proposed solutions differs greatly if a production increase of 30% is considered. This percentage is not realistic and feasible. However this clearly shows the greater flexibility of the proposed module (STP with robot), which permits the robot to be adapted more easily to the actual changeable farming conditions without altering the existing structures; this has psychological and economic advantages. As far as the Italian situation is concerned, the introduction of a robot whichever it may be, implies a marked increase in production costs.

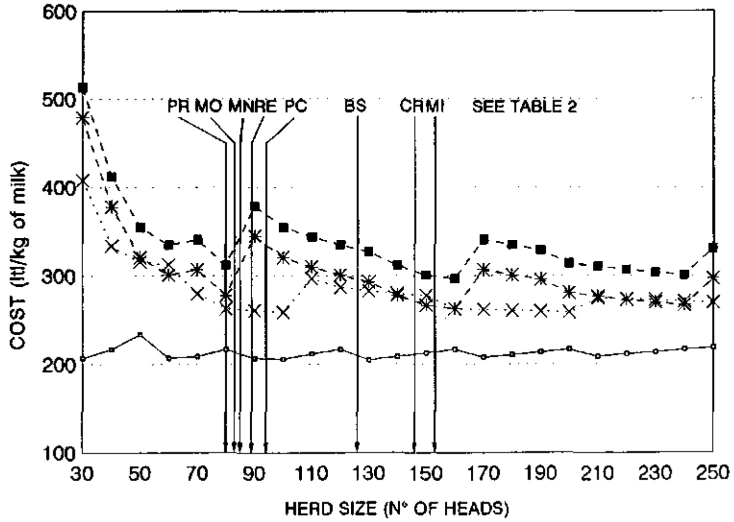


Figure 4. Relationship between the average herd sizes in selected provinces and the costs of adopting of an STP with robot (×), AMS (⋇), AMS & parlour (-■-) compared with an STP (□). See table 2 for explanation of the province codes.

Table 2. Herd size classes and average herd size in selected provinces.

Province		Herd size 31-60 farms	cows	61-100 farms	cows	101-200 farms	cows	>200 farms	cows	Average herd size
Parma	(PR)	225	9820	135	10749	82	11086	18	5480	81
Modena	(MO)	169	7325	115	8790	41	5860	26	7357	83
Mantua	(MN)	267	12154	236	18783	166	22405	20	5831	86
Reggio Emilia	(RE)	268	11849	166	12699	74	9989	35	14080	89
Piacenza	(PC)	87	3868	75	5672	62	8509	17	4665	94
Brescia	(BS)	109	4923	124	9906	165	24319	64	19218	126
Cremona	(CR)	59	2815	149	11986	294	41679	115	34142	147
Ano	(MI)	68	3269	104	8498	308	44733	125	36328	153

Fifty selected farmers were surveyed in order to evaluate the degree of acceptability of the different proposed solutions. It appears that:

- there are great expectations for the commercialization of milking robots.
- in view of the current uncertainty of the milk trade, farmers are unwilling to pay higher production costs.
- most farmers are willing to buy a machine that does not involve changing the current system.

Conclusions

The introduction of a robotized milking system needs to take flexibility and safety into account. If the system is introduced in a traditional structure, only minor changes in cattle management (that is feeding and milking) are necessary. What is most affected is the way labour is used, since milking times are still binding.

The AMS, on the contrary, implies a completely different way of managing the herd. It requires radical changes in the structures too. As things now stand, there is not enough experience to guarantee that there will be no problems in the medium or long term. The risk is therefore even higher; that is why a back-up parlour is advised.

The role of manpower is also completely different in the two proposed solutions. In the first instance a much less sophisticated automated system can be used since it is always possible for the attendant to intervene and adjust the machine. If the robot breaks down, the parlour can still operate, the only drawback being that milking will have to be done traditionally.

The AMS performs many operations without the need for an attendant, even if the attendant must be on the premises. On the other hand, if the machine works 20 hours a day, it is unlikely that human intervention will be needed often. The whole system (attaching teat cups and control of cows) must be very reliable. Even if the attendants in charge of the AMS have to be skilled labour, they should also perform some ancillary jobs, such as mucking out, feed preparation, etc., and this is not always easily accepted by skilled workers.

Thus, if STP's with robot were to be widely adopted, it would be possible to build up the necessary experience to improve the reliability of a system that does not require constant attendance. In other word STP with robot can be considered as a first step towards the complete automation of the dairy farm.

Acknowledgements

This research was made possible by a contribution from the Italian Governement funding programme 'MURST 60%'.

References

Rossing, W., A.H. Ipema & P.F. Veltman. 1985. The feasibility of milking in a feeding box. IMAG, Wageningen, The Netherlands, Report 85-2.

Rossing, W. & A.H. Ipema, 1989. Dalla identificazione delle vacche alla mungitura automatica. L'informatore Agrario 28:27-32.

Sangiorgi F., 1990. E' tempo di robotica per le sale di mungitura? Atti della Societa' Agraria di Lombardia 2:1-30.

Conditions for implementation of automatic milking on dairy farms

A. Kuipers & A.T.J. Van Scheppingen

Research and Advisory Station for Cattle, Sheep and Horse Husbandry, Runderweg 6, 8219 PK Lelystad, The Netherlands

Summary

A working group composed of representatives from various dairy organizations and research institutes in The Netherlands has prepared a report on current experiences with automatic milking and its prospects for implementation on dairy farms.

Model calculations indicate that increased milk yields of 10-15% affect returns positively, but keeping cows all year indoors, thus no grazing, reduces returns very significantly. The possibility of reduced labour requirements in the long run is very important for the economic result. Increased milk yields are favourable towards meeting environmental goals. Positive and negative factors for introduction of automatic milking systems on dairy farms were examined. Economic and social aspects will be the most important.

Most interest in automatic milking is expected on the larger family farms and on farms with 3 or more employees. In the long run, aside from financial aspects, less attachment to the dairy operation and a saving of labour are the main factors in the decision making. Management aspects that need special attention are the separation of abnormal cows from the system and the grazing/feeding routine as part of the system.
Keywords: automatic milking, economics, social aspects, adoption.

Introduction

Two types of automatic milking systems are being tested on the experimental farms the "Waiboerhoeve" in Lelystad and "De Vijf Roeden" in Duiven. The goal of automatic milking is to dispense with the need to have the dairyman in the milking parlour all the time. realization of this goal will be a very important milepost in the automation of the dairy farm. It will have a huge impact on the management of the dairy farm, on the farmer, the cow and on the farm family as part of society. However, many technical, economic and social questions still remain. Therefore, a working group composed of representatives from various organizations in The Netherlands studied current experiences with automatic milking systems and their prospects.

As other papers in this proceedings point out, a number of technical and management factors concerning the use of the automatic milking system need further attention:

- Speed and accuracy of robot arm when locating teats;
- Behaviour of cows and voluntarily entering of the automatic milking system;
- Optimal frequency of milking;
- Capacity of the automatic milking system;
- Cleanliness of cows and milk quality;
- Separation of mastitis milk;
- Development of extensive management programmes;
- Labour benefits (less work, ease of operation, etc.);
- Change in grassland management.

Research is already in progress or is planned on most of these topics. So far, agricultural research has put much less emphasis on the economic and social factors influencing the implementation of an automatic milking system on the dairy farm. Therefore, model calculations were performed to estimate the economic and environmental effects of adapting automatic milking on the farm. Social factors were also studied. The main conclusions of this report (Kuipers & Van Scheppingen, 1992) are presented in this paper.

Economic aspects

An automatic milking system will require a substantial capital investment. In most cases the decision to invest in automatic milking arises when the old milking parlour has to be replaced or renovated. Changes in the annual yields and costs may also occur when an automatic milking system has been adopted. In most cases such a system may require modifications to the housing system but also to the entire farming system. Calculations were done to estimate the economic consequences of these adaptations.

The research station's dairy farm model (Mandersloot & Van Scheppingen, 1992) was used to compute economic returns of automatic milking under Dutch circumstances and prices. The main factors studied were:

- Milk yield per cow and milk composition. Based on research by Ipema et al. (1987) it was assumed that milk production per cow would increase by 1000 kg, as a result of more frequent milking. Decreases of 0.15% in fat and 0.05% in protein contents of milk were assumed.
- Grazing and feeding strategy. Because cows will be kept closer to the milking process, summer feeding (cows indoors all year) or perhaps limited grazing is needed as management practice. The consequences of these changes were calculated.

- Traditional milking parlour. Capital normally invested in renovation or building a new milking parlour is available for investment in automatic milking facilities. Various levels of automation in traditional parlours were assumed.

The calculations were done under two levels of annual costs of automatic milking systems (20% and 30% of the replacement value), two levels of milk quotas (10 000 and 15 000 kg per ha) and three herd sizes (40-50 cows, 70-80 cows, 100-110 cows).

The contribution of an increase of 1000 kg in milk yield per cow and a 0.15% decrease in fat content and 0.05% in protein content added NLG 70-200 per ha to net returns. This increase is largely attributable to a decrease in total costs, being a combined effect of lower cattle maintenance costs and (for farms with large milk quotas) less forage to be purchased. Extra returns become smaller with small milk quotas per ha, because such circumstances result in surpluses of roughage, which are sold at low prices.

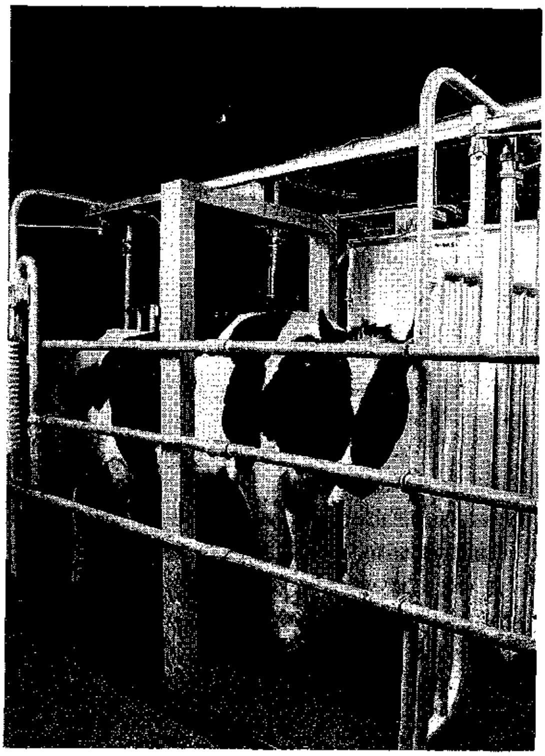


Figure 1. Efficiency requires that cows will be held close to the milking robot.

A change from an unlimited grazing system to limited grazing reduces net returns by NLG 200-350 per ha, and from unlimited or limited grazing to summer feeding by NLG 225-575 per ha. This decrease is mainly due to the higher costs of forage production and of disposing of more manure on the land. In general, systems in which the cow collects the roughage herself are most economically attractive. However, they are difficult or impossible to combine with automatic milking.

The profitability of automatic milking is also greatly affected by the annual costs of a traditional milking parlour. The investment in traditional parlours varies widely from NLG 975-3800 per cow depending on herd size and on the farmer's wishes regarding layout and degree of automation. The associated annual costs vary from NLG 200-880 per cow.

The economic returns of the automatic milking system are expressed by the maximum acquisition value. This figure gives the amount of capital that can be invested in the automatic milking system to achieve the same net return (net farm income) as with a traditional milking parlour. If more capital than the maximum acquisition value is invested in the automatic milking system, net returns are smaller. The smaller the investment the larger the returns. The maximum acquisition value (MAV) was computed by accumulating the returns from increase in milk yield (R_{my}), the costs of altering the grazing system (C_{gs}) and savings in annual costs by not investing in the traditional parlour (AC_{tp}) and then by dividing this total by the estimated annual costs (20% or 30%) of the automatic milking system (AC_{ams}).

In formula:

$$MAV = \frac{(R_{my} - C_{gs} + AC_{tp})}{AC_{ams}}$$

Table 1 presents the calculated maximum acquisition values and the currently mentioned prices of automatic milking systems. In Table 1 two investment levels for traditional parlour, two annual costs of automatic milking systems, three herd sizes, three grazing systems and two quota levels are considered. Prices of actual investment in automatic milking systems per farm are listed.

Transition from an unlimited grazing system to feeding cows year-round indoors reduces returns strongly. Changing to a limited grazing system shows more favourable returns than those depicted in Table 1. However, it is doubtful whether automatic milking can be combined with limited grazing. Certainly, the assumed increase in milk production will not be achieved in such a set-up.

The investment levels listed for parlours also significantly affect the acquisition values for the automatic milking system. Choosing a lower investment level for the conventional milking parlour causes the maximum acquisition value for the automatic milking system to lower. As a consequence, individual wishes as to the layout of the milking parlour play an important role in the profitability of the automatic milking system.

Table 1. Maximum acquisition values (× NLG 1000) per farm for automatic milking system.

Change of grazing system[1] from	to	Quota (kg/ha)	Investment-level	Number of cows / annual cost 40 - 50		70 - 80		> 100	
				30%	20%	30%	20%	30%	20%
UG	S	10 000	high	82	123	79	119	78	116
			average	24	36	34	51	30	45
LG	S	15 000	high	115	173	135	202	156	233
			average	58	86	90	135	108	162
Mentioned prices automatic milking systems				200-275		275-400		300-550	

[1] UG = unlimited grazing; LG = limited grazing; S = summer feeding

The level of the annual costs also influences the prospects considerably (Table 1). The maintenance costs of automatic milking systems are not yet known, but they will affect the final level of the annual costs.

It is assumed that in the first few years after the system is introduced, there will be no real labour saving on the farm. However, in the long run labour saving will be one of the main factors determining the profitability of automatic milking systems. The effect on net returns of employing less labour is not included in Table 1. A reduction in costs is easiest to achieve on large farms with several employees.

Environmental aspects

More frequent milking increases milk production per cow. If dairy farming is performed under a quota system, as in Western Europe, fewer cows are needed to produce the same quota. calculations (Mandersloot, 1992) have shown that an increase in milk production of 500-1000 kg fat-corrected milk, resulted in a lower stocking rate of cows, which led to the ammonia emission from the farm being reduced by 5-10% and of the nitrate leaching to groundwater being reduced by 2-5%. It was assumed that the reduction in number of dairy cows was not compensated for by keeping more beef or other cattle.

Introduction in practice

The following factors influencing the introduction of automatic milking systems to commercial dairy farmers were mentioned by the working group:

- Size of dairy herds. Smaller farms (less than 40 cows) may be less interested in automatic milking systems, due to investment level and type of farm.
- Housing system. Present automatic milking systems require the cow to report voluntarily. Cows will also be allowed to enter the automatic milking system several times a day. This implies that a loose housing system is required.
- Production level. High production levels are associated with more frequent milking. This may influence the idea of animal welfare.
- Labour costs. When an automatic milking system results in savings of labour hours, high labour costs will stimulate the introduction of the system.
- Grassland management system. In several countries, including The Netherlands, grazing of dairy cows is part of the dairy operation. However, automatic milking requires the cows to be near the automatic milking system. Grazing becomes a difficult part of such a farm set-up. Grass has to be grown more or less as an arable crop, possibly encouraging other forage crops being included in the cropping plan. If cows are kept indoors year-round, society may react negatively to the animal welfare and landscape aspects. Therefore, limited grazing in combination with automatic milking needs further exploration.
- Contact with animals. Less contact with the animals can be a negative factor in control of the herd. However, more experience is needed to determine to what degree a management programme and sensors can take over this task of the farmer. Also, some farmers may consider less direct contact with the animals to be at odds with their profession.
- Ease of working. It is expected that automatic milking will reduce physical labour. The stockman's function will shift more to general supervisory work. This demands other skills from the farmer.
- Attachment to farm. In the long run it is expected that the farmer (and his family) will be less tied to the farm, because the milking process requires only incidental attendance. This may place the profession of dairy farmer more in line with general developments in society.

- Capital position and income. The financial position of the dairy farm is important when deciding upon such a considerable investment as is required for automatic milking. Trends in farm incomes will also influence the rate at which automatic milking systems are introduced in practice.

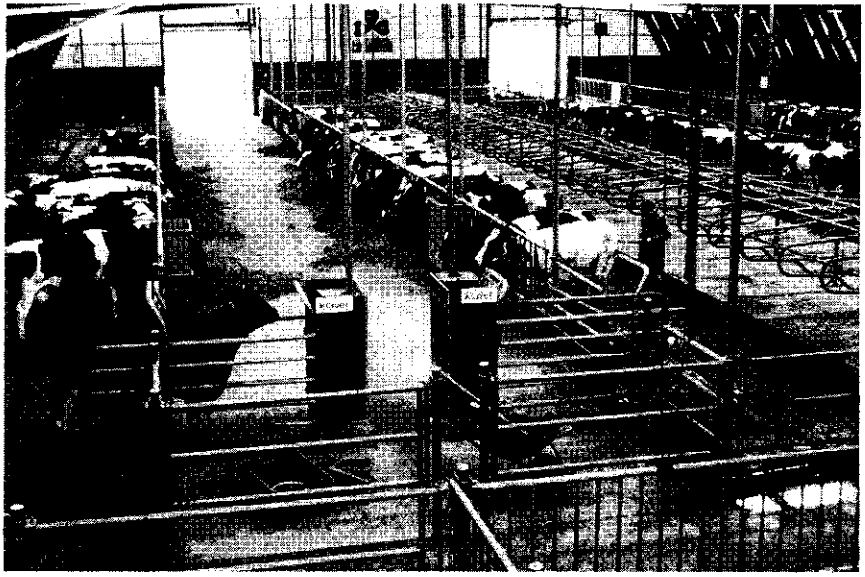


Figure 2. Research about implementation of milking robot in whole farm set-up is needed.

The introduction of automatic milking systems on dairy farms can probably be pictured in two stages. In the first stage, use of an automatic milking system means a further automation of the milking process. The cows can be milked without manual assistance of the farmer or milking personnel. The farmer must be present regularly, to identify abnormal cows, especially cows with mastitis. Also, some "difficult" cows need additional care in entering the automatic milking system and during the milking process. At this stage of introduction no labour saving can be expected.

In the second stage, a complete automatic milking system will be developed. A management programme with various sensors is meant to take over most of the control tasks of the farmer in the traditional milking parlour. After the automatic attachment of teat cups, the detection and separation of abnormal and dirty cows (and milk) is another major challenge to an automatic milking system. However, to what extent this goal will be reached is difficult to assess at present.

In the long run, these developments may result in a saving of labour which, under certain conditions, contributes significantly to the economic returns from automatic milking. But social aspects may be as important as economic factors. When the dairy farmer (and his family) are less tied to the milking process and therefore to the farm, the profession of the dairy farmer will have achieved a major breakthrough.

Saving of labour is the easiest to capitalize in large herds with several employees. On family farms with 1-1.5 family members usually employed, less attachment to the dairy operation will be appreciated most. Therefore, the introduction of automatic milking systems seems to be most attractive to family farms with full labour input and to large dairy farms with more than two employees.

References

Kuipers, A. & A.T.J. Van Scheppingen (Eds.), 1992. Dairy farming and automatic milking: present knowledge and perspectives. Report of a working group. Research Station for Cattle, Sheep and Horse Husbandry, Lelystad, The Netherlands (in press).

Mandersloot, F., 1992. Farm economic consequences of reducing nitrogen losses at dairy farms. Research Station for Cattle, Sheep and Horse Husbandry, Lelystad, The Netherlands, report no. 138.

Mandersloot, F. & A.T.J. Van Scheppingen, 1992. The role of simulation models. In: Applied research in The Netherlands. Research Station for Cattle, Sheep and Horse Husbandry, Lelystad, The Netherlands, p. 15-18.

Ipema, A.H., E. Benders & W. Rossing, 1987. Effect of more frequent milking on production and health of dairy cattle. In: Proceedings of the third Symposium Automation in Dairying. IMAG, Wageningen, The Netherlands, p. 283-293.

6. Poster presentations

Voluntary entrance into the milking parlour

J.L. Albright, A.R. Cennamo & E.W. Wisniewski

Purdue University, Department of Animal Sciences, Poultry Science Building, West Lafayette, Indiana 47907, U.S.A.

Summary

Through proper training or behaviour modification of heifers and cows into the milking parlour, they can be induced to cooperate within the system rather than being forced to conform. Cows have individual preferences for music, weather, dairy operators, stall positions and the side of the parlour on which they choose to be milked. Since cows are creatures of habit and respond well to automation, it is vital to be consistent from one milking to the next.
Keywords: behaviour, training, music, milking parlour, automation.

Introduction

Cows learn quickly while adjusting to new equipment and environmental changes. In order to avoid problems, caretakers should be patient while being firm and consistent (Albright, 1981, 1992). Alert caretakers are perceptive and have the ability to read body language in animals. In some cases, the way the animals behave is the only clue that stress is present (Livestock Conservation Institute, 1992; Resler & Kendra, 1989).

Entering the milking parlour

Chasing cows into and out of the milking parlour is often a frustrating and time-consuming task. Through proper training of cows and milking parlour operators, cows can be induced to co-operate within the system instead of being forced to conform.

Previously, 40 Jersey cows were trained over a 25 day period to enter the milking parlour in a specific order by having an attendant call out the cows barn number (Albright et al., 1966). By the 15th day of training, 70% of the cows responded when called. Another 15% of the cows found their place without being called and the remaining 15% did not respond to their called number and were indifferent as to when they entered the parlour. By the 25th day, cows in the first, second and third group entered the parlour in the right group but not always in their trained order. When the attendant was not present, the effect of training disappeared and the more aggressive cows entered first. It was concluded that after 25 days of training, there was little effect on the subsequent entrance order. Entrance order after training eventually (4 weeks later) reverted back to the order observed during the pre-training time.

Fast and efficient movement into parlours depends on good planning of holding yards and approach lanes as well as good cowmanship as evidenced by training cows by encouraging them instead of forcing them to enter the parlour. It was observed that the training period was prolonged when cows were trained by prodding. Some cows become conditioned to being prodded, waiting for it to happen and considered the goad as a part of the normal milking routine. Labour required for milking can also be reduced either by eliminating grain feeding in the parlour or by using milker units on both sides rather than in the centre of a herringbone parlour. The habit of leaving the pit to move cows into the parlour happens to be an indication of poor training of both cows and operators during the first week of milking in a new parlour. It was suggested that cows be trained to new facilities gradually, preferably when dry. Proper training and yard design can increase milking parlour throughput with little or no additional cost.

Parlour location need not be a limiting factor for future production or management changes. Armstrong (1992) has observed problems in New Zealand. After roaming pastures all day for their feed, cows were walking over 1.6 kilometres on cinder lanes twice a day for milking. Many Western U.S. dairies built in the late 1960's have similar problems. With a parlour located at the front of the property near the road for easy access by the milk tanker, the milking herds are housed in two long rows of corrals extending up to 0.8 kilometres behind the parlour. Both milkers and cows get tired and late lactation cows on milking 3 times a day were observed lying down in the return lane. Armstrong (1992) recently designed a 2500 cow dairy with eight milking groups and 0.70 square metres of corral space per herd. The maximum walking distance to the parlour was only 160 metres.

Regression of voluntary entry

Over the years at Purdue, there has been a deterioration in cow voluntary movement into the milking parlour. Twenty-five years ago when entrance order in a side-opening parlour was first checked weekly for one year, about 15% of the cows had to be chased in. Also, the cows which had been milked on one side of the parlour entered that same side of the parlour 95% of the time in the following season (Ferguson, 1967). As Total Mixed Rations were fed outside with mixer wagons in 1965, the number of cows having to be chased in rose to approximately 25%. About 10 years later this figure had risen to approximately 50% of the milk cows having to be chased in. Voluntary entrance deteriorated more so and morning and afternoon milkings were watched once weekly for one year and it was found that 97% of the cows were waiting for someone to come get them; only 3% (actually 2.8%) would come in by themselves (Wisniewski, 1977). A simple solution is to provide a dependable crowd gate. Mechanical crowd gates are commercially available and most cows respond to them. Crowd gates reduce the space in the holding pen. Without a crowd gate most dairy cows remain stationary and essentially motionless. A crowd gate wakes cows up, keeps cows moving and encourages their voluntary entrance. Field studies show better cow traffic with no doors and a common holding pen-milking parlour arrangement (in cold climates an overhead garage-like door between the parlour and holding area works very well). Having electrified crowding gates ("electric dogs") can be unproductive as they seem to create fear in cows and they take longer to enter (Albright, 1971).

Research studies at Purdue University

Entrance behaviour of dairy cattle was evaluated in two previous studies of the former Purdue facilities. The first study by Ferguson (1967) considered entrance order, entrance rank and the relationship of yield to entrance order. Ferguson found that cows who entered the parlour early tended to produce a higher yield than later cows. The second study was conducted by Wisniewski (1977) to evaluate entrance order, its relationship to production, and the effects of behaviour modification on entrance order. Wisniewski attempted to improve the milking efficiency and concluded that the entrance behaviour of cows could be successfully modified using operant conditioning techniques.

Data were collected from 12 222 individual cow observations over 85 morning and afternoon milkings during a one year period at the Purdue double 5 herringbone parlour. Average entrance and exit times were 10.9 and 14.1 seconds per cow respectively. Average milking time was 3.5 hours per milking at a rate of 41.8 cows milking per hour. Only 2.8% of the cows observed entered the parlour voluntarily and unassisted. (Highest yielding cows were found consistently in the first two herringbone stalls and lowest yielding ones in the last stall).

It was hypothesized that milking efficiency could be improved by reducing the entrance time per cow and increasing the number of cows entering the parlour by themselves without the assistance by the operators.

Training heifers and cows to enter the milking parlour

Two groups (summer and fall) or 15 springing Holstein heifers (18-24 months of age) were trained to enter the Purdue parlour using operant conditioning with negative reinforcement (i.e. electric shock prod). After familiarization with the facilities the heifers were divided into three training groups of 5 heifers each. The first group was trained to enter as soon as the door was opened. The second group was trained to enter after 4 sequential flashing red lights were turned on. The third group was trained to enter when a buzzer was activated. The training stimulus (door opening, lights or buzzer) was activated and the heifers were allowed 60 seconds (later reduced to 30 seconds) to enter the parlour. Heifers not entering within the allowable time period were shocked. The summer training period consisted of 1 to 10 daily trials over 15 days while the fall period was reduced to 10 days.

Statistical analysis indicated no difference among training stimulus or between training periods for percent heifers entering by themselves (74.4%), average entrance time (8.2 seconds) and average exit time (7.4 seconds). Differences among the heifers were detected for their ability to learn as well as their rate of learning (Table 1). Most learning had occurred by the end of the third day.

Table 1. Entrance behaviour summarized for trained heifers (Wisniewski, 1977).

	% Heifers in unassisted		Average entrance time sec/heifer	
	Summer	Fall	Summer	Fall
Day 1	1.3	32.7	17.4	15.0
Day 2	50.0	68.1	15.3	11.3
Day 3	79.3	86.7	11.6	7.0
Day 4	93.3	94.0	6.4	5.8
Day 5	94.7	83.3[1]	4.0	5.6

[1] Milking parlour routines interrupted by cleaning, scrubbing, etc.

After calving the conditioning stimulus was not used regularly and eventually the conditioned response habituated. After a brief re-training period (14 trials over 4 days) using the shock prod, the performance was returned to near peak levels. Untrained heifers mixed with trained heifers learned to enter the parlour quickly by following the trained heifers without the assistance of the operators (Wisniewski, 1977).

Thirty late lactation Holstein cows (2.5-9 years) were trained between milking periods to the buzzer using the techniques described for the naive heifers. Six daily (non-milking time) trials were conducted over 10 days of training. During the training period the percent entering unassisted, average entrance time and average exit time were 80.7%, 6.5 seconds and 7.1 seconds respectively. Peak performance was observed on day 7 when 99.2% of the cows entered the parlour by themselves at an average rate of 3.8 seconds per cow (Table 2). Performance of the cows decreased after the training period (64.9% entering unassisted versus 80.7%) but this represented a large improvement over the pre-training period of 2.2%. Untrained and partially trained cows, followed the fully trained cows into the parlour.

Table 2. Parlour entrance and exit behaviour for cows summarized by training day (Wisniewski, 1977).

Day	No. of obs	% Cows entering unassisted	Entrance time (sec) average	Exit time (sec) average
1	150	32.7^{a}	14.3^{a}	4.6^{a}
2	144	66.7^{b}	8.9^{b}	5.9^{b}
3	132	81.7^{bc}	6.2^{bc}	6.8^{bc}
4	132	83.3^{c}	5.9^{c}	6.4^{b}
5	132	90.0^{c}	4.6^{cd}	7.4^{cd}
6	132	91.6^{c}	5.2^{cd}	8.2^{de}
7	114	99.2^{c}	3.8^{d}	7.9^{e}
8	150	86.7^{c}	5.3^{cd}	7.1^{de}
9	150	86.7^{c}	5.3^{cd}	8.8^{f}
10	150	92.6^{c}	4.1^{d}	7.7^{e}
Average	1386	80.7	6.5	7.1

a,b,c,d,e,f statistically significant difference in column (Duncan's Multiple Range Test, $p < 0.05$).

From this study it was concluded that the behaviour of naive heifers and mature cows could be trained through operant conditioning without adversely affecting milk production or temperament at milking. When the conditioning stimulus was not used regularly, the entrance behaviour of the trained animals regressed (Wisniewski, 1977).

Voluntary entrance

Since the construction and completion of the present dairy facility at Purdue in 1988, evaluation of parlour entrance order had not been conducted. In June and July 1992 Cennamo (1992) documented the behaviour of dairy cows entering the milking parlour for 16 complete milkings over a 4 week period to determine the effects of possible environmental factors and human-animal interaction on voluntary entrance. Two regular milkers, one working the am shift and one working the pm milking and two substitute milkers, one working the am milking and one the pm shift, were observed each week. Observations of the Holstein milking herd were conducted at the Purdue

Dairy Research Centre near Montmorenci, Indiana. The milking area consisted of a 6.1 × 12.2 metres double 6 herringbone parlour. The holding area was approximately 4.9 × 24.4 metres containing a mechanical crowd gate and two other standard gates. This combination of gates was designed to accommodate a total of 3 separate experimental groups.

On average of 134 cows milked, of the total 2138 observations over the 16 different time periods, 458 cows or 21.4% came in voluntarily or by vocal request from the milker. Average entrance time for these cows was 4.8 seconds per cow with an average exit time of 7.0 seconds per cow. Behaviour notations were kept and summarized as Table 3. Visual inspection revealed that 114 (81%) different animals of the 140 head herd came in voluntarily at some point in the study. Of these 114 different cows, 79 cows had repeat entrance by free choice or at least twice and several had as many as 11 times by free choice. For the total of 458 cows that voluntarily entered the parlour, 265 (58%) entered the parlour in the absence of music. The remainder of 193 cows entered the parlour while the radio was playing country music (36%) and rock 'n' roll (6%). The radio was not played consistent from one milking to the next. Only half the time the radio was in use.

Table 3. Entrance into milking parlour-cow response (Cennamo, 1992).

%	Description
16.2	Free choice[1]; sound and sight of gate opening
5.2	Free choice; animal responds to milkers voice
14.8	Milker leaves pit and stands on apron[2]
33.0	Milker leaves pit and enters holding area
19.1	Milker leaves pit and cow responds to some form of physical contact[3]
10.2	Mechanical crowd gate[4] encourages cow movement
1.5	Mechanical crowd gate plus vocal or physical contact
100.0	

[1] Voluntarily entered/unassisted
[2] Area where cows stand and look into milker's pit
[3] Minimal touch
[4] When operable

For cows entering the parlour voluntarily, cows responded to clear weather best (45%), then rain (28%), cloudy (23%) and partly cloudy (4%). The percentage of days with differing weather during the trial was clear weather (44%), rain (19%), cloudy (31%) and partly cloudy (6%). Considering all the cows entering the parlour unassisted, 55% preferred to enter on the east side. The west side (45%) had congestion with cows exiting nearby while the east side was clear.

No clear distinction existed between the regular operator and the weekend or substitute operators. An operator with the third highest percentage (37%) for voluntary entrance was considered to be a substitute milker and the operator with the second lowest percentage (6.5%) was a full time regular milker. The best milker had 43% entering the parlour and had only worked for two weeks while another substitute milker had only 5% of the cows entering by free choice. Because of his performance, male milkers in this study were slightly higher for cow free choice movement into the parlour (23%) than for women (19%). These data for the most part suggest that familiarity of the cows with the milker is not an influential factor in entrance behaviour.

References

Albright, J.L., 1971. Electric Crowding Gates Lower Efficiency. Hoard's Dairyman 116:846.

Albright, J.L., 1981. Training Dairy Cattle. Dairy Science Handbook, Agriservices Foundation, Clovis, California, USA, 14:363-370.

Albright, J.L., 1992. The Keys to Cow Co-operation Growthlines Summer Issue, Hoffman-La Roche, Inc. Nutley, New Jersey, USA, p. 1,3.

Albright, J.L., W.P. Gordon, W.C. Black, J.P. Dietrich, W.W. Snyder, C.E. Meadows & R.W. Etter, 1966. Behavioral Responses of Cows to Auditory Training. Journal of Dairy Science 49:104-106.

Armstrong, D.V., 1992. Where Should the Parlour Go? The Dairyman 73(8):46.

Cennamo, A. R., 1992. Animal Behaviour Study. To Meet the Requirements of ANSC 491 Special Problem. Purdue University, West Lafayette, Indiana, USA.

Ferguson, R.S., 1967. Dairy Cattle Entrance Order into a Milking Area as Related to Milk Production, Age, Body Weight and Milking Characteristics. MSc. Thesis, Purdue University, West Lafayette, Indiana, USA.

Livestock Conservation Institute, 1992. Understanding Dairy Cattle Behaviour to Improve Handling and Production (videotape). Madison, WI, USA.

Resler & Kendra, 1989. Bovine Language Reveals Animal's Moods. Purdue School of Agriculture, West Lafayette, Indiana, USA. Discover 5(1):8.

Wisniewski, E.W., 1977. Behavioral Modification of Milking Parlour Entrance Order in Dairy Cattle Trained by Operant Conditioning Methods. Ph.D. Dissertation, Purdue University, West Lafayette, Indiana, USA.

Simulation as a tool for designing automatic milking systems

E. van Elderen

DLO Institute of Agricultural Engineering (IMAG-DLO),
P.O. Box 43, 6700 AA Wageningen, The Netherlands

Summary

A simulation tool (PERSONAL PROSIM) is used to find good configurations of the automatic milking system (AMS). The model of the AMS is tuned to the quality of milking in relation to the characteristics of the cow herd. Examples of the simulation tool and of the input and output show the approach.
Keywords: automatic milking system, cow herd, simulation.

Introduction

A simulation tool to model the automated milking of a herd of cows has to find answers to the following questions:

1. What is the influence of herd characteristics such as herd size, calving pattern, standard production and cow behaviour on the performance of the AMS and the quality of milking?
2. Which is the best configuration of an automatic milking system (AMS) and what are the relations between the use of selection and milking units and the "quality of the milking processes"? That quality is expressed in the amount of milk per milking, the length of the queues of cows and the intervals between milkings.
3. What are the relations between cow herd and the configuration of the AMS (number of selection and milking units, the waiting space before the units) and its use? The use is described by the selection criteria for milking, the queue discipline (first-in first-out or highest production first) and the cleaning schedule of the milking units.

The AMS model in this study consists of several units to select cows and of some units for automated milking. The configuration is related to the IMAG-DLO research (Ipema & Benders, 1992; Devir, 1992). In the model the cow presents herself for selection in a queue in front of the units after a presentation interval randomly drawn from a distribution. The cow moves from the queue into a selection unit, which checks if she can be milked or not. After being rejected for milking or after milking a cow returns to the barn; a new presentation interval is drawn for the cow. And so on. This process is interrupted by cleaning the milking units several times a day.

PERSONAL PROSIM simulation tool

PERSONAL PROSIM (Anonymous, 1992) is an object oriented simulation tool for a Personal Computer. It delivers a framework for:

- Modelling
- Simulation
- Validation

The object oriented approach of modelling with classes of objects (cow, selection unit, milking unit, cleaning unit) enables the system to be configured during the simulation. A class consists of the declaration of the variables and of the process description of the activities of objects of that class. The latter also describes the relations between objects (cow and selection unit) and the dynamic aspects of the system in time (duration of selection and of milking). Each object has its own characteristics (variables) and follows the process in its own way. The language handles discrete processes (discrete time advance: cow starts/ends selection/milking) and continuous processes (continuous change of certain variables: milk yield as function of day time).

The simulation is supported by animation on the screen to show the behaviour of the model (Figure 1) and by several means, e.g.:

1. A trace of all creations of objects, all activations and deactivations of objects, all moves of objects from sets and to sets. It is a very efficient instrument to check the validity of the model as a description of the process dynamics in reality.
2. A state analysis: all characteristics of all objects and memberships of sets can be displayed on screen. The characteristics can be changed.

The validation of the model by comparing data from a real experiment and a simulation experiment is also supported by several means, e.g.:

1. An 'environment' of the model connects specific input and output files to the required input and output of the model. This supports the flexibility of experimental frames without changing the model.
2. A build-in facility stores values during the simulation and presents them during the simulation or afterwards in pictures.

```
┌ PERSONAL PROSIM RUNTIME SYSTEM ──────────────── MODEL IS AMS_3      ┐
│ Licensed to Ministerie LNV -DLO - IMAG te Wageningen                │

MONTH:    2          NUMBER of COWS       LACTATING                DRY
DAY    :  7                      80                 77                3
HOUR:0  1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
    >>>>>>>>>>>>>>>>>>>>>
Cows in and in front of selection unit:  6          Cow in selection: Cow.....59
                                     ►►►►►►           29.21 kg per day    Milking
Cows between selection and milking unit: 2►►       in waiting space of  2 cows
                                          Preceding milking
Milking unit Action        Cow            .. hours earlier  Production  Milking in
Milking..1   MILKING       Cow.....69       5.74 h             6.0 kg      4.7 min
Milking..2   MILKING       Cow.....18       6.96 h             6.1 kg      4.7 min

┌ Time =          13.28355─────────────────────────────────────────────┐
└ Esc:Interrupt ── F9:Freeze ── F20:Abort ──────────Press a key to continue┘
```

Comment

Constants per month

Daytime Selection unit

Milking units

Figure 1. Screen output during simulation (runtime animation) at time 13.28355 (Month 2, Day 7 and daytime 6:48.. = 0.28355)

Experiments

A simulation experiment depends on three aspects:

1. The model as defined in the PERSONAL PROSIM simulation tool;
2. The input requested by the model interactively: some herd characteristics and parameters to configure the system (Figure 2);
3. The input required by the model to know some initial characteristics of individual cows (given in a file and linked to the model via the environment).

```
┌ PERSONAL PROSIM RUNTIME SYSTEM ──────────────── MODEL IS AMS_3      ┐
│ Licensed to Ministerie LNV -DLO - IMAG te Wageningen                │
          COW HERD DATA
Number of cows?                                                 80
Calving pattern? SPREAD, SPRING, AUTUMN                     SPREAD
Standard cow production kg per day?                             40
          Input of herd data correct? Y, N                       N

          CONFIGURATION OF AUTOMATED MILKING SYSTEM
Selection criterium: minimum milk yield in kg?                 3.5
Number of milking units?                                         2
Max. number of cows waiting just before milking units?           2
          Input of system data correct? Y, N                     N
                                                                   ──Rpl┐
└ Enter value ─────────────────────────────────────────────────────────┘
```

Figure 2. Input from screen.

Results

The results given below are only intended to illustrate the facilities of the simulation tool; they are not meant to be used for drawing conclusions about automated milking.

Table 1 gives the data from an output file. After inputdata follows monthly the number of visits per cow per day to the selection units and to the milking units. The relative use of the milking units, the average milk yield, the number of lactating cows and the number of cows are presented. Finally the frequencies of productions (>12 kg) are available.

Table 1. Output file data.

Data							Comment
Number of cows in herd:					100		Input data
Calving pattern:					SPREAD		
Standard cow production (kg milk per day):					40		
Selection criterion (min. milk yield kg):					3.50		
Number of milking units:					2		
Waiting space between selection and milking (cows):					2		
Days simulated per month:					7		
Month number	Visits SU (average)	Visits MU (average)	Use of MU (% time)	Milk Yield (kg/cow/day)	Lactating cows	Total cows	Use of systems units: Cows
1	4.457	3.917	75.955	25.736	100	100	
2	4.496	3.835	72.145	24.177	97	100	
11	4.571	4.287	72.036	30.638	84	100	
12	4.509	4.178	77.790	29.744	94	100	
	4.571	3.884	64.011	25.681			
Freq. of Top production of > 12 kg milk per milking:					631		'Quality of milking'
Freq. of Top production of > 14 kg milk per milking:					138		
Freq. of Top production of > 24 kg milk per milking:					0		

Figure 3 shows the use of one selection unit and of two milking units for twelve months and herd sizes of 60, 80, 100 and 120 cows. It also presents the number of lactating cows and the relative time consumed by the milking units.

Figure 4 presents some results for a herd of 120 cows, reflecting the quality of the milking process i.e. the frequencies of production, of waiting time and of intervals; and the relation between production and interval.

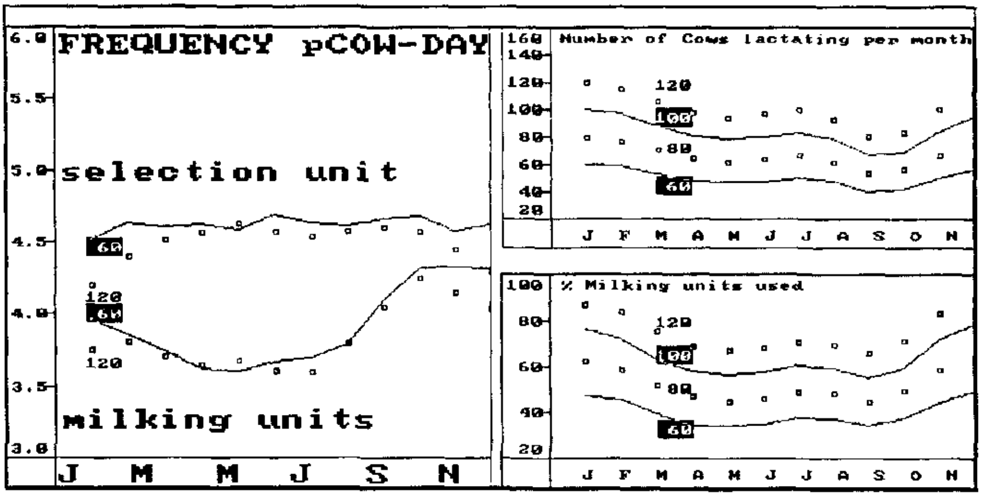


Figure 3. (A) Use of the selection unit and two milking units (in frequencies per cow and day) during various months of the year; herds of 60 and 120 cows (left). (B) Number of cows lactating (upper right) and the occupation time in % of milking units (lower right) for herds of 60, 80, 100 and 120 cows. Situation: calving spread over the year; standard cow production 40 kg/day.

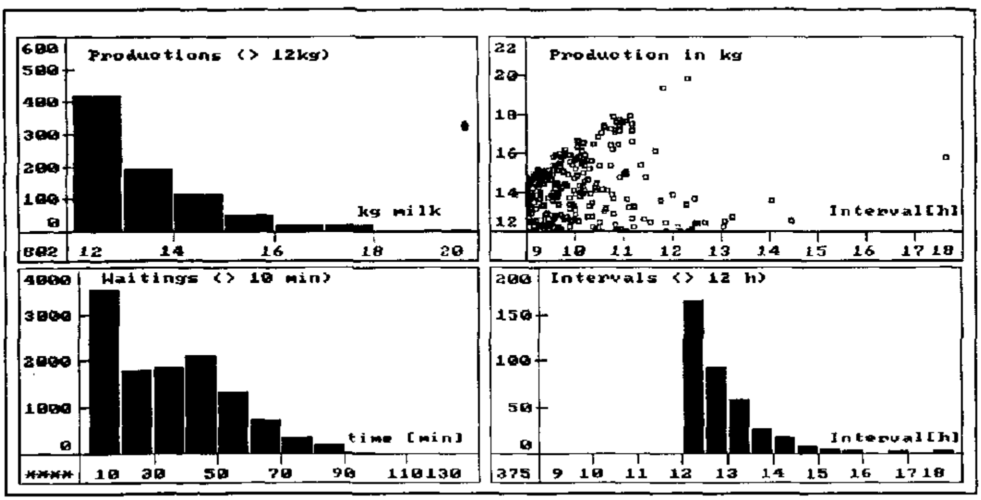


Figure 4. (A) Frequency histograms of productions > 12 kg per milking (upper left), waiting times (> 10 min) between reporting at selection unit and arriving at milking unit (lower left) and intervals between milkings > 12 h (lower right) for herd size of 120 cows. (B) The relation between production (> 12 kg) and interval length (> 12 h) as a plot (upper right).

Discussion

The use of simulation is a very fruitful technique to test real systems or systems still in development. It is used to find the effects of several configurations of a system without physically building that system. It is able to find the sensitivity of results to certain input parameters. And it throws light on the need to gain better data from real situations (i.e. a guide for experiments in practice).

The crucial question is of course: 'Is the model valid?'. This includes three questions:

1 Is the construction of the model in the simulation tool such that the processes in the model are the same as seen or expected in reality (dynamic model validity)?

2 Are enough aspects incorporated in the model so that aspects not considered are indeed irrelevant for the processes or can be given via the input?

3 Is there agreement between data from real situations and those gained from the model (data validity)?

The PERSONAL PROSIM simulation tool has considerable power to build a model and to check the processes during simulation. It presents results gained from a model and enables statistical procedures to be used to evaluate the output. Clearly, it is a useful aid for developing automatic milking systems for cows.

References

Anonymous, 1992. PERSONAL PROSIM Textbook, Reference Manual, User Guide and Supplements. Release 2.05. Sierenberg & de Gans, Waddinxveen, The Netherlands.

Devir, S., 1992. Control and management in the automatic milking system dairy farm. In: A.H. Ipema, A.C. Lippus, J.H.M. Metz & W. Rossing (Eds.): Proceedings of the International Symposium on Prospects for Automatic Milking, EAAP publication No. 65, Pudoc Scientific Publishers, Wageningen, The Netherlands, p. 315-321.

Ipema, A.H. & E. Benders, 1992. Production, duration of machine-milking and teat quality of dairy cows milked 2, 3 or 4 times daily with variable intervals. In: A.H. Ipema, A.C. Lippus, J.H.M. Metz & W. Rossing (Eds.): Proceedings of the International Symposium on Prospects for Automatic Milking, EAAP publication No. 65, Pudoc Scientific Publishers, Wageningen, The Netherlands, p. 244-252.

Assessment of the use of a decision support system to manage insemination through routine milk progesterone analysis

R.J. Esslemont & M.E. Williams

University of Reading, Department of Agriculture, Earley Gate, Reading, Berkshire RG6 2AT, United Kingdom

Summary

A planned system of milk progesterone testing to measure cyclicity in dairy cows has been computerised. Linked to a general cow recording scheme, it lists cows for testing and subsequently cows for serving. The program also lists cows for veterinary inspection (possibly anoestrus, short cycles, persistent corpora lutea) and cows considered pregnant. The program can be used by named cows only. The effect is to raise heat detection rates to 85% or more in practice, without reducing conception rates. Herds using the system properly have calving intervals of 365-370 days, selling only 7% of cows for failure to conceive. Even in previously well run herds, the use of the system has significant financial benefits.

Introduction

The program has been developed over a period of two years from rules derived in a three year study of the tactical use of milk progesterone tests in dairy herds (McLeod et al., 1991). The purpose is to raise the submission rate of cows for A.I. for the first and subsequent services, at the same time identifying cows not cycling normally, without having to rely on normal heat detection.

MOIRA is a module of DAISY, The Dairy Information System (Esslemont et al., 1991), which copes with any type and any amount of individual cow records. Reports can be produced on a wide range of topics. The system could be automated within parlour control devices.

Cows can be put "onto" or taken "off" at any time and, once on, the rule based system suggests the times for three weekly milk progesterone tests as soon as the cow reaches 20 days post partum (alternatively, cows with a definite delay imposed on their breeding are started on the module 24 days before the start of their breeding season). Cows showing abnormal progesterone patterns can be diverted for veterinary attention. Cows cycling normally are put forward for further tests 15 days after the low, and tested on alternate days until another "low" is found. When six "high" tests are found, from day 15 to 25, the cow is considered pregnant. The DAISY program is already loaded with the records of calving dates, services, pregnancy diagnosis, etc.

System Description

When running MOIRA the farmer can choose which day of the week he wants to "test" for milk progesterone. The weekly testing can be spread across all the days of the week, and alternate day testing can be arranged to avoid relief milking days. It is not possible to have a gap of more than 2 days, and so testing must be carried out on two consecutive days once a week. Alternatively, the pattern can be allowed to shift by a day each week, so the alternate day tests are adhered to.

Based on a menu driven system, the dairy information system produces:

List of Cows to Test

A list is produced daily of cows to test. The farmer enters the results of the milk progesterone tests into the information system as a "high", "medium" or "low".

The module analyses the patterns of the milk progesterone tests, and, when the correct pattern is found to show that the cow is cycling (e.g. HHL, LHH, HHL), she is not listed for further tests for 15 days from the low progesterone.

Lists of the Cows with Abnormal Cycles (Cows for the Veterinarian)

Cows showing abnormal patterns in the weekly testing are listed on the Action List, and can be diverted for veterinary attention. This list includes cows that have an apparent persistent corpus luteum (HHH), those that are anoestrus (LLL), those with short cycles (LHL), and cows that have started cycling and then stopped (HLL or LML).

Cows with MM are also listed on the Action List as a "check accuracy of test" command. The results of the milk progesterone test should be presented to the veterinarian on his visit, so that accurate treatment can be given, and these cows returned to the testing module. There is no need to take these cows "off" as the program will continue to set up tests accordingly.

List of Cows for Service

The alternate day testing starts 15 days after the "marker" low or ovulation. The dairy information system produces a list of cows to test on each test day. Provided the cow has passed her "fit to serve" date, the information system will list the cows to be served on the basis of a low milk progesterone result. These cows are listed to be served on the day after the low progesterone, without any signs of heat being observed (Foulkes & Goodey, 1988).

Cows for Pregnancy Diagnosis

After service, the tests are stopped for 15 days, and then the dairy information system lists the cows for testing every other day. If the cow is pregnant, 6 high progesterone results are recorded from days 15 to 25 after service, and then testing is stopped. If she is not pregnant, a low progesterone result is recorded, and the cow should be served the next day. This procedure continues until the cow is pregnant, or a decision is made to stop serving her. Cows assumed to be pregnant should later be confirmed in calf by rectal palpation or ultrasound scanner.

Between days 26 and 40 after service, embryo loss can occur. Cows which are not pregnant to the manual check can be treated and put back onto the weekly testing on the dairy information system.

Materials and methods

This study involves a dairy farm of 132 Friesian cows which used the DAISY MOIRA protocol in 1990/1991, and compares herd reproductive performance with that of the previous year (1989/1990), when the dairy information system was not in use. The farm used the Ridgeway Science Well Test (Ridgeway Science, Rodmore Mill, Alvington, Gloucestershire, U.K.) for monitoring progesterone concentrations.

The farm operates a DIY A.I. system, with no natural service. The calving pattern is being moved to get more cows calving in the summer months, and so the service period ran from 14th September, 1990, to 1st May, 1991 (Experimental), compared to 5th October, 1989, to 17th May, 1990 (Control). The interval to first allowed service was 30 days in both years. The farm purchased the DAISY Cow Recording program (University of Reading) in 1989. The MOIRA module was purchased in 1990 to improve fertility management.

Analysis of Data

For the purpose of this study, only cows which followed the DAISY MOIRA protocol from calving to conception (or until it was decided to stop serving a cow) were included in the analysis.

These were cows calving from 1st June, 1990, to 21st October, 1990. For a comparative Control herd, only cows which calved over the same period in 1989/1990 in the respective herds were analysed. The economic evaluation was based on model figures quoted by Esslemont (1992).

Results and Discussion

As a result of purchasing DAISY in 1989 to monitor fertility in this herd, the reproductive performance was already higher than in previous years, due to improved record keeping and the use of the analysed data for management decisions. Therefore the improvement to be made by using the dairy information system could only be relatively small.

Table 1. Summary of reproductive performance, cows calving 1st June to 21st October, 1989 (Control), and 1990 (Experimental).

Herd 1	Control	Experimental
Total number of calvings	101	95
% Served of calved	96	95
Mean calving to first service interval	61	56
First service 24 day submission rate (%)	70	71
% of re-serves 16-28 days	49	86
First service pregnancy rate	44	43
All service pregnancy rate	42	38
% Conceiving of served	86	94
% Conceiving of calved	83	90
Mean calving to conception interval	90	85
Mean number serves per conception	2.3	2.5
Mean calving interval	372	365
% Culled of calved	23	18
% Culled for "failure to conceive"	13	5

Results for cows calving from 1st June to 21st October in 1989 (Control year) and in 1990 (Experimental year) are presented in Table 1. Analysis of the data shows that the use of the dairy information system reduced the calving to first service interval by five days (56 versus 61), and increased by 8 points the percentage of cows conceiving of those served (94 versus 86). First service pregnancy rates remained the same (44 versus 43). Calving interval was reduced from 372 to 365 days.

The use of the DAISY MOIRA protocol to detect cows which returned to service between 16 and 28 days after the previous insemination was significantly higher in the Experimental year (86 per cent), compared to detection by herdsman observation alone (Control year, 49 per cent, $P < 0.001$).

Oestrus detection is kept to a minimum on this farm, with MOIRA forming the basis for detection. This is a great benefit to the farmer, especially at busy times of the year.

The overall culling rate was reduced by 5 percentage points (23 and 18 per cent, Control and Experimental years respectively), but since the dairy information system can only affect the number of cows culled for failure to get in calf, it is this figure which is used in the economic calculations.

There were 8 per cent fewer cows culled for failure to conceive in the Experimental year (5 per cent), compared to the Control year (13 per cent). Improvements of a similar nature were found in other herds (Watson, 1992) (Collis, 1991).

The farmer reported a reduction of almost 50 per cent in his veterinary bill in the Experimental year. This was a reflection of the reduction in the number of cows being examined for oestrus not observed (29 per cent in the Control year, and 15.3 per cent in the Experimental year).

Table 2. Economic evaluation of the use of DAISY MOIRA Protocol in HERD 1 (Per 100 Cows).

TOTAL SAVINGS		7003
Improvement of 7 days on the Calving (£)		
• Interval @ £3 per day	2100	
• 8 FTC culls saved @ £600 per cull	4800	
• Reduced ONO and FTC vet costs @ £7.50 per case	103	
TOTAL COSTS (£)		1020
• 3 per cow @ £3.90 per cow	390	
• Time; 120 hours @ £4 per hour	480	
• DAISY MOIRA (share) (£)	150	
NET BENEFIT PER 100 COWS (£)		5983

It was assumed that every case costs £7.50 per cow (Esslemont, 1992). Table 2 gives the economic calculations of the benefit of using the dairy information system in this herd. It is estimated that a benefit of £7003 was made per 100 cows, by reducing wasted days, and reducing the culling rate for failing to conceive. The costs incurred, based on the cost of the module (£350 to buy), labour to sample and test the milk, and the milk progesterone tests (13 per cow at 30 pence per test), total £10.20 per cow (Table 2). Thus a net benefit of £5983 was made per 100 cows in the herd.

Conclusions

The uptake of new technology by farmers will often be slower than anticipated, however much systems such as MOIRA report on the benefits that can be achieved, since an educational process is often involved. Heat detection is a major problem on many dairy farms, and so any system that makes the task easier and more accurate must be of benefit.

References

Collis, M.J., 1991. New Techniques in Herd Fertility Management. Proceedings of the Conference and Open Day. Department of Agriculture, University of Reading, Reading, United Kingdom.

Esslemont, R.J., B.R. Wassell, L.M. Grimbleby, T.R. Wassell, J.L. Lamb & S.R. Horne, 1991. The Application of Planned Animal Health and Production to Dairy Farms: DAISY - The Dairy Information System. The Bovine Practitioner 26:38-41.

Esslemont, R.J., 1992. New Management Indices for Dairy Herd Management. Journal of Farm Management 8:33-36.

Foulkes, J.A. & R.G. Goodey, 1988. Fertility of Friesian Cows after Insemination on the Second, Third and Fourth Days of Low Milk Progesterone Concentrations. Veterinary Record 122:135.

McCleod, B.J., J.A. Foulkes, M.E. Williams & R.F. Weller, 1991. Predicting the Time of Ovulation in Dairy Cows Using On Farm Progesterone Kits. Journal of Animal Production 52:1-9.

Watson, C., 1992. The Use of Milk Progesterone Samples for Complete Herd Oestrus Control. XV11 World Buiatrics Congress, XXV American Association of Bovine Practitioners. St. Paul, Minnesota, USA.

A computer program to analyze herd management using DHI testday information

R.H. Fourdraine, M.A. Tomaszewski & T.J. Cannon

Texas A&M University, Department of Animal Science, 432 Kleberg Center, College Station, Texas 77843-2471, U.S.A.

Summary

A microcomputer program to analyze current herd management was developed using TURBO PASCAL and PDC PROLOG. Data is downloaded from an external data source transparent to the user. Data used includes production, udder health and reproduction management parameters for the current and previous date of test. These values are compared to standard values that are matched to the herd's production level, parity and stage of lactation. Analysis results are available to the user in three forms: 1) tables, 2) graphs, and 3) lists.
Keywords: dairy, microcomputer, herd management.

Introduction

Microcomputers have moved from the office to the home, and now are used on the farm to aid with management decisions. On-farm computers are commonly used by producers, consultants, and veterinarians for management evaluation. Easy accessibility and use of Dairy Herd Improvement (DHI) data from dairy record processing centres (DRPC's) and on-farm computers have become essential for timely decision-making. Historically, most dairy software was targeted towards data collection and simple report writing. With the increased power of microcomputers, the development of analysis software has seen a major increase. Currently, the development emphasis is on lactation curve analysis, and a number of lactation curve programs are currently available. These programs are generally used to analyze historical herd management problems and are unable to identify specific management problems such as reproductive performance. It became apparent that an additional program was needed to analyze current testday production, which also includes reproduction and health data. The Current Testday Analysis Program (CTAP) was developed in response to this need.

Objectives

There were five objectives for the development of the CTAP program:

- Develop a program to retrieve data from an external database, perform calculations, and present key management analysis parameters.
- Graphically display a four-year history on production, reproduction and health parameters.
- Establish a set of production, reproduction and health parameter averages by herd production level and parity.
- Develop a separate module to allow the program to be customized to an individual user's needs.
- Develop a user-friendly interface.

The main menu of CTAP has three major options which form the individual modules in the program:

- A Download Module to download from DRPC's or on-farm database programs.
- An Analysis Module to analyze previously downloaded data.
- A Limits Module to user-customize the program.

Download module

In order to access any of the DRPC's, the communication program (COMTEST.EXE) requires the user to input a herdcode, password, remote access code, baud rate, phone number, phone type, communications port, and capture disk drive. This program calls a program written in Basic by the DRPC at Raleigh (DMENU.EXE) which will execute the actual download. If an on-farm database is used, the communication program will allow the user to import a file from the hard disk of the computer. After downloading (or importing), the data is processed and stored in a Borland TURBO PASCAL database file with the appropriate index files.

Analysis module

The analysis module (CTAPMENU.EXE) is written in Borland TURBO PASCAL and is executed from the main menu when the analysis option is selected. This option asks the user to select a herd, and then it processes the data and stores all calculated parameters in memory. After processing, the user can select from three different types of analysis:

1. Testday summaries.
2. Cow listings.
3. 4-year and testday graphs.

The following variables can be analyzed:

Production:
- Milk production
- 3.5% Fat corrected milk
- 3.5% Fat, 3.2% protein energy corrected milk
- Fat and protein percent
- Somatic cell count
- Body condition score

Reproduction:
- Pregnancy rates
- Conception rates
- Services per conception
- Days to first breeding
- Days open
- Days dry
- Calving interval

In order to evaluate herd management, the production and health standards were calculated from Texas DHIA data by herd production level (453.6 kg increments), parity (1st, 2nd, 3rd and greater lactation) and stage of lactation (<45, 46-100, 101-200, 201-300, >300 days in milk). Reproduction standards were calculated by herd production level and parity. Production and reproduction goals were gathered from scientific literature.

CURRENT TEST DAY PRODUCTION INFORMATION						
Date of Test: 920518	DIM <45	DIM 45-100	DIM 101-200	DIM 201-300	DIM >300	DIM ALL
1st lactation						
No. of cows	42	70	136	103	76	427
Avg DIM	26	77	148	243	371	187
Avg milk (lbs)	64.3	79.7	74.7	60.9	46.4	66.1
Avg FCM (lbs)	61.0	72.5	69.0	58.8	47.7	62.5
Avg ECM (lbs)	61.3	72.8	69.6	59.3	48.2	63.0
Avg fat %	3.2	3.0	3.1	3.3	3.8	3.3
Avg protein %	3.1	3.0	3.1	3.2	3.5	3.2
Avg SCC (ls)	3.4	3.2	3.2	3.6	4.0	3.4
Avg days open	0	73	104	125	204	130
Avg days dry	0	0	0	0	0	0
Avg ME milk	0	24180	24983	25902	26598	25416
Herd name: 74157280 RHA: 21162 Use following keys PRESS ESC TO QUIT						

Figure 1. Current testday production for first lactation cows.

Testday summaries allow the user to analyze testday production (Figure 1), testday persistency, udder health, body condition, yearly reproduction, last breeding interval reproduction, and group performance by parity and stage of lactation. Values can be compared against calculated standards and goals by pressing the appropriate function key.

Cow listings allow the user to create management lists for fresh, peak, early lactation, high somatic cell count, problem breeders, delayed breeders, and all cows. Lists are displayed on the screen, and management codes are assigned for cows with possible ketosis, fat protein inversion, possible mastitis or reproductive cull.

Seasonal and management changes are reflected in four-year history graphs, which allow the user an instant view of trends over the last four years. Figure 2 shows the rolling herd average milk over the last 4 years.

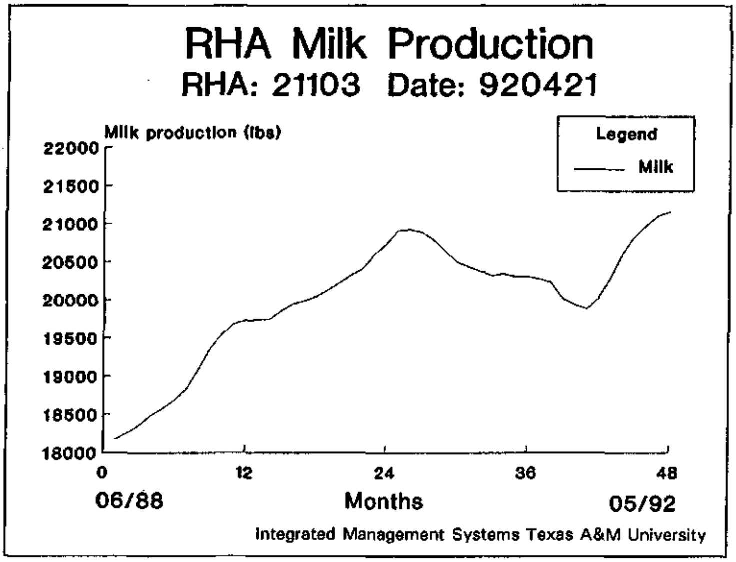


Figure 2. Rolling herd average milk production.

Limit module

Because management varies across breeds, geographical regions and individual dairies, certain analyses that use a set value for comparison might not give an accurate picture of the real management situation. Therefore a third module (LIMIT.EXE) written in TURBO PASCAL was added to the program. In this module the user can change default values within a certain range and process a herd using the new values. Limits for the following parameters can be changed:

- Breeding herd
- Detection of mastitis, ketosis, fat protein inversions, and possible culling for reproductive reasons
- Delayed breeders
- Problem breeders
- Herd breed.

Conclusion

In Texas, several dairies have been monitored since October, 1991, using a lactation curve program (LACCURV) and CTAP as analysis tools (Fourdraine et al., 1992). Problems associated with milking equipment, udder health, nutrition, or breeding strategies have since been detected in several herds. The program has proven to be an excellent tool to monitor and evaluate herd management. Management opportunities can be identified and these changes in management can be evaluated and quantified after implementation.

Future directions include a merger of the CTAP program with other dairy management software such as the Dairy Expert System and Lactation Curve Graphing Program (DXGRAPH). Efforts are underway to develop a financial module that will combine production analysis with financial analysis. Currently, a research project is underway with the primary objective of investigating the use of a artificial neural network as a tool to assist users in analyzing herd management changes. The secondary objective is to evaluate the possibility of using a neural network for simulation purposes and to forecast future herd performance.

References

Fourdraine, R.H., M.A. Tomaszewski & T.J. Cannon, 1992. Dairy herd lactation expert system, a program to analyze and evaluate lactation curves. In: A.H. Ipema, A.C. Lippus, J.H.M. Metz & W. Rossing (Eds.): Proceedings of the International Symposium on Prospects for Automatic Milking, EAAP publication No. 65, Pudoc Scientific Publishers, Wageningen, The Netherlands, p. 331-337.

Computer aided system for health and reproduction control in dairy cows

P.H. Hogewerf*, K. Maatje** & W. Rossing*

* *DLO Institute of Agricultural Engineering (IMAG-DLO), P.O. Box 43, 6700 AA Wageningen, The Netherlands*
** *DLO Research Institute for Animal Production 'Schoonoord' (IVO-DLO), P.O. Box 501, 3700 AM Zeist, The Netherlands*

Summary

During recent years, sensors have been developed to measure quarter milk conductivity, milk temperature and the physical activity of animals. These sensors are used for monitoring health and reproduction in dairy cattle. IMAG-DLO and IVO-DLO have developed a programme which processes the data from sensors and displays significant deviations in the data. This programme also includes other data on cows in such a way that a farmer can use it in the daily management of his herd. After every milking a list is generated which signals deviations. When a cow appears on the attention list the system makes it possible for the farmer to retrieve information on this cow for the preceding fourteen days.
Keywords: mastitis, oestrus, health, reproduction, conductivity, milk temperature, activity.

Introduction

Research institutes, in cooperation with industry, have developed sensors for monitoring the health and reproduction cycle of dairy cows. Sensors are available to measure quarter milk conductivity (QMC) (Maatje et al., 1983), milk temperature and animal activity. The information from these sensors can be used to support the farmer's daily management. The data from the sensors should also be combined with data on: milk yield, concentrate intake and information on the pregnancy status (status) and calving dates of cows. Status data are important; they help the farmer interpret data obtained from sensors and to make the appropriate decisions. The expected effect of illness and oestrus on different parameters are shown in Table 1. From Table 1 it appeared that health disturbances and oestrus effect cow variables in different ways.

In order to keep track of damaged sensors or sensors that are out of order, it is important that the system reports sensors with large deviations in their measurement.

Table 1. The influence of illnesses and estrus on different cow variables.

	Production	Temperature	Conductivity	Activity	Concentrates intake
Infection diseases	lower	higher	no	lower	lower/no
Mastitis	lower	higher	higher	no	lower/no
Lameness	lower	no	no	lower	lower
Metabolic diseases	lower	no	no	lower	lower
Estrus	lower/no	higher	no	higher	lower/no

Technical equipment and processing of data

Sensors

The sensor measuring QMC is build into the milking claw (Figure 1) or into the short milk tube. During milking the QMC is measured every five seconds. Figure 1 shows the conductivity curves of the four quarters of a cow with mastitis. The mean of the twenty highest values from each quarter is used as the basis for calculation.

The temperature sensor is also built into the milking claw or tube, preferable close to the teats, in combination with the conductivity sensor, for example (Figure 1). With this sensor, the milk temperature is monitored during milking (Maatje & Rossing, 1976); the highest values are stored for further processing.

The activity sensor is attached to the animal's leg (Figure 2) (Maatje et al., 1987) . The activity sensor is build into the identification tag. The movement of the cow is registered with a so-called mercury switch. This switch activates a module thousand counter which is read out in the milking parlour or feeding station. The activity between two visits can be calculated (Eradus et al., 1992).

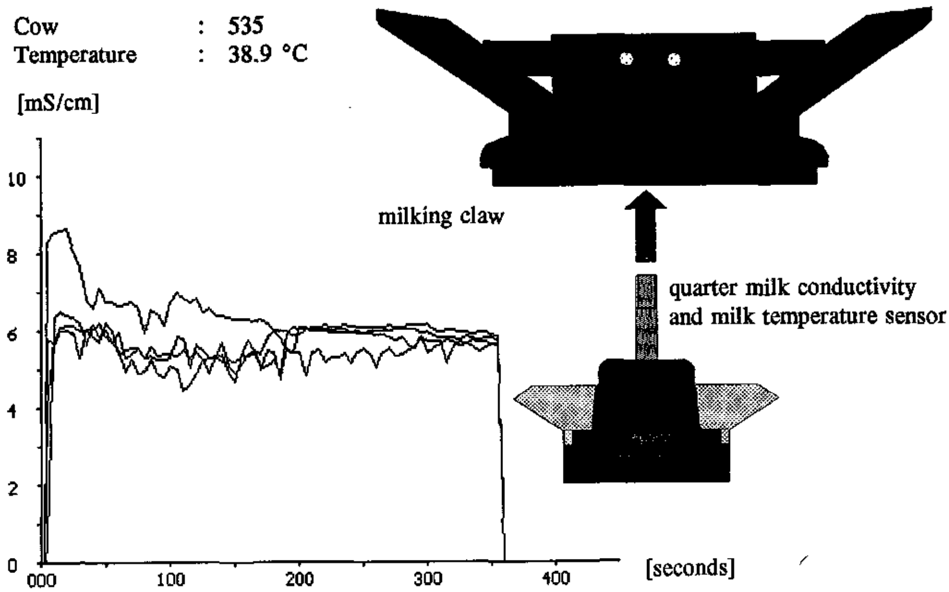


Figure 1. Quarter milk conductivity and milk temperature measurement during milking.

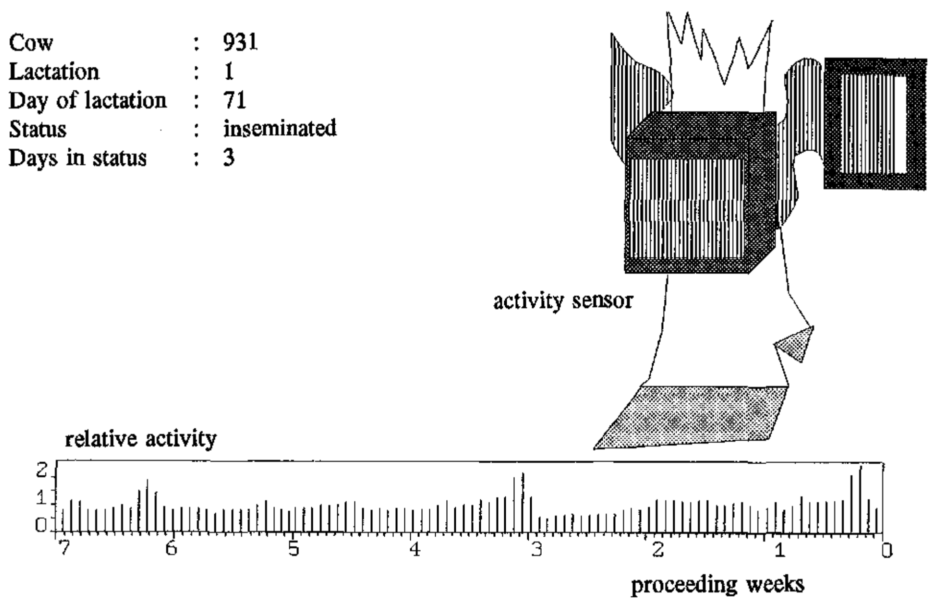


Figure 2. Activity sensors and activity pattern of preceding weeks.

Calculations

After each milking temperature and conductivity measurement, data are corrected for sensor influences. This method assumes that all cows are spread equally over all stalls for a longer period of time. First, a mean value is calculated for temperature and conductivity over all milkings per sensor. A running mean is calculated for every sensor. A mean value for all sensors measuring the same parameter and a standard deviation is calculated. Sensors which deviate more than two times the standard deviation appear on the attention list. By using the mean value over all the sensors and the running mean, values from a single sensor are corrected for sensor influences.

A. QMC calculations

A running mean R_{CND} is calculated for each quarter. Quarters in which the data $V_{CND} > 1.2 \times R_{CND_L(N\text{-}1)}$ for two milkings and $R_{CND} > 1.15 \times R_{CND_L}$ are put on the attention list in the event of treatment. V_{CND} is the conductivity value which has been corrected for sensor influence and R_{CND_L} is the lowest running mean for the four quarters. $R_{CND_L(N\text{-}1)}$ is the lowest running mean for the four quarters from the previous milking. A cow which has $R_{CND} > 1.15 \times R_{CND_L}$ during the first two milkings after calving is placed on the attention list as well. A cow with a temperature attention and $V_{CND} > 1.15 \times R_{CND_L(N\text{-}1)}$ is also put on the attention list. Cows which have $R_{CND} > 1.1 \times R_{CND_L}$ at least five times in eight successive weeks suspected of having sub clinical mastitis and are put on an attention list for therapy as soon as they become dry (Maatje et al., 1992).

B. Temperature calculations

A running mean R_{TMP} and a standard deviation D_{TMP} is calculated. For morning and evening milkings a different running mean and standard deviation are calculated, because of the systematic difference in body temperature between morning and evening (Metz et al., 1987). Only cows who received attention because of QMC, milk yield or concentrate intake or who could be in oestrus (according to their status) receive temperature attention. For temperature attention $V_{TMP} > R_{TMP(N\text{-}1)} + 0.3$ and $V_{TMP} > R_{TMP(N\text{-}1)} + 1.4 \times D_{TMP(N\text{-}1)}$ are also considered. V_{TMP} is the temperature value which has been corrected for sensor influences, $R_{TMP(N\text{-}1)}$ is the running mean temperature and $D_{TMP(N\text{-}1)}$ is the standard deviation from the previous day.

C. Activity calculations

A 24-hour pattern is used in the processing of the activity data. A 24-hour pattern that has been corrected for group influences V_{ACT} is calculated. For every cow a running mean R_{ACT} and a standard deviation D_{ACT} is calculated once a day. Only cows who could be in oestrus (according to their status) receive activity attention. For activity attention $V_{ACT} > 1.4 \times R_{ACT(N\text{-}1)}$ and $V_{ACT} > R_{ACT(N\text{-}1)} + 1.4 \times D_{ACT(N\text{-}1)}$ are also considered. $R_{ACT(N\text{-}1)}$ is the running mean activity and $D_{ACT(N\text{-}1)}$ is the standard deviation from the previous day.

D. Milk yield calculations

Processing is based on the daily milk yield (corrected for the intervals between the milkings). The daily milk yield, corrected for group influences V_Y, is calculated. For every cow a running mean R_Y and a standard deviation D_Y is calculated once a day. Cows in which $V_Y < 0.9 \times R_{Y(N\text{-}1)}$ and $V_Y < R_{Y(N\text{-}1)} - 1.4 \times D_{Y(N\text{-}1)}$ are placed on the attention list (Rossing, 1981). $R_{PRD(N\text{-}1)}$ is the running mean milk yield and $D_{PRD(N\text{-}1)}$ is the standard deviation from the previous day.

E. Concentrates intake

Animals who have $V_{FEED_L} > 0.1 \times V_{FEED_T}$ and $V_{FEED_L} > 1\ kg$ at the end of the supply period, are put on the attention list. V_{FEED_L} is the amount of left-overs and V_{FEED_T} is the amount of concentrate the cow was allowed to eat during that particular period.

F. Status data calculations

Cows who were not seen to be in oestrus after calving are put on the attention list when they signal activity or temperature attention and when the actual day of lactation of a given cow is 30, 40, 50 and so on. Cows who have been in oestrus or are inseminated are placed on the attention list when the given number in status is > 19 days and < 23 days or > 38 days and < 44 days.

Output

There are two kinds of attention lists. First there is an attention list which the system generates after every milking. This is printed automatically. All animals with large deviations are put on this attention list. It comprises: cow number, status, number of days in status, number of days in lactation, deviations in QMC, milk temperature, milk yield, activity and concentrate intake. An example of such list is shown in Figure 3. Sensors which indicate too large a deviation are also signalled. The magnitude of deviation is given by the number of stars. One star (*) means a small deviation and three stars (***) refers to a large deviation. Animals with a deviation in more than one parameter are displayed in inverse video. The number of cows that could possibly be in oestrus because of their status are put in a square. A second attention list gives indications for dry cow therapy. This list is also generated at each milking, but it is not printed automatically. Using the menu, this list can be called up.

Cow	Status	Numb. Status	Days Lact.	Conductivity RR	RF	LF	LR	Temp.	Prod.	Acti.	Rest Feed
212	in calf	202	267		*			***			
325	insemin	4	85						*		
435	in calf	141	240		***	***					
451	in heat	10	92								*
453	empty	17	128						**		
458		87	87						*		
468	insemin	41	93								
469	in heat	29	43						*		
494	insemin	11	85						*		
519	in calf	72	147						*		
521	in calf	70	126						*		
523		6	6				/				**
524	insemin	20	133								
526	insemin	20	163								

Figure 3. Attention list which reports deviations to the farmer twice a day.

The user of the programme can ask the information which forms the basis of the attention lists from all animals. The information is available for the fourteen days preceding the request. The user can also ask for QMC curves in which the conductivity of the four quarters during milking is given (Figure 4). The following data are displayed: the milk temperature and mean temperature of the milk from the previous milkings, the daily milk yield and the mean daily milk yield from the previous milkings, the total amount of concentrates the animal was allowed to eat and the amount of concentrates not eaten, the milking stall number, and the milking time. The user can ask for an overview (Figure 5) which gives the course of the QMC, temperature and yield for the last 14 days (Carmi, 1987) as well as the course of activity for a seven weeks period. In this overview it is possible to see whether a cow has eaten all her concentrates for a period of 14 days. The status data of the animal are also included in this overview. An overview in which the performance of the QMC sensors and the temperature sensors is given for the last 14 days is also available to the user.

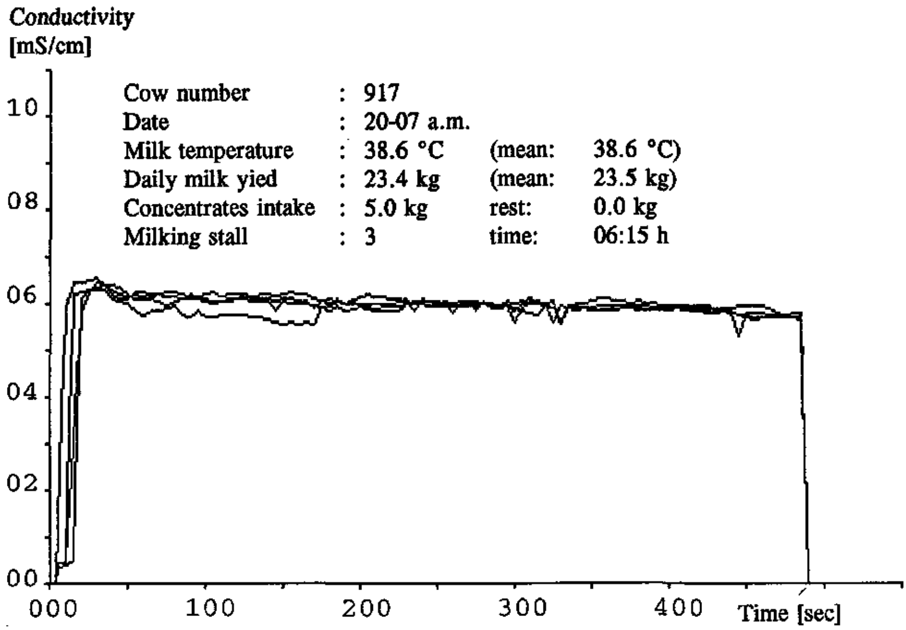


Figure 4. Quarter milk conductivity pattern and other data from cow 917.

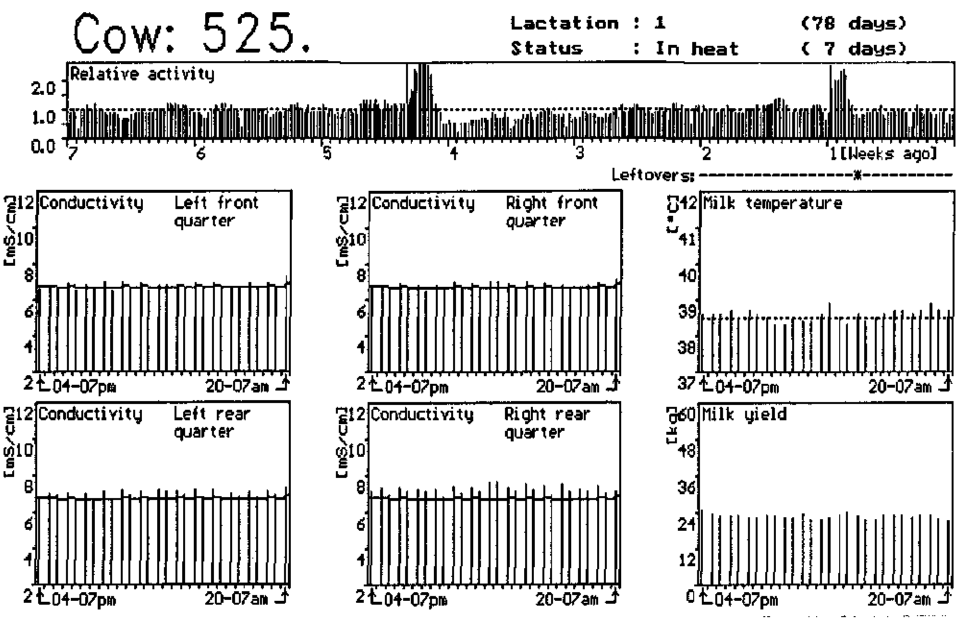


Figure 5. Overview from the data of cow 525 for a period of 14 days.

Practical experience

The programme was tested for practical use on the IVO-DLO experimental farm, "De Bunzing" and on the IMAG-DLO experimental farm, "De Vijf Roeden". The testing period on the IVO-DLO farm was three months and on the IMAG-DLO farm two months. The conclusion of these experiments was that the programme can provide the modern farmer with an effective working tool. The operation of the programme depends on the quality of the data from the sensors and the management information system. Incorrect or disturbed data is fatal for the performance of the programme. There has to be more research on the exact attention levels for the different parameters. For more information about the performance of the programme see Maatje, Hogewerf et al., 1992.

References

Carmi, S., 1987. Automatic computerized herd management: heat detection, mastitis and health monitoring. In: Proceedings of the third Symposium Automation in Dairying, IMAG, Wageningen, The Netherlands, p. 18-27.

Eradus, W.J., W. Rossing, P.H. Hogewerf & E. Benders, 1992. Signal processing of activity-data for oestrus detection in dairy cattle. In: A.H. Ipema, A.C. Lippus, J.H.M. Metz & W. Rossing (Eds.): Proceedings of the International Symposium on Prospects for Automatic Milking, EAAP publication No. 65, Pudoc Scientific Publishers, Wageningen, The Netherlands, p. 360-369.

Maatje, K. & W. Rossing, 1976. Detecting oestrus by measuring milk temperatures of dairy cows during milking. Livestock Production Science 3:85-89.

Maatje, K., W. Rossing, G.J. Garssen & H.G. Pluijgers, 1983. Automation of electrical conductivity measurements during milking. In: Proceedings of the Symposium Automation in Dairying, IMAG, Wageningen, The Netherlands, p. 89-100.

Maatje, K., F. Wiersma & W. Rossing, 1987. Measuring milk temperature during milking and the activity of the dairy cow for detecting sick cows and cows in oestrus. In: Proceedings of the third Symposium Automation in Dairying, IMAG, Wageningen, The Netherlands, p. 176-184.

Maatje, K., P.J.M. Huijsmans, W. Rossing & P.H. Hogewerf, 1992. The efficacy of in-line measurement of quarter milk electrical conductivity, milk yield and milk temperature for the detection of clinical and sub clinical mastitis. Livestock Production Science 30:239-249.

Maatje, K., P.H. Hogewerf, W. Rossing & R.T. v. Zonneveld, 1992. Measuring quarter milk electrical conductivity, milk yield and milk temperature for detection of mastitis. In: A.H. Ipema, A.C. Lippus, J.H.M. Metz & W. Rossing (Eds.): Proceedings of the International Symposium on Prospects for Automatic Milking, EAAP publication No. 65, Pudoc Scientific Publishers, Wageningen, The Netherlands, p. 119-125.

Metz, J., F. Wiersma, W. Rossing & V. v.d. Berg, 1987. First experiences with a telemetry system for measurements of body temperature by dairy cattle. In: Proceedings of the third Symposium Automation in Dairying, IMAG, Wageningen, The Netherlands, p. 185-197.

Rossing, W., 1981. Automation of processing and management in milk production using microprocessors. Agricultura (Heverlee) 3:393-418.

Free fatty acids; influence of milking frequency

A.H. Ipema* & E. Schuiling**

* *DLO Institute of Agricultural Engineering (IMAG-DLO), P.O. Box 43, 6700 AA Wageningen, The Netherlands*

** *Research and Advisory Station for Cattle, Sheep and Horse Husbandry, Runderweg 6, 8219 PK Lelystad, The Netherlands*

Summary

In an experiment the effect of 2, 3 and 4 times daily milking on the free fatty acids (FFA) contents of milk of individual cows was established during complete lactations. The FFA content at 4 times milking was 0.77 meq. per 100 g of milk fat; this was statistically significantly higher than the values of 0.36 and 0.48 meq. per 100 g of milk fat at respectively 2 and 3 times milking. Stage of lactation influenced the FFA contents. At 4 times daily milking the FFA levels in the lactation periods 0-100 and 200-300 days were respectively 0.86 and 0.85 meq. per 100 g of milk fat and were statistically significantly higher than the value of 0.60 meq. per 100 g of milk fat at 100-200 days ($p < 0.05$).
Keywords: free fatty acids, milking frequency, stage of lactation.

Introduction

The content of free fatty acids (FFA) in milk is important for the quality of milk products, especially for fatty products such as butter and cheese. Too high a level will cause a rancid taste. So FFA is taken into account in the system for paying for raw milk in the Netherlands. The milk is tested twice a year for FFA content (Anonymous, 1986); if a threshold of more than 1.00 meq per 100 g of milk fat is exceeded payment is reduced. In 1991 82.09% of the samples from on-farm bulk milk tanks had an FFA content of less than 0.61 meq per 100 g of milk fat; only 1.66% of the samples exceeded 1.00 meq per 100 g of fat.

The content of free fatty acids depends on the predisposition of the milk and on the damage to the fat globules caused by the handling of the milk (e.g. transport from udder to bulk milk tank).

Fat is present in milk in globules surrounded by a protein layer. The protein layer protects the fat inside against contact with lipase, which is always present in milk. Improper handling of the milk (e.g. mixing with air) will damage the protein layer of the fat globule and so cause lipolysis of the fat.

The predisposition of the milk depends on the lipase content and on factors inhibiting the lipase which are also present in milk. The predisposition of the milk varies between cows, within lactations and with the interval between two successive milkings; with shorter intervals the predisposition increases (Suhren et al., 1981; Jellema, 1986; Ipema et al., 1991).

We examined the effects of the milking frequencies 2, 3 and 4 times daily on the level of FFA in milk.

Materials and methods

In a period of one year a group of 36-39 HF/FH dairy cows was milked approximately 2 (group F2), 3 (group F3) or 4 (group F4) times daily. The cows were kept in a cubicle house and were able to go to the milking parlour voluntarily. They were only admitted to the parlour for milking after a certain interval which depended on the desired milking frequency. The intervals for the groups were: F2 = 10 h, F3 = 6 h and F4 = 4 h. If a cow reported earlier she was refused for milking. If a cow did not turn up for milking within a certain interval she was fetched by the milker. The criteria for fetching were respectively 14 h (F2), 8 h (F3) and 6 h (F4). For a more comprehensive description of the experimental set up, see Ipema & Benders (1992).

Once every three weeks all milkings on one day were sampled: one sample was taken for fat and protein analysis and one for determination of the free fatty acid content. The latter sample was incubated for 12 h at about 5 °C. Than the lipolysis was stopped by adding hydrogen peroxide to the sample, after which the FFA content was determined. The content of FFA is expressed as a number which corresponds to the amount of NaOH necessary to neutralize the amount of free fatty acids in 100 g of milk fat.

Below we present an analysis of the results from 18 dairy cows (6 per frequency group). Each group contained one cow with parity 1, one with parity 2 and four with parity > 2.

Results

The interval between consecutive milkings is an important factor that may influence the content of FFA in milk. Table 1 gives a review of the mean milking intervals per group over the complete lactation and over three parts of the lactation. The intervals of the different groups are statistically significantly different and fit well with the desired intervals of 12 h for group F2, 8 h for group F3 and 6 h for group F4. Within groups the differences in milking interval between lactation periods are small.

Table 2 shows that there is a statistically significant difference in milk yield per milking caused by the different milking intervals. The milk fat contents are lower (not statistically significantly) for frequency groups 3 and 4 and the contents of free fatty acids are higher in these groups. The differences are statistically significant between groups F2 and F4 and between F3 and F4.

Table 1. Milking interval (h) per frequency group at different lactation stages.

Stage of lactation (days)	Frequency group F2	F3	F4
0 - 100	11.2^{a}	7.9^{b}	6.3^{c}
100 - 200	11.8^{a}	8.2^{b}	6.1^{c}
200 - 300	11.6^{a}	8.1^{b}	6.1^{c}
0 - 300	11.5^{a}	8.0^{b}	6.1^{c}

a,b,c statistically significant difference ($p < 0.05$).

Table 2. Effect of milking interval on milk yield and contents of free fatty acids.

	Frequency group F2	F3	F4
Milk yield per milking (kg)	12.1^{a}	10.2^{b}	8.3^{c}
Milkfat content (%)	4.79	4.30	4.50
Free fatty acids (meq./100 g of milkfat)	0.36^{a}	0.48^{a}	0.77^{b}

a,b,c statistically significant difference ($p < 0.05$).

When the data of all groups are considered together, the influence of the stage of lactation on the level of free fatty acids seems to be significant (Table 3). At the beginning of lactation the average values are 0.58 meq. per 100 g of milk fat; by mid-lactation they have decreased to 0.45 and they increase again in the last part of lactation to 0.58. Table 3 shows that the largest part of the differences between the lactation periods is attributable to frequency group F4. In this group the differences between the lactation periods 0-100 days compared with 100-200 days and 100-200 days compared with 200-300 days were statistically significant. The other groups show the same tendency as group F4; however, the differences are not statistically significant.

Table 3. Effect of lactation stage on the contents of FFA (meq./100 g of milk fat) per frequency group.

Frequency group	Lactation stage (days) 0-100	100-200	200-300
F2	0.41	0.30	0.37
F3	0.47	0.45	0.53
F4	0.86^{a}	0.60^{b}	0.85^{b}
F2+F3+F4	0.58^{a}	0.45^{b}	0.58^{a}

^{a,b} statistically significant difference ($p < 0.05$).

The intervals between milkings within a cow (or frequency group) were variable, because of the criteria for accepting a cow for milking and for fetching a cow to the milking parlour if she did not come in time. For all cows in all frequency groups the average free fatty acid content per hourly interval period was established. Only those periods in which there were at least 5 measurements per cow were taken in account. For group F2 all cows met this criterion only in the interval periods 10-11 and 11-12 hours. For group F3 the interval periods 6-7, 7-8 and 8-9 hours and for group F4 the interval periods 4-5, 5-6 and 6-7 hours were usable on that basis.

Figure 1 gives the average of the free fatty acid content at the different intervals. Figure 1 shows that the FFA levels of the groups increase with the higher frequency groups. It is also clear that the variation between cows in a group depended on the milking frequency. In group F2 all cows were more or less at the same level. In group F3 the variation between cows was already larger and group F4 showed the largest variation.

Within the groups the different reactions of decreasing the interval were rather clear. In group F2 there was hardly a difference between the interval periods 11-12 and 10-11 hours; only cow 630 showed an increase in FFA contents at the shorter intervals. In group F3 almost all cows showed the tendency to increase FFA contents at shorter intervals. The same occurs in group F4. However, in that group it was very clear that cows with the highest level of FFA showed the greatest reactions to changes in the milking interval.

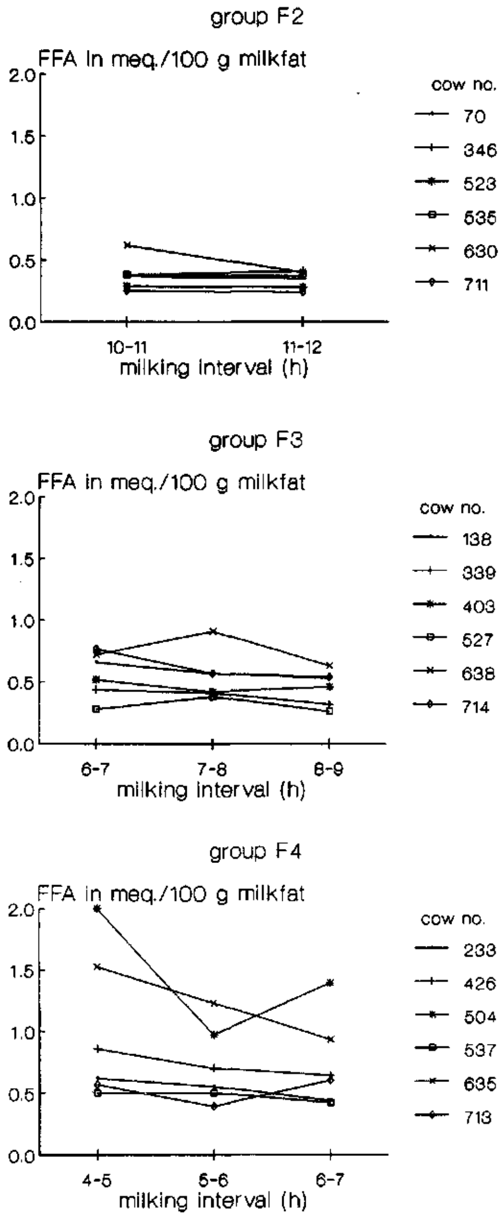


Figure 1. Effect of milking interval within the cows of each frequency group on the contents of free fatty acids (meq./100 g of milkfat).

Discussion

The results of this research showed that there is a clear effect of the milking interval on the FFA contents of milk of dairy cows. Also it was evident that cows react different to changes in the milking interval. This confirms other research (Jellema, 1986; Ipema et al., 1991).

There was a particulary marked increase in the group that was milked four times daily. The FFA contents were highest in the first and last 100 days of the lactation. This means that in these parts of the lactation it is most necessary to be careful with short intervals between milkings. The results of this experiment suggest that the FFA values at milkings with intervals less than 6 hours might easily exceed 1.00 meq./100 g of milk fat. This implies that in the Netherlands a dairy farmer would receive a reduced payment when this value is measured in the bulk tank milk.

The greater predisposition for an increase in the FFA contents at higher milking frequencies also means that other factors that influence this should be optimized. For example. the milking equipment in an automatic milking system should be constructed and installed in such a way so as to prevent damages to the milk fat droplets.

References

Anonymous, 1986. Melkwinning. Consulentschap in algemene dienst voor melkwinning, melkhygiëne en boerenkaasbereiding, Wageningen, 365 pp.

Ipema, A.H. & E. Benders, 1992. Production, duration of machine-milking and teat quality of dairy cows milked 2, 3 or 4 times daily with variable intervals. In: A.H. Ipema, A.C. Lippus, J.H.M. Metz & W. Rossing (Eds.): Proceedings of the International Symposium on Prospects for Automatic Milking, EAAP publication No. 65, Pudoc Scientific Publishers, Wageningen, The Netherlands, p. 244-252.

Ipema, A.H., C.C. Ketelaar-de Lauwere & J. Metz-Stefanowska, 1991. The influence of six times per day milking on milk production, technology and cow behaviour. IMAG-DLO, Wageningen, The Netherlands, Report 91-20, 24 pp.

Jellema, A., 1986. Some factors affecting the susceptibility of raw milk to lypolisis. Milchwissenschaft 41:553-558.

Suhren, G., J. Hamann, W. Heeschen & A. Tolle, 1981. Zum Einfluss tierindividueller Factoren der Gemelksfraktion und des Melkzeitintervalles auf den Gehalt freier Fettsäuren (FFA) in Rohmilch. Milchwissenschaft 36:150-153.

Monitoring cow performance using lactation curves

L. Jones

Cornell University, Department of Animal Science, 272 Morrison Hall, Ithaca, New York 14853, U.S.A.

Summary

Milk production in a dairy cow follows a biological lactation curve that is influenced by environmental and managerial factors. Comparing actual milk production to reference lactation curves can be a means of determining the influence of these factors. Consequently, these factors may be identified and modified. Three approaches for using lactation curves are presented. A strategic view including historical lactation curves, a scatter graph using sample day milk productions, and a graph of an individual cow's lactation curve. An interactive program has been developed to aid in monitoring lactation curves.
Keywords: dairy management, lactation curves, milk production.

Introduction

Lactation is a normal mammalian function following parturition; however, the dairy cow has been bred to produce milk far in excess of that necessary to nourish its young. The excess milk is harvested to supplement the human diet. This is the basis of the dairy industry worldwide. Consequently, monitoring and optimizing the milk production of dairy cattle is extremely important to the dairy industry.

The focus of this manuscript is to discuss the main issues in monitoring cow performance. A general discussion of lactation curves will be followed by a discussion of three approaches to analyzing performance using lactation curves.

Lactation curves

Milk production normally increases from parturition to peak production between 7 to 10 weeks. From the peak, production steadily decreases until the cow ceases milking. Several factors are known to influence milk production. Underlying factors are genetic potential and maturity of the animal. Lactation curves for first lactation animals peak lower and are more persistent than second lactation animals. The same trend is true for second versus third lactation animals (Stanton et al. 1992). Generally, animals in their third or greater lactation are combined into a single parity group. The difference in production between the mature cows in different lactations is small, and there are usually few animals in each of the lactations. However, it is extremely important that milk productions not be averaged across parity groups. Other factors known to influence milk production include management level and pregnancy. Pregnancy appears to impair production after 160 days of gestation (Strandberg & Lundberg, 1991). It is unclear if the season of calving influences the shape of the lactation curve. Traditional models of lactation curves suggest that season of calving is important (Wood, 1969); however, recent modelling efforts have concluded that the season of production is more important than season of calving (Stanton et al. 1992; Strandberg & Lundberg, 1991).

To analyze lactation curves, the variation contained within the data must be appreciated. The standard deviation between cows for daily milk production is approximately 13 pounds, and the standard deviation for an individual measurement is approximately 5 pounds.

The primary issue in lactation curve analysis is determining the shape of the "normal" curve. Presumably, factors other than genetics, maturity, and pregnancy can be managed. Unfortunately, models describing the biological shape of the lactation curve have been slow forthcoming. However, if one is to pursue lactation curve as a means to monitor production, a "reference" must ultimately be adopted. Without a reference curve, it is difficult to place milk production in its proper context and to identify weaknesses. Recently, a procedure to separate environmental factors from biological factors has been proposed (Strandberg & Lundberg, 1991), but estimates have only been developed for a small set of animals. Nonetheless, procedures to analyze lactation curves should be independent of the actual reference curve. For the remainder of this manuscript, reference curves will represent the average production for a parity group summarized within a herd productivity group (Jones, 1989).

Strategies for using lactation curves

The first approach to using lactation curves is for a strategic view of performance. Lactation curves for all animals within a parity group are summarized and graphed. In addition, all animals in the same parity group that have been recently culled can be similarly summarized. Figure 1 demonstrates such a graph.

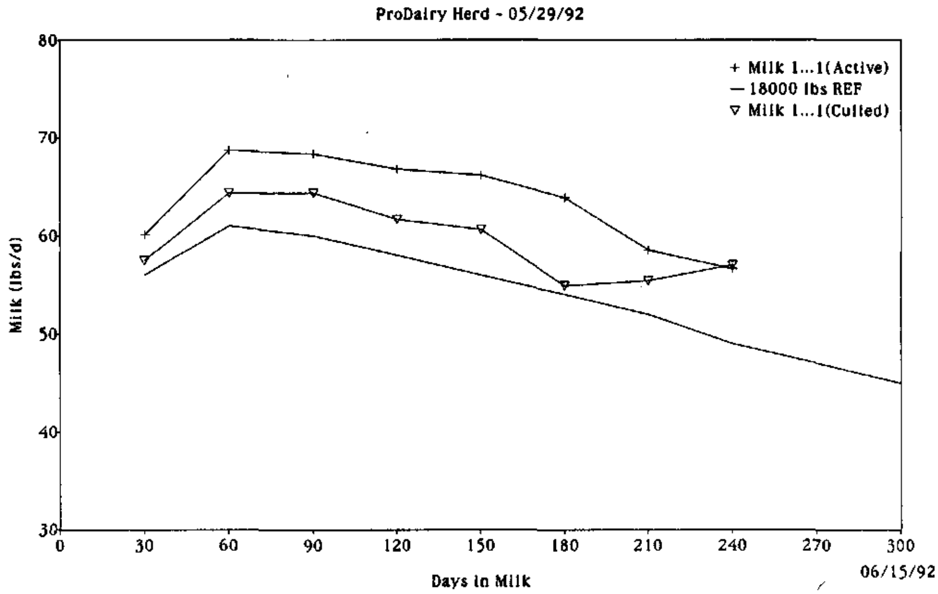


Figure 1. A tactical view of lactation curves.

In this figure, the culled and active animals are both above the reference line that corresponds to the herd's level of productivity. The active animals peak 4.4 pounds above the culled animals. This would suggest that culling is based either directly or indirectly on milk production. This is not the case in the mature cows in this herd. The culled mature cows peaked 6 pounds above the active animals and above the reference line. In this situation, reasons for culling need to be further investigated.

One must be cautious when using composite lactation curves. Because they are based on several months of data, it is important to insure that significant management changes have not occurred during this time. For example, consider the situation where a group of animals calved three months ago and are peaking better than their herd mates did during the last year. In this situation, the composite curve may appear to have poor persistency simply because these animals are represented only in the early part of the curve.

Another approach to lactation curves is to view each cow's current milk production compared to the reference value. This view gives a snap-shot of the current performance. Figure 2 contains the scatter graph of the sample day milk production for first lactation animals in the same herd as above.

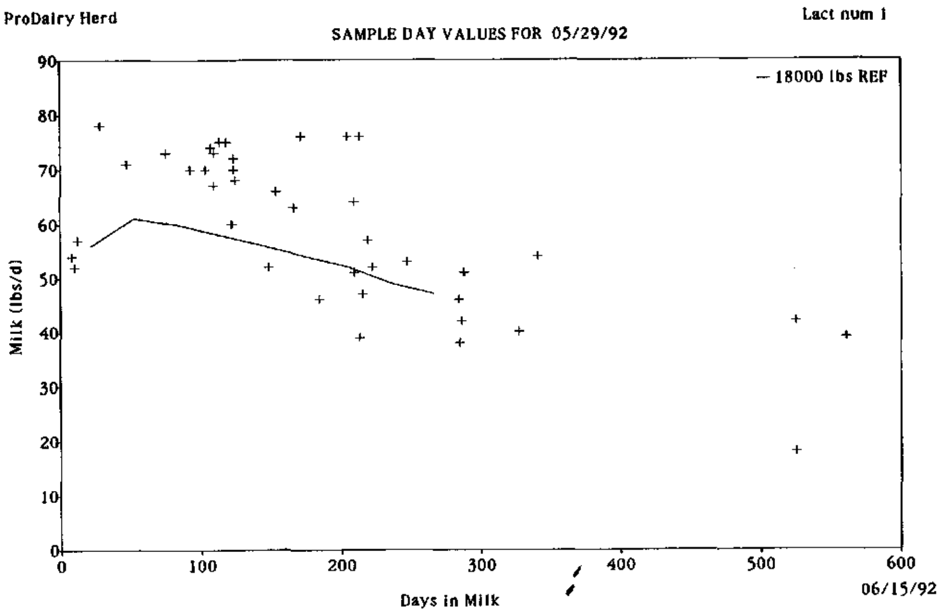


Figure 2. An individual cow lactation curve.

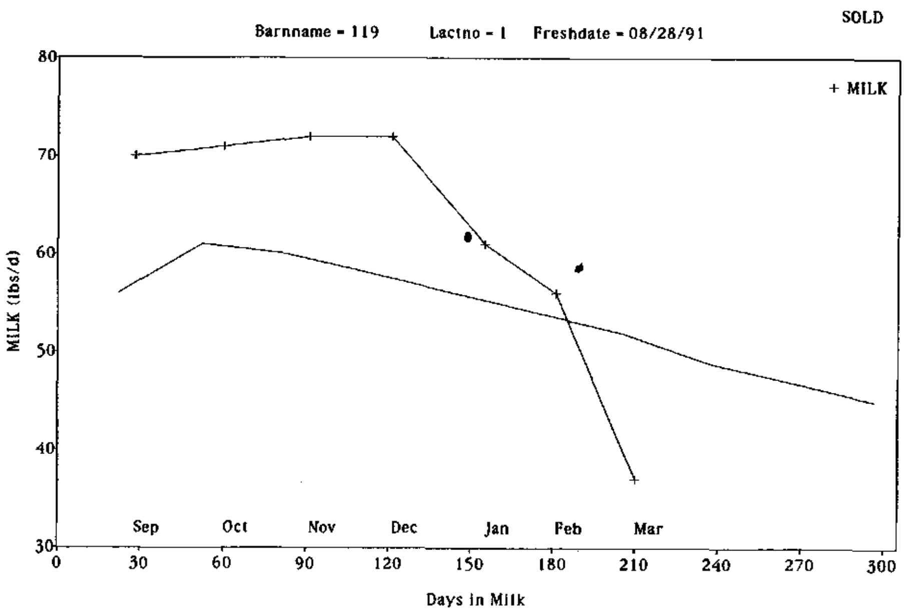


Figure 3. A strategic view of lactation curves.

With this view, it can be noticed that essentially all animals less than 150 days in milk are producing above the reference value. Beyond this point, the animals are normally scattered around the reference curve. This approach to lactation curves also can demonstrate outliers (i.e., exceptions) in the herd. For example, in this herd there are three cows with lactations longer than 500 days.

The third approach is to plot an individual cow's milk production compared to the reference curve. Figure 3 contains the lactation curve for a first calf heifer that calved in August 1991. She maintained a very flat lactation curve through December and then experienced a rapid decline until March when she left the herd. Comparing the individual cow's lactation curve to a "normal" reference curve can help place her production in the proper context and assist in making management decisions. It is conceivable that a management intervention in January may have corrected the milk production problem. In this particular case, there was significant loss of milk production along with the loss of a first calf heifer with great potential.

PLOTPLUS

PLOTPLUS is a microcomputer-based interactive graphical system to assist in monitoring cow performance using lactation curves. The above figures were all generated with this program. It graphs milk, fat percent, protein percent and somatic cell data for individual cows. PLOTPLUS also generates scatter graphs for any two variables in the database. It also generates historical lactation curves for milk, fat percent, protein percent, somatic cell data, and protein:fat ratios. These graphs can be subsetted on parity. Furthermore, PLOTPLUS contains milk, fat, and protein reference curves for 10 different levels of milk production, 3 levels of fat production and 1 level of protein production, respectively. Separate reference curves are presented for each of the three parity groups.

References

Jones, L.R., 1989. Lactation curves: a key dairy herd management index. Animal Science Mimeograph Series 123. Cornell University, Ithaca, New York, U.S.A.

Stanton, T.L., L.R. Jones, R.W. Everett, & S.D. Kachman, 1992. Estimating milk, fat and protein lactation curves with a test day model. Journal of Dairy Science 75:1691-1700.

Strandberg, E. & C. Lundberg, 1991. A note on the estimation of environmental effects on lactation curves. Animal Production 53:399-402.

Woods, P.D.P., 1969. Factors affecting the shape of the lactation curve in cattle. Animal Production 11:307-316.

A study of the energy consumption and power requirements of electrical equipment used on Turkish dairy farms

A. Kasap

University of Cumhuriyet, Faculty of Agriculture, Department of Farm Machinery, 60110-Tokat, Turkey

Summary

Electrical equipment was investigated to ascertain its energy consumption and optimum power requirements on a dairy farm. Some experiments were done on milking, milk cooling and cleaning devices on the farm. The electrical energy consumed by the milking machines was measured in the morning and evening milkings separately. The ambient temperature and the effect of the loading degree on the energy that the cooling unit consumed were studied. The working period of a water-heating unit provided with water of different temperatures and the energy it consumes were studied.

The average rate of milk flow and consumption of electrical energy were found to be 1.08 kg/min and 5.66 Wh/kg respectively in the morning milking and 0.876 kg/min and 6.99 Wh/kg in the evening milking. Increasing the flow decreased the milking time and the consumption of electrical energy.

Key words: dairy farm, energy consumption, electrical devices milking machines.

Introduction

Recent developments in electricity and electronics are having a major impact on the animal husbandry side of agriculture production (Erdiller, 1987). In developing countries like Turkey in the agriculture the most energy is consumed for domestic purposes. The next highest consumption rate of electricity is for dairy farms (Anonymous, 1987).

The electricity is used in the following areas on modern dairy farms (Ayik, 1983):

1. milk production;
2. feeding;
3. manure removal;
4. climate control;
5. control of animal and automation.

Intensive use of electricity and automatic control systems on modern dairy farms provide quality milk production and reduce loss of time and labour (Yavuzcan, 1971; Kasap, 1976).

In this study we evaluated the electricity consumption and optimum engine powers regarding milking, cooling, preparation of hot water and lighting systems on a dairy farm.

Results and discussion

Energy consumption of the milking system

The electricity consumption of the engine of a vacuum pump is directly dependent on the working time during milking. However, the difference between the flow rates of morning and evening milking affects the energy consumption rates. This relationship affects the specific energy consumption of the milking system.

The relationship between energy consumption and milking flow rates in the morning milking is shown in Figure 1.

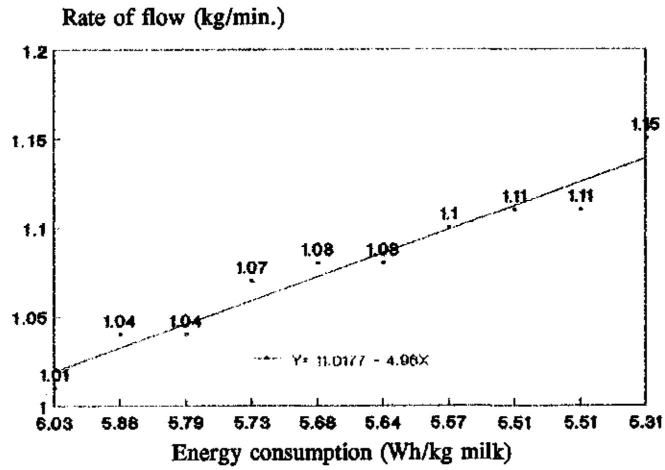


Figure 1. Relationships between energy consumption and milking flow rates in the morning milking.

Average rates of milk flow were found to be 1.08 kg/min in the morning milking and 0.876 kg/min in the evening milking. The values of consumption of energy were 5.66 Wh/kg milk in the morning milking and 6.99 Wh/kg milk in the evening milking.

Energy consumption of the milk cooling system

The energy consumption of the milk cooling system is needed to cool the milk and to keep it cool during storage. Energy losses depend on the ambient temperature, the structural characteristics of milk tank, and the amount of milk in the storage tank. The relationship between the ambient temperature and the energy consumption values for a representative dairy farm is shown in Figure 2.

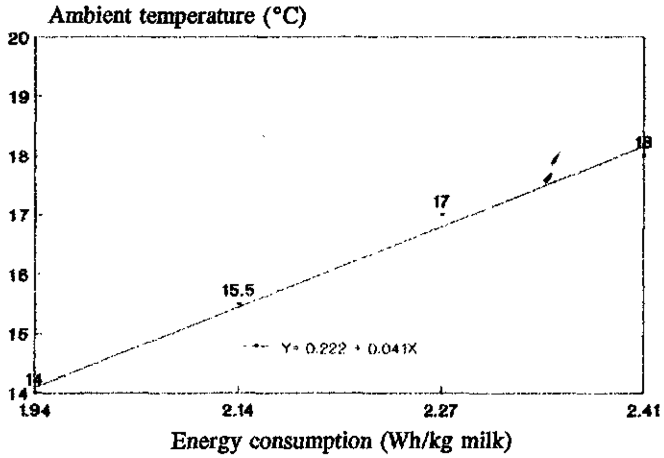


Figure 2. Relationship between ambient temperature and energy consumption values at capacity storage.

The energy consumption of water-heating systems

The energy consumption values of water-heating systems for different temperatures of inflowing water are shown in Figure 3.

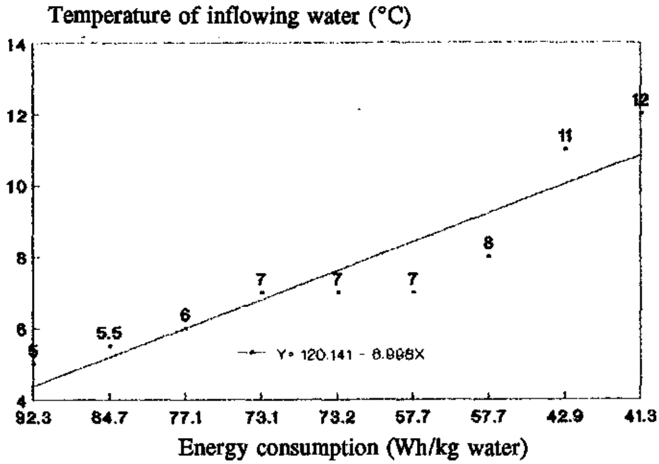


Figure 3. Relationship between temperature of inflowing water and energy consumption by the water-heating system.

The power needs of a milking system

The engine power of a vacuum pump can be calculated as:

$$N = 0.2 + 0.003 \times V; \qquad V = 150 + 60 \times k$$

N : power needed (kW)
V : air capacity needed (dm^3/min)
k : number of milking stalls

With 6 milking stalls:

$$V = 510\ dm^3/min; \qquad N = 1.73\ kW$$

The power needs of a water-heating system

The power needs of a water-heating system illustrated as N:

$$N = N_1 + N_2$$

$$N_1 = \frac{G \times c \times (T_2 - T_1)}{n \times t} \qquad N_2 = \frac{F \times Y_1}{1000} \qquad Y_1 = 1008 - 39.7 \times x$$

N	:	optimum power (kW)
N_1	:	the power needs of the water-heating system (kW)
N_2	:	the power needed to compensate for loss of heat exchange (kW)
G	:	water capacity needed (kg)
c	:	specific energy consumption (kJ/kg°C)
T	:	water temperature (°C)
n	:	efficiency (%)
t	:	time (s)
F	:	pipe surface area (m^2)
Y_1	:	specific temperature loss (W/m^2)
x	:	ambient temperature (°C)

When the following values are used in the equations:

$$G = 70\ dm^3/unit \quad T_2 = 55\ °C \quad t = 72000\ s \quad F = 12\ m^2$$
$$c = 4.18\ kJ/kg°C \quad T_1 = 5\ °C \quad \eta = 93\% \quad x = 12\ °C$$

The power needs are (for 6 units):

$$N_1 = 11.50\ kW; \quad N_2 = 6.38\ kW; \quad N = 17.88\ kW$$

References

Anonymous, 1987. Türkiye Elektrik Kurumu Faaliyet Raporu (report of activities). Turkish Electricity Company, Ankara, Turkey.

Ayık, M., 1983. Süt inekçiligi isletmelerinde Elektrik Enerjisi Gereksinimi (Demand for electrical energy on dairy farms). MPM Verimlilik Dergisi (MPM Journal of fertility), Ankara, Turkey.

Erdiller, B., 1987. Tarimsal Mekanizasyonda Mikro Elektronik ve Bilgisayar Kullanimi (Use of micro electronics and computers in agricultural mechanisation). Atatürk University, Department of Agriculture, Ankara, Turkey. Publication 937.

Kasap, A., 1976. Sigircilik isletmesindeki Süt sagma Tesisinin is Verimi ve Enerji Tüketimi (Performance and energy consumption of the milking installation). thesis. Atatürk University, Department of Agriculture, Ankara, Turkey.

Yavuzcan, G., 1971. Sagim Debisinin ve Sagim Sirasinda Harcanan Enerjinin Sagim Zamanina ve Süt Verimine Bagli Olarak Degismesi Üzerine Karsilastirmali Bir Arastirma (A comparative research on the dependence of milk flow and energy consumption during milking on milking time and milk production). Atatürk University, Department of Agriculture, Ankara, Turkey. Publication 462.

Quality control of 'ex-farm' milk in The Netherlands

C. de Koning

National Reference Centre for Livestock Production (IKC-V), Runderweg 2, 8219 PK Lelystad, The Netherlands

Summary

A farmer is required to produce milk under clean and hygienic conditions. This is stimulated by a quality payment system. In The Netherlands the standards are formulated by a national committee in which the dairy factories, the farmers' unions and the government participate. Compared with other countries, the Dutch control system for milk quality has many tests and a relatively small price penalty for sub-standard milk. The average results in 1991 are presented. It is essential that automatic milking systems meet the current and future requirements for milk quality.
Keywords: milk quality, automatic milking systems, milk payment system, The Netherlands.

Introduction

In recent decades the requirements for milk quality have been increased. At the same time the average hygienic quality of milk has greatly improved. The construction and cleaning and disinfection of milking machines and equipment are important factors in achieving milk of high quality. Automatic milking systems must meet or, if possible, improve current quality levels. Therefore, a study was done on the basis of the monthly reports of COM (Central Organization for Hygiene of Milk; Anonymous, 1990-1992), to give a view of the current and future quality levels of farm milk in The Netherlands.

Quality payment system

Each of the approximately 40 000 dairy farmers (1992) in The Netherlands is subjected to the same standards for milk quality. There is no difference between the different dairy factories. A milk sample is taken from each delivery. Every two weeks one of the 5 or 6 samples is subjected to test on hygiene. This sample is always chosen at random. The other samples are used to test for composition. The results are used to fix the payment of milk in accordance with quantity, fat, protein.

Table 1. Payment system for milk according to hygienic quality (1992) in The Netherlands. (Source: Central Organization for Milk Hygiene)

Test	Frequency	Score	Rating	Deduction on payment (cts/kg)
Total bacterial count	every 2	I	≤ 100 000/ml	0
	weeks	II	101 000 - 250 000/ml	1
		III	≥ 2 510 000/ml	2
Purity test (sediment)	once every	I	no or little dirt	0
	4 weeks	II	moderately dirty	1
		III	very dirty	3
Somatic cell count	once every	I	≤ 400 000/ml	0
	4 weeks	II	400 000-500 000/ml	1
		III	≥ 500 000/ml geometric average of 3 results	2
Antibiotics	once every	I	≤ 0.006 IU/ml	0
	2 weeks	II	≥ 0.007 IU-0.09 IU/ml and sulfa detected	4
		III	≥ 0.1 IU/ml	8
Acidity of milk fat	March-April 1 test	I	≤ 1.00 meq/100 g fat	0
	September-October 1 test	II	> 1.00 meq/100 g fat	2
Butyric acid bacteria	6 times du-	I	-- (tested in duplicate)	0
	ring winter	II	-+ (tested in duplicate)	0
	season	III	++ (tested in duplicate) If test is -+ or ++, extra test follows in next period	2
Freezing point	once every	I	≤ -0.505 °C	0
	6 months	II	> -0.505 °C	1

The standards for milk quality are formulated by the COM national committee. In which the dairy factories, the farmers' unions and the government are represented. The costs of the quality control system are paid by the dairy industry (farmers) and the government.

Table 2. The average results in 1991 of the different hygienic tests. (Source: Central Organization for Milk Hygiene)

Test	Rating	Deduction on payment (cts/kg)	% samples in 1991
Total bacterial count	≤ 100 000/ml	0	96.71
	101 000 - 250 000/ml	1	2.21
	≥ 2 510 000/ml	2	1.07
Purity test (sediment)	no or little dir	0	91.77
	moderately dirty	1	7.98
	very dirty	3	0.26
Somatic cell count [1]	≤ 500 000/ml	0	91.24
	> 500 000/ml	1	8.76
	geometric average of 3 results		
Antibiotics	≤ 0.006 IU/ml	0	99.85
	≥ 0.007 IU-0.09 IU/ml and sulfa detected	4	0.14
	≥ 0.1 IU/ml	8	0.01
Acidity of milk fat	≤ 1.00 meq/100 g fat	0	99.43 [2]
			97.26 [3]
	> 1.00 meq/100 g fat	2	0.57 [2]
			2.74 [3]
Butyric acid bacteria	--	0	90.69
	-+	0	7.64
	++	2	1.66
Freezing point	≤ -0.505 °C	0	98.73
	> -0.505 °C	1	1.27

1) At this moment (1992) approximately 15% of the farmers cannot meet the current standards (< 400 000/ml - Table 1) for cell counts
2) Results of tests in March/April
3) Results of tests in September/October

When a farmer is penalized because of the results of the milk quality test, his whole delivery in the 14 days prior to the sample will be paid as sub-standard milk. The penalties are collected by a national committee and every 3 months the money is divided among the farmers who were not financially penalized for poor hygienic quality. So those farmers receive an extra bonus for delivering milk of the required quality standards, which is paid by the farmers who have delivered milk of a bad or poor quality. A survey of the Dutch system of paying for milk on the basis of hygienic quality is presented in Table 1.

Results in 1991

The average results (1991) of the different quality tests in The Netherlands are presented in table 2. The results represent all milk delivered to the dairy factories.

In 1991 96.7% of the milk samples had a total bacterial count of less than 100 000/ml, 85% of the samples had a total bacterial count < 25 000/ml. About 91.2% of the milk samples had a somatic cell count less than 500 000/ml. The cell count in 1991 for The Netherlands stands at an average of 301 000/ml.

Discussion and conclusions

The milk quality payment system in The Netherlands has been rather successful. In 1991 about 90% of all milk samples met the national quality standards. Farmers have a good understanding of milk quality and know how to handle milk. Milk quality is expected to be an important issue in the coming years (Anonymous, 1992a). European legislation on milk hygiene and quality control will affect the national quality payment system. The dairy industry expects an increasing demand for milk products of a high quality.

Automatic milking systems must meet the current and future standards of quality control and hygiene. Possible critical quality tests concerning automatic milking systems are the total bacteria count, free fatty acids, purity and the freezing point (Westerbeek, 1992). Few results are available. From recent data (Anonymous, 1992b) it can be concluded that levels of free fatty acids increase with a higher milking frequency. It is still not possible to detect dirty udders, yet such udders can adversely affect the purity test. It seems there are no differences between total bacterial count and cell count in conventional and automatic milking.

References

Anonymous, 1990-1992. Monthly reports, Centraal Orgaan voor Melkhygiëne, Gorinchem, The Netherlands.

Anonymous, 1992a. From more to better. Policy proposals. Ministry of Agriculture, Nature Management and Fisheries, Directorate-General for Rural Areas and Quality Management, The Hague, The Netherlands (in Dutch).

Anonymous, 1992b. Dairy farming and Automatic Milking, Research Station for Cattle, Sheep and Horse Husbandry, Lelystad, The Netherlands, publication no. 74 (in Dutch).

Westerbeek, R., 1992. New quality regulations for milk, National Reference Centre for Livestock Production (IKC-V), Lelystad, The Netherlands, RSP-bulletin no. 5 *(in press; in Dutch)*.

Search for a criterion for oestrus detection based on telemetric measurement of body temperature

J. Metz-Stefanowska, A. Keen & W. Rossing

DLO Institute of Agricultural Engineering (IMAG-DLO), P.O. Box 43, 6700 AA Wageningen, The Netherlands

Summary

In this study various approaches were used for analysing body temperature data of dairy cows observed hourly in order to detect oestrus. Thirteen cows with temperature sensors implanted in the peritoneum delivered data on 34 cases of oestrus. The analyses were based on body temperatures observed during 15 consecutive days (including the oestrus period). Means and standard deviations were calculated, exceedings of daily pattern during oestrus were followed and, finally, running means were applied to differences in mean hourly temperature between the day of oestrus and preceding days. A combination of five hours for the running mean and two preceding days was found to be most satisfactory for detecting oestrus. Values of the increase in body temperature (for 5 hours in reference to 2 preceding days) ≥ 0.30 °C were selected to indicate oestrus. Use of this criterion led to the recognition of 85% cases of oestrus. False positive notifications were found in 9 of the 34 cases of oestrus and in 4 of the 13 cows only.
Keywords: body temperature, oestrus, detection of oestrus, telemetry, on-line data.

Introduction

Cows with an "open period" (the number of days between two pregnancies) of more than 100 days are an economic liability because they reduce the farmer's income (Smith et al., 1985). Reproduction results can be improved by achieving reliable oestrus detection at the appropriate time. Since it is known that body temperature rises during oestrus, the telemetric measuring of a cow's body temperature may enable oestrus to be detected: a sustained temperature rise could indicate oestrus. This theory encounters problems in practice. Body temperature can be influenced by many factors and changes caused by oestrus may not be so obvious. So ways have to be found of reducing the irrelevant variation and simultaneously of detecting variation related to oestrus as accurately as possible.

In our study we aimed to investigate possible ways of detecting oestrus from on-line processed body temperature data. Maatje & Rossing (1976) measured the milk temperature during milking in order to detect oestrus. In future, automated detection of oestrus on the basis of body or milk temperature could be incorporated into computer controlled herd management on modern dairy farms.

Material and methods

The research was conducted at the IMAG-DLO experimental station "De Vijf Roeden" in the period January-June, 1991. Thirteen cows, crossbreeds of HF and FH were involved. They were kept inside a compartment of a cubicle house with automated forage, concentrates and water supply. The age of the cows ranged from two to seven years; two of them were in first lactation. They were milked twice daily at 06.30 h and 17.30 h.

Body temperature was measured via a sensor (developed by TFDL-DLO, Wageningen) implanted in the cow about two months before she calved. The sensor (thermistor) was encapsulated in an active transmitter (60 mm long, 19 mm in diameter) attached to the uterine peritoneal fold on the right hand side. The body temperature data was measured every 20 minutes: in later processing hourly means were used to provide easy comparison with previous days and other cows. The temperature signals were received by two aerials (connected in parallel) suspended above the lying area in the cowshed. The overall accuracy of the temperature measurements was better than 0.1 °C.

Visual inspections of cows for oestrus detection were carried out three times daily within the periods: 06.00-10.00 h, 15.00-17.00 h and 22.00-23.00 h. Oestrus behaviour was recorded after all the cows had been observed and those who were more active than normal (restlessness, turning about, mounting) had been noted. The milk samples of all cows were collected twice weekly and tested for progesterone contents (in a commercial laboratory). The results of the progesterone test were available one week later and were used in this study to confirm visual detection of oestrus and to identify possible cases of "silent" oestrus i.e. oestrus not manifested by overt behaviour.

Taking the differences in body temperature at the same hours of the day between oestrus and several preceding days corrects for the daily pattern. Increasing the number of preceding days (n_D) reduces variation, but only to some extent, since the daily pattern may change gradually over time. Because the increase in temperature during oestrus is sustained for several hours, averaging over several hours (n_H) has the advantage of depicting oestrus temperature more precisely and reducing random variation. Thus we inferred that there would be an optimal combination of n_D and n_H

which can be used as the criterion of imminent oestrus. The following notation was used to describe oestrus in cows on the basis of body temperature:

- $\bar{T}$ — mean body temperature per day or period of days (°C),
- T_{max} — maximum body temperature during the day with oestrus (°C),
- $\Delta(n_D,n_H)$ — difference between the mean body temperature during n_H hours of oestrus and the mean of body temperature during - n_H successive hours on n_D preceding days (°C),
- ET — "oestrus temperature period", duration of period of body temperature during oestrus that was higher than previous day (hours) (our definition),
- $\Delta_{max}(n_D, n_H)$ — maximum of $\Delta(n_D,n_H)$ during oestrus period (°C),
- $s_\Delta(n_D,n_H)$ — estimate of standard deviation of $\Delta(n_D, n_H)$ during non-oestrus period (°C),
- $Q(n_D,n_H) = \dfrac{\Delta_{max}(n_D,n_H)}{s_\Delta(n_D,n_H)}$ — ratio used to select the best combination of n_H and n_D.

$S_\Delta(n_D,n_H)$ gives the variability in body temperature in the period outside oestrus. It is assumed that it happens only exceptionally that outliers in the non-oestrus period reach 3 times the standard deviation. If outliers are $\geq 3 \times s_\Delta(n_H,n_D)$ it is most likely something happened to the cow: maybe she is in oestrus or sick.

The daily pattern in body temperatures was based on temperatures observed during 10 days preceding oestrus. The course of means calculated per hour represents the daily pattern. To compare the body temperature during the oestrus with the daily pattern we calculated, one-sided 95% prediction limits per hour for the daily pattern (Montgomery & Peck, 1982).

Results

The transmission efficiency of the temperature sensors was, on average, 65.9% per cow (with a range of between 31.4% and 83.5%). This means that 65.9% of the programmed signals were received by aerial, the rest were lost during transmission (Metz-Stefanowska et al., 1992).

Description of body temperature during oestrus

Thirteen cows delivered data on 34 cases of oestrus on the basis of body temperature and progesterone test. Oestrus behaviour was observed in 10 cases before body temperature increased and in 17 cases after body temperature increased. Two other cows were seen to be in oestrus, but exact time of observation is not known. In five of the 34 cases the cows were not observed to be in oestrus, although a progesterone test and the temperature data indicated that they were ("silent" oestrus). The mean duration of the "open period" was 103 days per cow. In the analyses some cases of oestrus were sometimes omitted because of shortcomings in temperature data sets.

Increases in body temperature began at different times of the day, with one exception: the period between 07.00 and 10.00 h when no increase in body temperature was recorded. This, however, may be purely coincidental, as the distribution of times when oestrus temperature began to rise was spread uniformly over four periods in the day (01.00-06.00 h, 07.00-12.00 h, 13.00-18.00 h, 19.00-24.00 h) ($P \approx 0.20$).

The $\bar{T}$ per day of 31 cases of oestrus during the five days preceding oestrus was 38.65 ± 0.15 °C. $\bar{T}_{max}$ during oestrus was, on average, 39.45 ± 0.52 °C. The mean Δ_{max} in body temperature in relation to the temperature at the same time on the previous day was 0.86 ± 0.45 °C.

The ET (according to given definition) lasted 12.4 ± 5.7 h. The time between the beginning of the ET and the appearance of T_{max} was, on average, 4.6 ± 5.2 h. The time between the beginning of ET and the appearance of Δ_{max} was 5.3 ± 4.6 h. Only in one case was Δ_{max} observed outside ET (see definition); T_{max} occurred outside the period of ET in five cases: in four cases before ET and in one case much later.

Comparing means and standard deviations of body temperatures in oestrus and non-oestrus periods

In 55% of the cases an increase in body temperature due to oestrus was actually observed as being spread out over two days e.g. body temperature rise started on one day and ended the next day. The five preceding days were taken as the non-oestrus period. The difference between the average $\bar{T}$ in the non-oestrus period and the $\bar{T}$ on the oestrus day (in the case of oestrus spread out over two days day with higher $\bar{T}$) was, on average, 0.19 °C. The standard deviation per day during the non-oestrus period was, on average, 0.18 °C, and during the oestrus day (in the case of oestrus spread out over two days day with larger standard deviation) was 0.29 °C. From Figure 1 it can be seen that there is a remarkable overlap in the range of body temperatures and standard deviations between cows before oestrus and cows in oestrus.

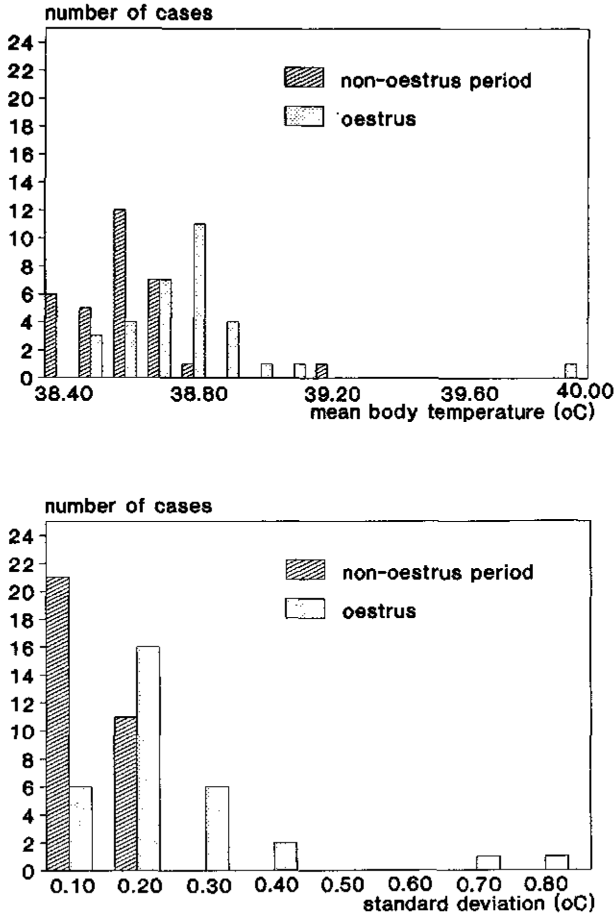


Figure 1. Frequency distribution of mean body temperature and standard deviation per day before (non-oestrus period) and during oestrus.

The body temperature during oestrus compared with the non-oestrus daily pattern

Sixteen out of 34 cases of oestrus with complete body temperature data during the 10 days preceding oestrus and during oestrus were analysed, to ascertain the feasibility of using the non-oestrus daily temperature pattern as a reference against which deviations in body temperature measured on-line could be observed.

The course of body temperature during the day in non-oestrus period (the hourly means over ten days) was rather regular (Figure 2), but 95% prediction intervals varied from 0.50 °C to almost 2 °C. Variations in body temperature during oestrus crossed the upper border in 11 cases (68.7%). Crossing the upper border occurred, on average, 1.6 h after an increase in body temperature (marking oestrus) had occurred. The body temperature remained above the upper limit for a mean period of 4.4 h. Obviously the magnitude of the exceedance depends on Δ_{max} as well as on the duration of ET. High values for these two factors make it very likely that the upper limit will be exceeded (Figure 2).

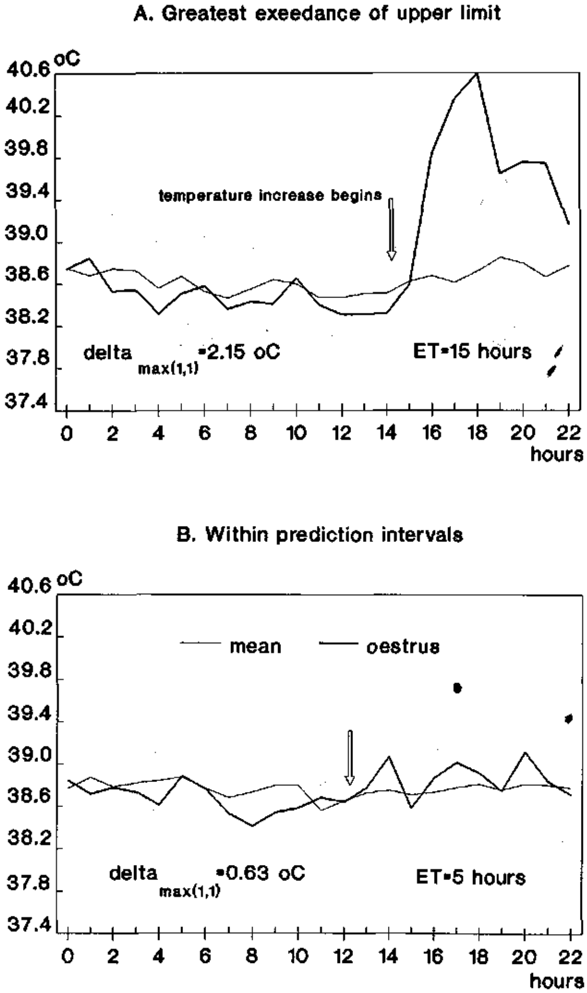


Figure 2. Two examples of course of body temperature during oestrus compared to the daily 24 hour pattern in non-oestrus period. (Dotted lines indicate upper and lower limits of 95% prediction intervals).

Running means of differences between body temperature with respect to preceding days

For each oestrus we calculated the average temperature ($\bar{T}$) and the $\Delta_{max}(n_D,n_H)$, $s_\Delta(n_D,n_H)$ and $Q(n_D,n_H)$ for all combinations of n_D=0...4 and n_H=1..24. To summarize the various values of $Q(n_D,n_H)$ we calculated their geometric mean $\bar{Q}(n_D,n_H)$. Figure 3 shows the contour plot of $\bar{Q}(n_D,n_H)$. From this Figure it can be seen that the optimum for Q is found for n_D=2 or 3 and n_H=5 to 10. We therefore concluded that, on average, Q(2,5) is a good choice, which can hardly be improved by increasing n_D or n_H.

Note, that Q is an estimate divided by its standard error, so Q is comparable to a t-value from the Student distribution. For $\Delta_{max}(2,5)$ to be a useful criterion (with not too many false alarms) Q should equal 3 or more. Since $s_\Delta(2,5) \approx 0.10$ °C it follows that the criterion is: $\Delta_{max}(2,5) \geq 0.30$ °C. In five cases out of 31 (15%) Q(2,5) was less than 3.

Applying criterion Q (n_D=2 and n_H=5) to the non-oestrus period resulted in 36 notifications of increase of body temperature ≥ 0.30 °C during 252 investigated days (Table 1).

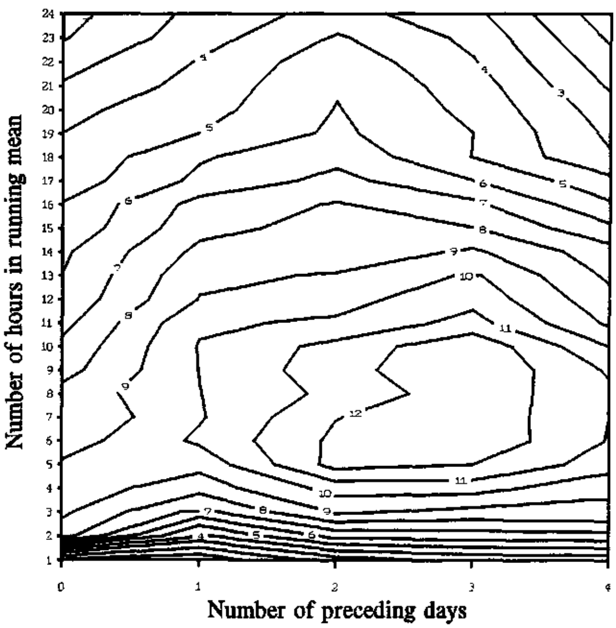


Figure 3. Contour plot of geometric mean of Q over all incidences of oestrus. (The line labelled 12 corresponds to Q=4.6, the line labelled 11 to Q=4.5, etc.).

Table 1. Number of false positive notifications in non-oestrus period for ranges of body temperature increases above 0.30 °C.

Number of cases of oestrus	Number of days monitored	Increase in body temperature (°C) in non-oestrus period 0.30-0.34	0.35-0.39	0.40-0.44	0.45-0.49	≥0.50	≥0.30 in total
34	252	11 (6 cases) (3 cows)	8 (6 cases) (4 cows)	6 (4 cases) (3 cows)	6 (3 cases) (3 cows)	5 (2 cases) (2 cows)	36 (9 cases) (4 cows)

Discussion

Oestrus-behaviour is activated by the increase of oestrogen (Hurnik, 1987). Clapper et al. (1990) reported that in cows the interval between oestradiol (one of oestrogen) peaking and the onset of temperature increase was 8.00 ± 8.94 h, whereas Mosher et al. (1990) gave 1.00 ± 5.90 h for the same interval in heifers (in both studies temperature transmitters were implanted in the vagina). These results support our finding that the temporary relation between oestrus behaviour and oestrus temperature is rather unstable. The intervals between the surge of luteinizing hormone and the onset of temperature increase (Clapper et al., 1990: 17.71 ± 4.54 h) and between the onset of temperature increase and ovulation (Mosher et al., 1990: 21.14 ± 6.07 h) are less variable. This suggests that the increase in body temperature during oestrus is more reliable for the proper timing of insemination than oestrus behaviour. Detection of oestrus on the basis of behaviour may fail, for example because observations have not been frequently enough and because of cases of "silent" oestrus. In our study we had five cases of "silent" oestrus (14.7%), confirmed later by progesterone test. These were, however, accompanied by body temperature increase. Nieuwenhuizen et al. (1979) reported eight cases of "silent" oestrus among 49 (16.3%) cases that were discovered by measuring rectal temperature five times a day.

Elevation of body temperature during oestrus measured telemetrically in the vagina lasted 8.14 ± 3.48 h in the research carried out by Clapper et al. (1990). This is a shorter period than we found, probably due to their criterion (an increase of ≥ 0.30 °C sustained ≥ 3h). Nieuwenhuizen et al. (1979) found that increases of body temperature above normal level during oestrus lasted 9.25 h. This is less than the 12.4 h we found. In their research the mean difference between reference temperature in the non-oestrus period and the T_{max} reached during oestrus was 0.62 ± 0.38 °C. This result remains in agreement with ours 0.80 ± 0.46 °C.

Fallon (1959) measured rectal temperature at 06.30 h and 18.30 h in ten cows and found that body temperature in the afternoon was 0.50 °C higher than in the morning in the non-oestrus period. During oestrus detected at 06.30 h the temperature was

0.73 °C above the average of the previous ten mornings, during oestrus detected at 18.30 h the temperature was 0.47 °C above the average of the previous ten evenings. Zartman & DeAlba (1982) measured body temperature once daily but for a long period using temperature transmitters implanted in the paralumbar fossa. They found that in 10 out of 11 cases the temperature increase during oestrus was 0.60-0.80 °C. They specified criteria for outliers caused by oestrus as 2.5 times standard deviations of the residuals. Zartman et al. (1983) carried out an experiment with 18 heifers fitted with intravaginal temperature transmitters. Measurements were obtained once a day at 06.45 h and increases of 0.50 °C above the previous five-day average due to oestrus were found. These optimistic results (Fallon, 1959; Zartman & DeAlba, 1982; Zartman et al., 1983) on oestrus detection on the basis of one or two measurements per day are not confirmed in our study. After selecting the values of body temperature measured at 05.00 h and 17.00 h from our continuous stream of data we found (using our criterion $\Delta = 0.30$ °C), that only 50% of oestrus would be detected in this way.

Rajamahendran et al. (1989) compared measurements of rectal and vaginal temperature during oestrus. They defined the criterion for measurable rise in temperature when the first of two consecutive values was greater than twice the standard deviation of basal values and they ascertained that only vaginal temperature met the criteria in all cows. Maybe our results could be improved by implantation of sensors in the vagina. However, smaller temperature transmitters would have to be available.

The mean and standard deviation of the body temperature per day seemed to be insufficient for detecting oestrus. First there is overlap in the magnitude of values of mean body temperature and standard deviation for cows before and during oestrus, thus there is no optimal oestrus temperature threshold for all cows. Second, in individual cows the mean body temperature or the standard deviation during one of the days preceding oestrus may be equal to or larger than that of the oestrus day. Finally, all these comparisons cannot be done directly on-line whilst measuring body temperature.

The prediction intervals of the daily pattern of body temperature are rather wide and the increase in body temperature during oestrus often remained inside these limits. Thus, plotting the oestrus temperature against the background of the daily pattern has limited value for the detection of oestrus: only cases with a strongly expressed increase of body temperature could be detected this way.

In the method based on a running mean the aim was to get the best result while using a minimum of hours and days in calculations. Obviously, if the same results can be obtained using less data, that option will be chosen (see Figure 3). The choice of 5 hours related to two preceding oestrus days yielded 85% cases of oestrus detected on the basis of body temperature. The failure in the case of five cows in oestrus (15%) that had a value of $Q \leq 3$ can be explained as follows: in two cases there was a shortage of data during oestrus, in one case there was a short sustained increase of body temperature, one case with a small increase of body temperature and one with Δ_{max} and T_{max} outside of oestrus temperature. Nevertheless the method of calculation could also have had some effect. The definition of the beginning/end of increase in body temperature dependents on two preceding days. If, during two preceding days something happened which caused body temperature to deviate from the normal level the precision of the estimation of beginning/end of increase of body temperature during oestrus could be affected. Also if the increase in body temperature is brief, or has two or more peaks with intervening decreases of body temperature, then Q could be smaller.

False positive notifications were found in 9 of the 34 cases of oestrus and in 4 of the 13 cows only. For the majority of cows the detection criterion worked well.

The running mean is often used when developing detection criteria (for instance, for mastitis detection: Maatje et al., 1992). Our method deviates from many others because of the correction for daily pattern and the explicit search for optimality.

Conclusions

1 Telemetric measurements of body temperature in dairy cows allow oestrus (including "silent" oestrus) to be detected.
2 Our Q-criterion may in future be incorporated into on-line processing of data on modern dairy farms.
3 The value of the Q criterion may be limited by brief lasting increases in body temperature or temperature peaks separated by a fall in body temperature; the criterion can be used in combinations with others criteria.

References

Clapper, J.A., J.S. Ottobre, A.C. Ottobre & D.L. Zartman, 1990. Estrual rise in body temperature in the bovine. I. Temporal relationships with serum patterns of reproductive hormones. Animal Reproduction Science 23:89-97.

Fallon, G.R., 1959. Some aspects of oestrus in cattle, with reference to fertility on artificial insemination. 3.Body temperature and oestrous cycle. Queensland Journal of Agricultural Science 16:439-447.

Hurnik, J.F., 1987. Sexual behaviour of female domestic mammals. In: E.O. Price (Ed.): The Veterinary Clinics of North America. Saunders and Co, Philadelphia, USA, p. 423-461.

Maatje, K. & W. Rossing, 1976. Detecting oestrus by measuring milk temperatures of dairy cows during milking. Livestock Production Science 3:85-89.

Maatje, K., P.J.M. Huijsmans, W. Rossing & P.H. Hogewerf, 1992. The efficacy of in-line measurements of quarter milk electrical conductivity, milk yield and milk temperature for detection of clinical and subclinical mastitis. Livestock Production Science 30:239-249.

Metz-Stefanowska, J., W. Rossing & E. Benders, 1992. Effectiviteit van de overdracht van signalen van geïmplanteerde temperatuursensoren bij melkkoeien. IMAG-DLO, Wageningen, The Netherlands, Report 92-7, 24 pp. (in press).

Montgomery, D.C. & E.A. Peck, 1982. Introduction to linear regression analysis, Wiley, New York, USA, 504 pp.

Mosher, M.D., J.S. Ottobre, G.K. Haibel & D.L. Zartman, 1990. Estrual rise in body temperature in the bovine. II.The temporal relationship with ovulation. Animal Reproduction Science 23:99-107.
Nieuwenhuizen, L., A.W.C. Dekker, J.H.A. Brake, K. Maatje & W. Rossing, 1979. Het verloop van de lichaamstemperatuur van melkkoeien tijdens de bronst. Tijdschrift voor Diergeneeskunde 104:314-319.
Rajamahendran, R., J. Robinson, S. Desbottes & J.S. Walton, 1989. Temporal relations among oestrus, body temperature, milk yield, progesterone and luteinizing hormone levels, and ovulation in dairy cows. Theriogenology 6:1173-1182.
Smith, R.D., P.A. Oltenacu & H.N. Erb, 1985. The economics of improved reproductive performance. Dairy Integrated Reproductive Management. Animal Science Mimeograph Series No.88, Cornell University, USA.
Zartman, D.L. & E. DeAlba, 1982. Remote temperature sensing of oestrus cycles in cattle. Animal Reproduction Science 4:261-267.
Zartman, D.L., D.M. Hallford, L.A. Tierney & M.Y. Hussain, 1983. Reproductive characteristics of Holstein heifers fitted with intravaginal temperature transmitters. Theriogenology 4:541-554.

Automatic feeding station for forage

S. Mihina*, K. Kovalcik*, M. Kovalciková* & S. Talich**

* *Research Institute of Animal Production, Hlohovska street 2, 949 92 Nitra, Czechoslovakia*

** *Research Institute of Agricultural Machines, Prague - Chodov, Czechoslovakia*

Summary

Equipment for individual feeding of forage and registration of its amount is described. The system consists of a feeding station, supply conveyors and a central control computer unit. Cows are identified automatically during the feeding. The duration of every visit and forage intake during that visit are stored in the memory of the central computer unit per individual cow. One feeding station can serve up to five dairy cows. The time needed for forage eating was evaluated. The Average time one cow spent eating per day fell when the number of cows per feeding station was increased. In observations of animal behaviour only a small decrease of lying time was recorded when automatic forage feeding equipment was used, but there was a relatively large increase in time spent standing near the feeding station. Cows waited until the feeding station was vacated. The time spent in the feeding station during day remained the same.

Keywords: automation, feeding, forage, behaviour.

Introduction

The introduction of automatic milking to farms also has repercussions on other technological lines and other elements of farm management. One such element is forage feeding. It requires substantially more time in the total daily regime of dairy cows: more than 20% when forage is fed twice a day. About 50% of total daily time is necessary for cows to rest and to lie down (Koch, 1968; Kovalcik et al., 1982). The rest of time is available for many other activities, such as: milking, feeding of concentrates, standing, moving, etc. The time allocated for activities differs, depending on whether all cows are milked together 2 or 3 times per day or whether they can be milked by milking robot at any time throughout the day as they wish. Another daily routine may appear if cows are given the possibility of eating forage all day. We created the latter situation by installing and using an automatic feeding station for forage. We solved the technical construction and found out how cows behave when forage is available round the clock, whenever they wish.

There are many techniques of automatic forage registration (Andersen, 1989; Ipema & Rossing, 1987; Klepper et al., 1989; Puckett et al., 1987). Our equipment was constructed on the basis of knowledge of the above mentioned authors, but our technical solution is new.

Design of the Automatic feeding station

The automatic feeding station for forage was constructed and installed in the Research Institute of Animal Production in Nitra in collaboration with the Research Institute of Agricultural Machines in Prague - Chodov.

The system, shown schematically in Figure 1, consists of three basic units:

- fenced-off feeding station
- set of filling conveyors
- central control computer unit.

Only one feeding station is available so far.

A forage and/or prepared feed mixture is transported by slanting conveyor to a horizontal conveyor belt. Both conveyors are on stands. At one end of the horizontal conveyor is a worm conveyor, adjusted to divert feed through a pipe to the mangers of the feeding station. There are two swivel mangers coupled together in the feeding station. One manger receive the feed and the one opposite it is accessible to the cows. Each manger has a weight sensor under it. The fenced eating space contains receivers for cow identification and sensors indicating the presence of a cow. The complete system is controlled by the central computer unit.

One feeding cycle can last either 12 or 24 hours. At the beginning of every cycle the horizontal conveyor belt is filled by the slanting one. When the conveyor is full the sensor above it gives the command for filling to stop. After the conveyors have stopped the system is switched to the automatic regime controlled by the computer programme.

Immediately the automatic regime is started, both mangers are separately filled. A cow can now enter the station and eat. If she does so, the identification receiver reacts to the responder hanging round her neck. The identification signal is transmitted to the central computer unit and the command for the forage intake registration of that cow during the visit is given. When the first manger is empty, the weight sensor under the manger gives a signal to the central unit. The mangers swivel. The full manger from the filling space is swivelled in front of the cow and she can continue to eat. The empty manger is swivelled to the filling space and any residual feed is weighed there.

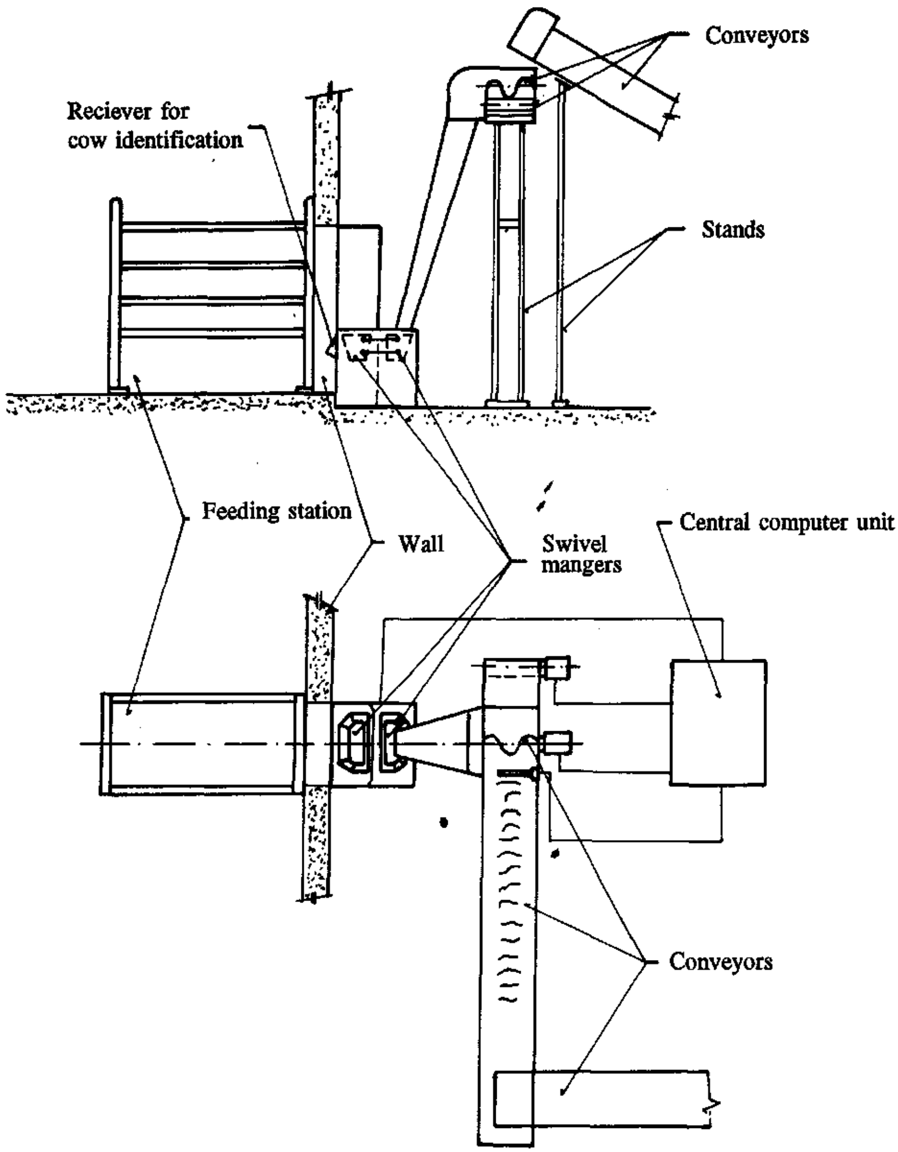


Figure 1. Scheme of automatic feeding station for forage.

The mangers are cleaned every 12 hours. Data are stored in the central unit, where the actual feed intake from this manger is calculated. Then the worm conveyor is automatically switched on. It throws down feed from the passing horizontal belt conveyor to the empty manger. The weight sensor under the manger gives a command for the filling system to stop once the adjusted value has been achieved. The maximum value is 3.5 kg per manger. The feed in the manger is weighed and data is stored in the memory of central unit. This way the process of feeding is repeated every time a cow visits the feeding station. The command for the carousel turning and refilling the manger may be given, when the cow leaves the feeding station even though the portion in the manger has not been wholly eaten. The impulse for the command is given by break of identification and a signal from the sensors indicating the cow's absence.

All data in the central computer unit are recorded and evaluated at the end of every feeding cycle. Data on feed intake during every visit, time of beginning and end of visit and cumulative intake of feed for a certain number of days are available there. The programme includes calculation of concentrate ratio related to actual forage intake, too. Data can be displayed on screen, printed out and/or stored in memory of the central unit or a floppy disk and evaluated in the personal computer, as wished.

Results and discussion

The equipment has been in use for a short period only. Nevertheless, interesting results have been obtained. The first task was to find out how many cows could be served by one feeding station. The number of cows was increased gradually from 2 to 5. Every week one cow was added. Before the observation with the automatic feeding station started, feeding the same cows in normal conditions was studied. The results proved that in normal conditions the duration of feeding is approximately the same regardless the number of cows. It was 4.8 hours on average i.e. 20.1% of a 24-h period. In one automatic feeding station only one cow can eat at time. This means that the total time the feeding station is occupied increases with increasing number of cows. In our experiments it was 9.26 hours with 2 cows, 13.49 hours with 3 cows, 15.03 hours with 4 cows and 19.04 hours with 5 cows. During the rest of the time the feeding station was empty. When 5 cows were being fed the feeding station was empty for only a very short time, mainly the time needed for preparing the feeding cycle and in the early hours of the morning (between 02.00 and 04.00 h). Obviously, it is not possible to feed more than 5 cows in one automatic feeding station. When the number of cows was increased from 2 to 5 the average feeding time per one cow decreased. If two cows were fed in one feeding station the average feeding time of one cow would represent 19.29% of the whole day. With three cows it was 18.74% and with four or five cows it was, 15.5%. The cows could use the remaining time for other activities. This increases the attractiveness of milking by robot, because cows can be milked at any time of day, even though other cows are in the feeding station.

The allocation of time over the day is very important. When five cows were fed in the automatic feeding station, the feeding station was occupied almost round the clock, though slightly more over day than at night (10.39 hours from 08.00 h to 20.00 h and 8.65 hours from 20.00 h to 08.00 h). Some cows preferred to eat during the day. Less assertive cows visited the feeding station while the others were resting. From 02.00 to 04.00 h the feeding station was least occupied. The use of the automatic feeding station influenced the behaviour of the cows, too. Surprisingly, time spent lying down only fell from 53.06% to 51.04% of the diurnal period. However, the proportion of time standing spent in the feeding corridor increased greatly, from 11.8% when cows ate from normal manger to 17.92% when five cows were fed from the automatic feeding station.

We have discussed only some aspects of the results of our experiment with the automatic feeding station for forage. They mainly concerned the behaviour of the cows and time spent in the station. Of course, the food intake we currently observe is decisive. It is impossible to draw conclusions on the basis of short-term trials. However, it turns out that with 5 cows per one station the food intake of some cows decreases. Evaluation of forage feeding in the automatic feeding station continues. An improved version of equipment with more feeding stations has already been prepared using the results obtained so far.

References

Andersen, B.B., 1989. Futteraufnahmevermögen als Selektionsmerkmal? Der Tierzüchter 41(10):446-447.

Ipema, A.H. & W. Rossing, 1987. Automated individual feeding of dairy cattle. In: Proceedings of the third symposium Automation in Dairying. IMAG, Wageningen, The Netherlands, p. 41-51.

Klepper, R., G. Kragenings & H. Krausslich, 1989. Grundfutteraufnahme automatish messen. Der Tierzüchter 41(12):528-529.

Koch, J., 1968. Ethologishe Studien an Rinderherden unter verschiedenen Haltungsbedingungen. Schriftreihe des Max-Planck-Institute fur Tierzucht und Tierernahrung 205:35.

Kovalcik, K., M. Kovalcikova & S. Mihina, 1982. Vyuzivanie stelivovych a bezstelivovych boxov v ustajnovacich objektoch pre dojnice. Polnohospodarstvo, 28(9):810-817.

Puckett, H.B., S.L. Spahr & G.C. McCoy, 1987. Sequence Control of Batch Mixing and Distribution of a Total Mixed Dairy Ration. In: Proceedings of the third Symposium Automation in Dairying. IMAG, Wageningen, The Netherlands, p. 28-40.

A model for monitoring health and reproduction based on a combined processing of variables

R.M. de Mol*, R.T. van Zonneveld*,**, B. Engel***, A. Keen***, W.J. Eradus*, G.H. Kroeze*, A.H. Ipema*, K. Maatje** & W. Rossing*

* *DLO Institute of Agricultural Engineering (IMAG-DLO), P.O. Box 43, 6700 AA Wageningen, The Netherlands*

** *DLO Research Institute for Animal Production 'Schoonoord' (IVO-DLO), P.O. Box 501, 3700 AM Zeist, The Netherlands*

*** *DLO Agricultural Mathematics Group (GLW-DLO), Wageningen, The Netherlands*

Summary

A project for developing a model for the detection of cows with mastitis and cows in oestrus is outlined. This project is based on earlier research on sensors and on management information systems. The sensors are for measuring milk temperature, electrical conductivity of milk and activity of cows. The model will be incorporated in a management information system. Different data processing techniques for its development will be evaluated. The most promising techniques will be used to build a decision support model.

Keywords: detection model, dairy cows, management information systems, sensors, data processing techniques.

Introduction

The results of two research areas can be used to construct a new model for the detection of mastitis and oestrus in dairy cows.

First, much research has been done in the Netherlands on the development of sensors for measuring milk temperature, electrical conductivity of milk and activity of cows. It started with measuring the milk temperature to detect oestrus (Maatje & Rossing, 1976). Other sensors for the same purpose record the activity of cows (Rossing et al., 1983 and Eradus et al., 1990) or the body temperature (Metz et al., 1987). Sensors for mastitis detection are often based on measurements of the electrical conductivity of quarter milk (Maatje et al., 1983, Rossing et al., 1987, Rossing et al., 1989). More recently, different sensors have been combined to improve results (Maatje et al., 1987, Maatje et al., 1992). In these models different variables are considered successively. In the new model variables will be considered simultaneously in a multivariate way. This can improve the results of a detection model as indicated in Maatje et al., 1987.

Secondly, management information systems (MIS) have been created for dairy farming and other branches of agriculture. One of the first management information systems for dairy farming in the Netherlands was developed by IMAG-DLO (Kroeze & Oving, 1987 and Kroeze, 1990). This management information system, called IMAG-VEECOMPAS, has been taken over by the joint venture ARGOS-NEDERLAND (AGRIDATA, BLGG and NRS). An extension of this management information systems is the addition of decision support systems (DSS), which shifts the emphasis from the registration to the use of recorded data in decision support models. The use of data from the management information system can also improve the detection.

These research results can be combined when the sensor measurements are used in decision support models incorporated in a management information system. In this paper the outline of a research project directed to such a model will be discussed. It should be capable of being applied for the detection of:

- oestrus;
- mastitis;
- other infectious diseases;
- metabolic diseases;
- lameness.

Emphasis will be laid on oestrus and mastitis. The model can help the farmer to improve his animal care and to select cows for culling.

Materials and methods

Data sets from the experimental farms of IVO-DLO in Zeist, the Netherlands and IMAG-DLO in Duiven, the Netherlands are being used for the development of the new detection model. The data sets contain sensor measurements of the following variables:

1) milk production;
2) milk temperature;
3) quarter milk conductivity;
4) activity (number of steps, measured by pedometers);
5) concentrates intake (part of ration remaining).

These variables have been measured in about 175 cows for more than a year. The first three variables are measured twice a day during milking (for details see Maatje et al., 1992). The activity is also given twice a day in the data set, the concentrates remainder only once a day. These variables will be used as input for the model.

Besides these sensor measurements the data sets also include measured cell counts and progesterone content, results of bacteriological examinations and other veterinary records; these will be used as a reference for the detection model.

The MIS ARGOS is being used on both experimental farms. Usable variables known from the management information system are:
- expected milk yield;
- oestrus data;
- cow calendar data;
- other data e.g. outside temperature.

The management information system can also be used to pass external information, for example cell counts known from the Milk Recording Service.

Both the sensor data and the data from the management information system will be input for the detection model. The following data processing techniques will be evaluated for the construction of this model:

Statistical techniques. These have also been used in previous research. Existing methods are mostly based on thresholds for the running average (e.g. Maatje et al., 1992) or variance (e.g. Eradus et al., 1990). Not all the statistical possibilities have been fully examined yet. More advanced statistical techniques like time series analysis have to be explored.

Rule-based techniques. Information on the occurrence of oestrus and deviations has to be incorporated in rules. An example of a possible rule is:

if: the electrical conductivity of the highest and lowest quarter differ by more than 15%

then: the cow is suffering from mastitis (cf. Maatje et al., 1987).

Fuzzy reasoning may be a useful extension of this crisp logic (Gui & Goering, 1990). These rules can be incorporated in expert systems.

Learning-based techniques. Artificial neural networks can be taught to distinguish possible situations (Masson & Wang, 1990). This method has also been used for the mastitis detection in Nielen et al., 1991, but the possibilities should be examined further.

In the course of 1992 a first prototype based on statistical techniques will be realized. In the meantime, the alternative techniques will be examined. After this promising techniques will be selected and these data processing techniques will be used to further develop and test the model.

Conclusion

The outline of a new project is given. By a combined processing of variables a better detection model for monitoring health and reproduction is to be realized. The most useful data processing techniques have to be selected. Results are not yet available, the prospects for the model will be assessed in 1993.

References

Eradus, W.J., W. Rossing & P. Hogewerf, 1990. Signal processing of activity-data for oestrus detection in dairy cattle. International Conference on Agriculture Engineering, 24-26 October 1990, Berlin, Germany.

Gui, X.Q. & C.E. Goering, 1990. Introduction to fuzzy set theory and applications. Transactions in Agriculture 33(1):306-323.

Kroeze, G.H., 1990. Management uses of cow-side data. In: Dairy Science Handbook. Vol. 20, International Stockmen's School.

Kroeze, G.H. & R.K. Oving, 1987. Management information systems for dairy farming. In: Proceedings of the Third Symposium Automation in Dairying. IMAG, Wageningen, The Netherlands, p. 338-344.

Maatje, K. & W. Rossing, 1976. Detecting oestrus by measuring milk temperatures of dairy cows during milking. Livestock Production Science 3:85-89.

Maatje, K., W. Rossing, G.J. Garssen & H.G. Pluijgers, 1983. Automation of electrical conductivity measurements during milking. In: Proceedings of the Symposium Automation in Dairying. IMAG, Wageningen, The Netherlands, p. 89-100.

Maatje, K., W. Rossing & F. Wiersma, 1987. Temperature and activity measurements for oestrus and sickness detection in dairy cattle. In: Proceedings of the Third Symposium Automation in Dairying. IMAG, Wageningen, The Netherlands, p. 176-184.

Maatje, K., P.J.M. Huijsmans, W. Rossing & P.H. Hogewerf, 1992. The efficacy of in-line measurement of quarter milk electrical conductivity, milk yield and milk temperature for the detection of clinical and subclinical mastitis. Livestock Production Science 30:239-249.

Masson, E. & Y-J Wang, 1990. Introduction to computation and learning in artificial neural networks. European Journal of Operational Research 47:1-28.

Metz, J., F. Wiersma, W. Rossing & V. van den Berg, 1987. Preliminary research with an implantable telemetric system for measuring the body temperature of dairy cows. IMAG, Wageningen, The Netherlands, Report 87-2, 32 pp.

Nielen, M., J.F. Schreinemakers & A. Brand, 1991. Mastitis detection using a connectionist model (neural network). (English abstract) In: W.H.G.J. Hennen, C.A.M. Graumans, A.J.L. Alkemade, G. Selman & M. Schakenraad (Eds.): Voordrachten VIAS-Symposium 1991 Informatica toepassingen in de agrarische sector. Agro-informaticareeks 5(1991):67-72.

Rossing, W., E. Benders, P.H. Hogewerf, H. Hopster & K. Maatje, 1987. Practical experiments with real-time measurements of milk conductivity for detecting mastitis. In: Proceedings of the Third Symposium Automation in Dairying. IMAG, Wageningen, The Netherlands, p. 138-146.

Rossing, W., A.H. Ipema & K. Maatje, 1983. Actrons for measuring activity of dairy cows. In: Proceedings of the Symposium Automation in Dairying. IMAG, Wageningen, The Netherlands, p. 127-134.

Rossing, W., K. Maatje, E. Benders, P.H. Hogewerf & W. Buist, 1989. Automatic mastitis detection in the milking parlour. In: Proceedings of the 28th Annual Meeting of the National Mastitis Council, Inc. Tampa Florida, USA, 9-11 February 1989, p. 58-67.

Automated cow and machine performance monitoring in the Ruakura milk harvester

R.A. Sherlock & M.W. Woolford

Dairying Research Corporation, Ruakura Agricultural Centre, Hamilton, New Zealand

Summary

The Ruakura Milk Harvester (RMH) is a milking system developed for the large herd, fast throughput, low-labour requirements of the New Zealand farmer. It implements separate milk transport to improve vacuum stability and reduce frothing and fat damage (resulting in higher milk quality and faster milking) and incorporates a novel "touch tag" animal ID method. The method of air/milk separation in the cluster provides an implicit volume metering capability at no extra component cost which, while not providing herd-test accuracy on a single measurement, gives a useful level of animal and machine performance monitoring. In this paper the key features of the RMH system are described and some results of the associated automatic performance monitoring software are presented.
Keywords: milking machine, air-milk separation, automatic performance monitoring, automatic exception identification, low cost yield and performance recording, touch tag animal ID.

Introduction

The combination of seasonal pasture-feed dairying and the need for low labour milking management of herds of several hundred high yielding, free milking cows that characterises the current New Zealand dairy industry has created conditions which expose the weakness of conventional pipeline milking systems. High-line herringbone dairies with 30 to 50 clusters are increasingly common in NZ, and with cluster attachment to a batch of cows occurring over a narrow time span the milk flows in the machine can be very large. During the peak production of the "spring flush" this frequently results in extreme vacuum fluctuations, cluster falls, and froth formation serious enough to stall the milk releaser pump.

All of the above problems arise from the use of a single pipe to implement two distinct functions, namely:

1 reticulation of the milking vacuum to the cluster;

2 transporting the milk from the cluster to the receiver (basically by blowing it along in an air-stream).

Although the problems are mitigated by the use of oversize (>100mm) main milk-lines, the only really satisfactory solution is to provide completely separate pipelines for the vacuum reticulation and for the milk transport (to a receiver at a higher vacuum level), and to implement some form of air-milk separation valve in the cluster. The RMH system, developed over the last seven years in collaboration with the Waikato International Co, takes this approach and introduces a number of novel features which also provide the basis of a low-cost performance monitoring and information management system.

Ruakura milk harvester - Outline description

The key feature of the system is the method of air-milk separation. This is achieved by actively controlling a fast-acting (<10ms response time) diaphragm valve in response to a milk-level indication from conductivity sensing electrodes, so as to maintain the milk level in the claw bowl within a narrow working range several cm above the exit point. As a result the milk flowing from the claw has typically <5% (by volume) entrained air, mostly in the form of very fine bubbles. The milk level sensing and generation of the milk valve control signal is implemented in an Electronic Control Module (ECM) based on a single chip microcomputer. Use of this technology gives great flexibility to modify operation by software changes, and has enabled a wide range of additional functions to be incorporated, e.g. volume yield measurement and display derived from milk valve operation, and implementation of a low-cost automatic ID reader in each bail position. These two major features are described in more detail below; others include identification of events such as let-down failure, end milkflow and implementation of appropriate responses, control of pulsation and milking mode on an individual cow basis, communication with a host PC to automatically log milking data to a herd database, implementation of a message display and keypad entry function in each bail to alert the milker to important cow status conditions and allow cowside interrogation/update of a herd database.

The system has now been available commercially for two seasons in NZ and is currently in use on 13 private farms and 3 research institutes and has proved very successful in solving the basic milk-handling problems described above. It's milking performance characteristics have been described elsewhere (Woolford & Sherlock 1987, Sherlock & Woolford 1990), the principal improvements being the expected increase in milking speed (around 20% on average) due to improved vacuum stability and reduced fat damage (vat FFA level typically reduced by a factor of 3) compared to an equivalent configuration conventional machine.

Volume yield measurement

The air-milk separation valve in the RMH claw is essentially a two-state device and in the open state the impedance of the milk-flow path from the claw to the milk receiver is defined principally by the (constant) long milktube dimensions. Since the difference between the (stable) claw and milk-receiver vacuum levels, deltaP, is also maintained constant (typically to within 1%) and the milk pipes remain filled so the hydrostatic head is constant, the milk flow-rate from the claw is also constant (after a short acceleration phase) when the valve is open. Thus the milk volume passed through the claw at each valve opening is relatively simply related to the open time. A conversion algorithm is executed by the microcomputer in the ECM to estimate the current flow-rate and update the cumulative yield measurement each time the milk valve closes.

The advantage of this measurement system is that it requires no extra components in addition to that necessary to implement the air-milk separation function, merely some additional software routines. It makes no pretence to be a "herd-test" meter in the sense of providing ICRPMA accuracy in a one-off measurement but, as has been pointed out by Goddard & Jones (1988), an equivalent accuracy is readily (and more economically) achieved by taking a mean of measurements over a number of milkings as long as there is no systematic bias. In fact, because of the day-to-day variation of yields due to environmental and intake variation with pasture grazed herds, there is arguably a fundamental advantage in this approach.

Because of the dependence of the "calibration" of this RMH metering on plant vacuum levels the question of bias needs to be seriously addressed. It can be corrected by actually recording deltaP during the milking and applying an algorithmic correction, and also by normalising the individual RMH yields by the ratio of their sum to the independently measured bulk vat content (if this is measure is available).

The performance of the RMH metering system in terms of absolute accuracy under normal milking conditions (i.e. with cows milking in all bails) is very difficult to measure as the insertion of test buckets completely changes the flow dynamics. However, on the basis of a measurements with inserted TruTest ICRPMA approved flask meters over extended periods we conservatively estimate that 95% of RMH yield indications are within +/-7.5% of true.

Touch tag automatic ID system

To take advantage of the availability of the implicit RMH milk yield measurement to implement "exception management" (e.g. Pucket et al., 1977) in cow performance (in addition to machine performance), it is of course essential to identify every animal to the machine at every milking. Because of the preponderance of herringbone installations with a wide breast rail in NZ (to allow right-angle cow placement), the use of ID readings from radio frequency (RF) transponder tags at an entrance gate is not practical in most cases - there are too many changes of cow order after the read point. The ideal situation would be a tag reader associated with every cluster, but this is not economically feasible with current RF technology where the reader is a high cost component.

In an attempt to overcome this problem we have completely eliminated the need for RF systems by making a direct electrical contact to a passive tag on an ankle strap. The circuitry inside the tag utilises the same storage concept as the common RF tags; i.e. a binary code in a shift-register structure is clocked out serially when the tag is energised. In our system, however, the tag is energised by a direct electrical contact to a touch plate and instead of the shift-register output modulating an RF transmitter stage it modulates the current drawn by the tag. The tag energisation current is sourced by the ECM so this modulation is readily decoded. (We have made use of the fact that the ECM microcomputer has "spare" capacity which can be utilised to implement the logic of the reader function). Another novel feature is that the current required is so small (always <1mA) that a metal-to-metal contact is not necessary. The current path is from the ECM to the milker via a metal plate on the cluster handle, through the milker to the tag via a finger touch, then through the tag to ground (metal platform or wet concrete) via the wet hair in the cow's leg.

The system is still in an early stage of development (patents are applied for), and is currently undergoing field trials on four herds. Performance can be degraded in very wet conditions when the tag becomes covered in mud and the signal/noise ratio is reduced by the large parallel leakage currents. However, under reasonable conditions very good results are being achieved and there is also some scope for improvement through use of more sophisticated signal detection algorithms. Error detection coding ensures that the probability of an erroneous read is negligible, and for the small percentage of read failures that do occur the ID can be entered manually via the ECM keypad.

Machine performance monitoring

We have developed software to run on an IBM compatible PC to maintain two-way communication with the ECM's during milking via a simple two-wire half-duplex link. Thus the data is collected and analysed as soon as it is available (e.g. cow ID and milking sequence on cluster placement; yield, duration, composite milk conductivity etc. on cluster removal). Any messages for display on the ECM concerning cow status, or commands to alter milking conditions (e.g. automatically divert "discard" milk), are transmitted back to the appropriate ECM. Compact databases recording the full history of both machine and (if ID's are available) animal performance at every milking are maintained automatically. This information is used by algorithms (currently being developed) for automatic detection of deviations or exceptions which are of significance to the farmer, and it can also be displayed graphically for confirmatory inspection.

An illustration of the machine performance monitoring is given in Figure 1 which shows the average yield per cow for one bail of a 21 bail machine, expressed as a percentage deviation from the mean over all-bails, over most of the season. The vertical bars are the results of individual herd milkings, and are typically comprised of 10 cow milkings. The day to day variability of the raw data (due to the different chance groupings of cows) obscures all but gross anomalies, but after low-pass filtering offsets (corresponding to calibration errors) changes and trends become clearly apparent. In Figure 1 it is seen that the 300 cow-milking running mean provides a good indication of the stability of the yield calibration, and the point at around 2800 cow-milkings when the machine was recalibrated is clearly evident i.e. under typical NZ milking conditions, data from around 300 cow milkings per bail is needed to normalise the yield calibrations to within +/- 3%. (It is reasonably assumed that the distribution of yields per bail is not biassed).

Where the yield calibration is as stable as in this example (i.e. no malfunctions) the raw yield data from that bail can be automatically corrected by the computed calibration error before storage in the cow performance database. This possibility of "auto-normalisation" also eliminates the need for a high accuracy calibration procedure - a nominal calibration to within 5% is quite satisfactory for the yield indication on the ECM during milking.

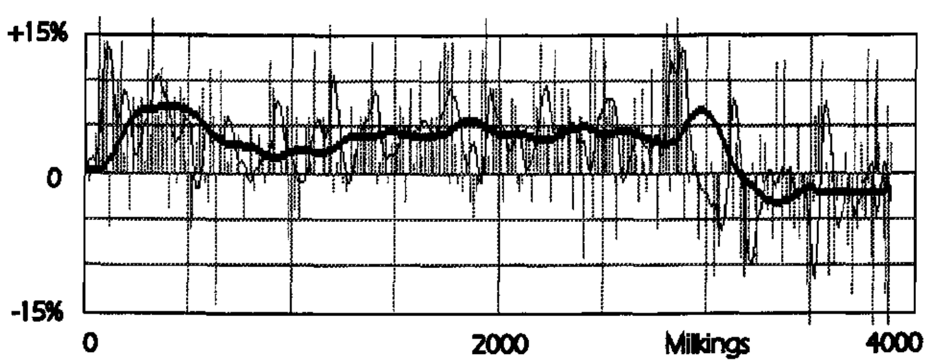


Figure 1. An individual bail yield, expressed as a percentage deviation from the all-bail mean, plotted against the total number of cow-milkings in that bail. The light and heavy curves are the result of low-pass filtering to implement 60 and 300 cow-milking running means respectively. The data covers approximately 250 days of twice-daily herd milkings.

Cow performance monitoring

In Figure 2 the volume production from an individual cow over a 16 week interval (starting a few weeks after calving) is shown expressed as a percentage deviation from the herd mean. This normalisation to the herd mean removes a typical +/-10% short-term variation due to environmental factors in this pasture grazed herd, and enables a clearer identification of inherent cow trends. This animal is obviously performing very consistently at the herd mean level up to week 10. Of particular interest are the large yield drops (to almost zero) followed by some compensation at the following milking seen in the 2nd, 5th and 8th weeks of the plot. These coincided with observed oestrus behaviour. Not all animals give such a clear indication of oestrus in their yield variation of course but, taken in conjunction with other information, useful rates of automatic identification are clearly possible.

A point of interest related to the volume yield measurement capabilities of the RMH is also evident in the data presented in Figure 2. After the 10th week of the plot the animal was milked on a conventional machine in which the yield data came from permanently installed herd-test flask meters (manually read). The change of milking system was the only change to which the animal was subjected. It is quite apparent that, for whatever reason(s), the variability of this data (which has been entered into the RMH database by hand) is larger than that from the RMH metering system.

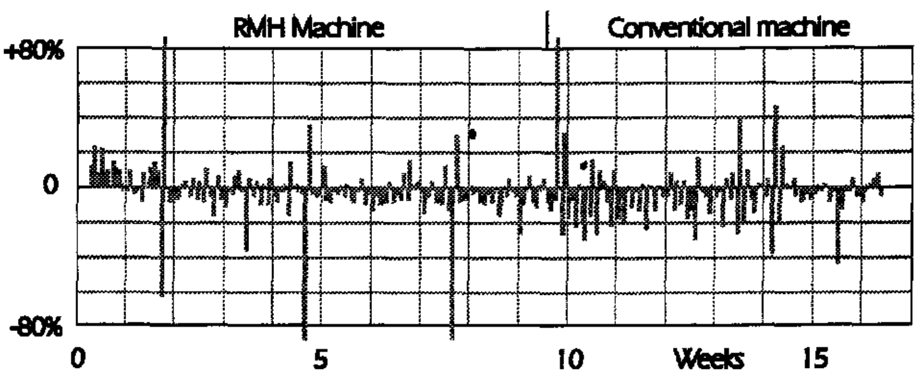


Figure 2. Per-milking yield from a 3 year old cow expressed as a percentage deviation from the herd mean over a 16 week period in early lactation.

References

Goddard, M.E. & L.P. Jones, 1988. Cost of measurement in dairy cattle improvement programs. In: Proceedings of the Australian Association for Animal Breeding and Genetics 7:182-191.

Puckett, H.B., E.F. Olver & K.E. Harshbarger, 1977. Management by exception: A program for efficient livestock production. Illinois Research 14(4):10-11.

Sherlock, R.A. & M.W. Woolford, 1990. New developments in milking machine design related to mastitis and milk quality. In: Proceedings of the International Symposium on Bovine Mastitis, Indianapolis. National Mastitis Council, p. 229-233.

Woolford, M.W. & R.A. Sherlock, 1987. Milking machine developments: The next advance. In: Proceedings of the 39th Ruakura Farmers' Conference. MAF New Zealand, p. 57-61.

Labour organization aspects of milking with an automatic milking system: structure of the problem

B. Sonck

DLO Institute of Agricultural Engineering (IMAG-DLO), P.O. Box 43, 6700 AA Wageningen, The Netherlands

Institute of Agricultural Engineering, Merelbeke, Belgium

Summary

As in every technological innovation, the introduction of the Automatic Milking System (AMS) also involves a revision of planning and organizational criteria. Some of the consequences for labour organization are discussed in this paper. Work planning will become even more necessary. A clear insight into labour requirement and an inventory of the various tasks (new, traditional and tasks that are no longer necessary) associated with an AMS are essential. Finally, some of the consequences for social organization are also discussed in this paper.
Keywords: labour organization, milking robot, automatic milking system.

Introduction

Practice and studies (Belt & Zegers, 1984; Belt, 1984; Stål & Pinzke, 1991; Sonck et al., 1991) have shown that milking demands extremely high physical and mental effort from the milker. The dairy farmer concentrates an important part of his daily labour effort on these milking times. In addition he is bound to his farm by the twice-a-day task of milking. To relieve him of this pressure and of the associated lack of freedom, attempts have been made since 1985 to automate the milking process (Automatic Milking System). The current state of the technique offers the possibility of automating the milking of cows. Cows are kept indoors the whole year. Cows may be milked at every hour of the day during voluntary visits to a milking station. In general, a combined unit for milking and feeding concentrates is appropriate (Frost, 1990).

A successful integration of a robotized milking system is only possible if the consequences of its introduction are taken into consideration: the consequences to the animals and their welfare, the layout and the equipment of buildings, milk quantity and quality, roughage production, farm management and organization, the organization of the farmer's social life, etc. A multidisciplinary approach is needed. The robotization project will prompt the involvement of researchers from various disciplines (ethologists, technologists, farm building specialists, nutrition experts, design engineers and constructors, etc.). Finally, the efforts of all these specialists must result in an integrated system in which the dairy farmer, the automatic milking system and the animals are completely in tune with each other (Figure 1).

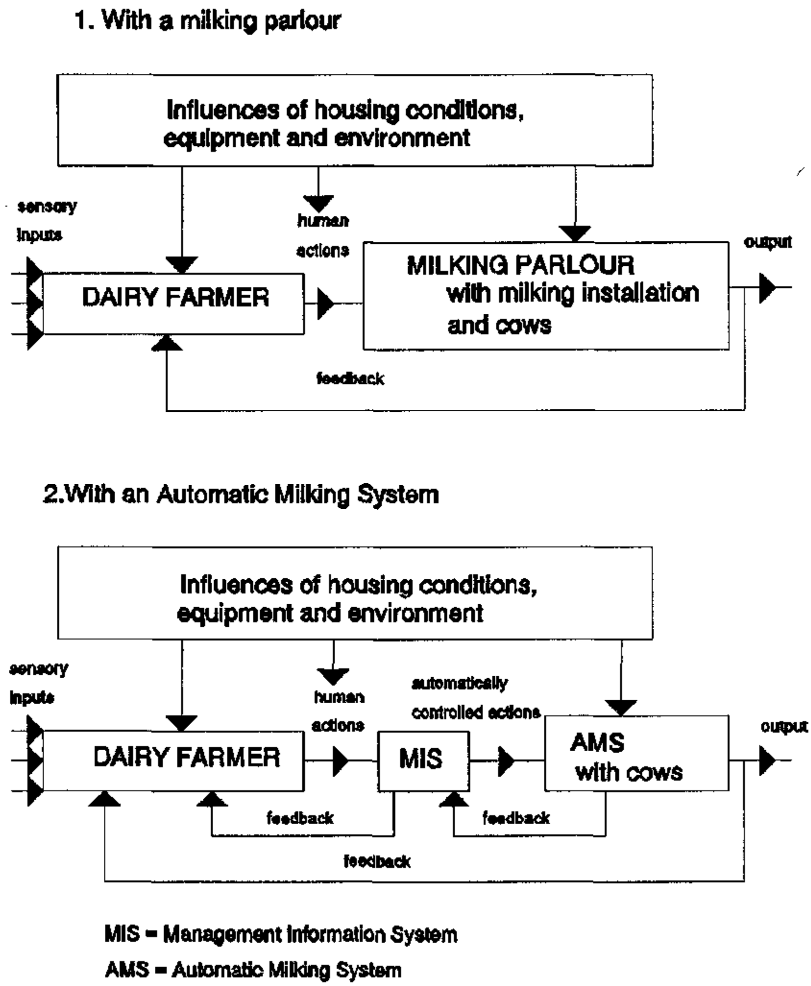


Figure 1. A diagrammatic representation of the farmer-milking-environment system.

The consequences for labour- and social-organization of the introduction of the AMS into the dairy farm are briefly described in this paper. Furthermore, labour savings with an optimal operation of the AMS (without technical malfunctions) are estimated on the basis of available labour time data.

Consequences for labour requirement and labour organization on the farm

To evaluate the consequences of the introduction of AMS for the labour requirements and labour organization of a dairy farm, it is a necessary to have a good insight into these aspects on conventional dairy farms. An inventory of the tasks on a dairy farm was made in the past and resulted in the publications "Taaktijden in de Landbouw deel I en II" (Anonymous, 1970 & 1971).

The introduction of a milking robot will thoroughly change the farmer tasks. The following tasks can be noted.

1. New tasks that are created with the introduction of the AMS (e.g. round up the cows that refuse to visit the milking robot).
2. Traditional tasks that were also done on the traditional farm with a milking parlour. These concern completely identical tasks (e.g. maintenance of the tractor) and changed tasks. Tasks with changed content are, for example, the change in labour time, labour quality, precision with which a task is carried out, frequency of appearance, the sequence in which the tasks or actions are done (e.g. cleaning and littering of the cubicles must be done with greater care to improve the cleanliness of the animals).
3. Cancelled tasks that no longer have to be done as a result of the introduction of AMS (e.g. twice-a-day milking of the cows, removing barriers in the pasture).

An inventory of these tasks on an AMS-equipped dairy farm will be necessary. If these tasks could be coupled to their respective labour times, the labour supply and demand on a totally modern dairy farm (with AMS) could be calculated. The dairy farmer himself, his production plan, the number of farm labourers he has, the machinery, the buildings and equipment, the degree to which the farmer calls in help etc. will decide whether the farmer will have a labour deficit or a labour surplus. A comparison between labour supply and demand on a traditional and an automated farm will show whether labour savings can be achieved by the introduction of an AMS. In 1991 the Working Group "Ontwikkeling van een Modern Melkveebedrijf" (Development of a modern dairy farm) developed plans for housing dairy cattle with different levels of automation (Anonymous, 1991). The labour requirement for the standard plan (cubicle house for 80 cows), for a plan with an AMS and for that combining an AMS and an Individual Feeding System (IFS) are 55, 43 and 35 manhours per cow and per year respectively (Figure 2). This means an annual reduction of approximately 12 man-hours per cow for an AMS and 20 man-hours per cow for an AMS combined with an IFS.

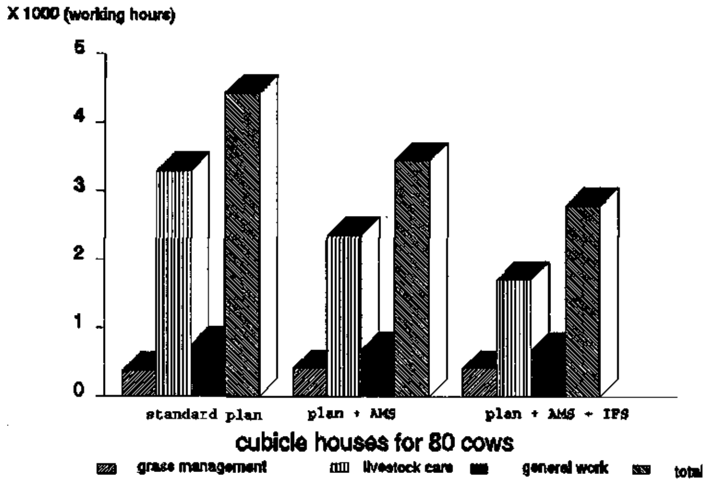


Figure 2. The annual labour requirement for different plans for cubicle houses (80 cows) (Anonymous, 1991)

These figures are estimates. A labour analysis on an actual farm will yield a more precise insight. This is the thrust of a research that has just been begun (July 1992). The following research items will be studied using observations in practice (labour time studies and analyses of video recordings) and more theoretical model studies (simulation):

- the phenomenon which occur during the initial phase of the introduction of an AMS;
- the effects on labour organization per day, per week and per year; the relation between "work planning" and realizing the plan;
- labour requirement for different situations (labour savings?);
- how bound the farmer is to his farm.

Different situations will be studied:

- a cubicle loose house with an AMS + with or without grazing of dairy cows and/or young cattle;
- a cubicle loose house without AMS with different kinds of grazing and milking systems.

Labour savings may not be the chief reason for buying a milking robot. The automation of the milking process also offers new perspectives for total farm management flexibility and can also mean that the farmer is less bound to his farm.

Separating labour and milking of cows gives an extra social dimension to farm life. The farmer can plan his time-off without restraint.

Labour organization in relation to accurate functioning of the AMS

Nevertheless these positive prospects can be overshadowed by a breakdown of the AMS. New electronic, electrical, mechanical and pneumatical devices have been applied in the AMS, technical malfunctions and "growing pains" can be expected. When failures occur, reactions must be immediate. Delay may be harmful to the animals, may have a detrimental effect on milk quality, may cause damage to the expensive milk installation, etc. The introduction of an AMS into a dairy farm may cause some inconveniences, especially in initial phase or "adaptation phase". But also in a later stage problems of all kinds may arise, often at the worst possible moment. A follow-up of the AMS after it has been installed, will make it possible to track down the most common problems and their causes. In this way it should be possible to make a probability function (the probability of a breakdown) for the various kinds of breakdowns.

Labour organization that takes into consideration the possibility of malfunctioning is not a luxury, especially in the early days of working with an AMS. The dairy farmer will be confronted with the need to make urgent decisions and to intervene without delay. He will also have to set priorities where some tasks or activities are concerned.

When planning his daily chores the farmer should consider where, when, how long, and at what distance from the AMS etc. a task is being done. He will have to pay attention to the critical points. Critical points or moments can be defined as those moments when the farmer is relatively far away from the AMS (distance dimension), for a long period (time dimension) and when there is a high risk of failure in the AMS (the risk dimension). An Advisory Support System (a computer dialogue program) could prove invaluable in making the right decisions in specific situations. Simulation models which take weather forecasting, crop situation and soil situation (workability) into account, could be developed and implemented in these situations.

A labour mill can show the critical points in the organization of the farm. The workplaces where certain tasks are done with their specific labour requirements can be illustrated on the labour mill (Figure 3). The working hours given in Figure 3 are the labour times of the tasks which are carried out at their specific places. These figures are calculated (estimated) by the Working Group "Development of a modern dairy farm". Social or family activities (when the farmer is not at home) can be included in the labour mill. Therefore, it would be preferable to call it an activity mill. The farmer obtains an improved insight into all his professional activities in this way. If necessary, he can ask his family or possibly a farm labourer to keep an eye on the animals and the AMS.

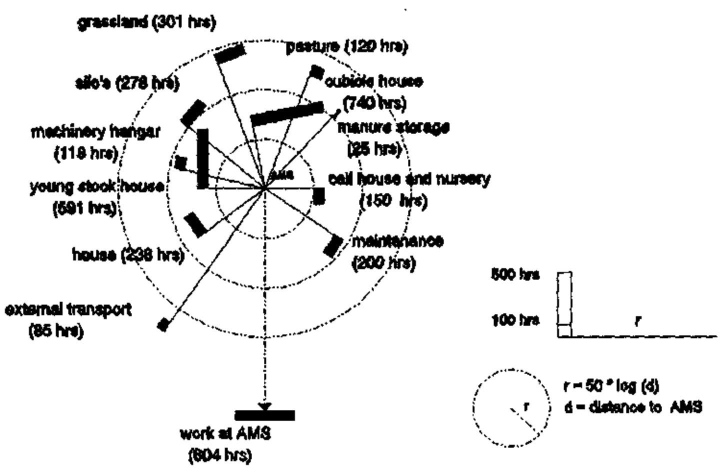


Figure 3. The labour mill.

Social-organizational consequences

Labour content

- With the introduction of an AMS, equipped with several sensors, an important package of information becomes available to the dairy farmer. An analysis of this information with knowledge of the facts and a good management system will enable the farmer to optimize his production.
- There will be task enlargement and enrichment because new activities will arise (e.g. programming, operation and maintenance of the AMS).
- Increase of the farmer's level of knowledge
- Supervisory tasks, these are more stress-related and replace the more physical tasks of ordinary milking

Labour conditions and environment

- Flexible planning of labour is possible. Labour tasks no longer have to be interrupted when the time comes to milk the cows (a preferential activity). The cows are now automatically milked day and night, at moments partly chosen by the cows and partly by the AMS computer program of the AMS.

- The work climate improves while the monotonous tasks of milking are eliminated. The milker no longer needs to work in a cold and humid milking parlour during the winter months. During spring and summer he can continue his normal activities without being interrupted for milking.
- The cows visit the AMS and are milked day and night. Here there are no labour peaks. A high work pressure can only arise when many failures occur within a short time.
- Some precautions are needed with regard to the safety of the milker and the cows and to protect the milking installation, e.g. some shock-sensitive parts of the AMS must be protected against "cow-vandalism" (Notsuki & Ueno, 1977; Montalescot, 1984; Middel & Oenema, 1985; Ordolff, 1987).

Training

- The AMS operator needs to be taught the possibilities of the AMS, its operation, its maintenance, troubleshooting etc.
- The greater the knowledge and insight the farmer has into the AMS, the greater the chance that the equipment will operate successfully. This has to be combined with the farmer's management capacities, his general knowledge and his experience in dairy farming.
- Teaching the farmer elementary troubleshooting and how to make simple repairs should be considered as this might help him to solve some problems and to get the AMS operational again without losing too much time.

Labour requirement

- Milking by means of an AMS requires less labour. Milking in a traditional milking parlour takes, on average, 1.5 to 2 hours. If an AMS is operational on the farm, a regular check of the functional working of the system will generally be sufficient.
- A reduction in the total labour requirement opens some new possibilities for the dairy farmer. Less labour (with the same number of cows) and a lower bondage to the farm gives the farmer the opportunity to take part in social activities (more than before). The time previously spent on milking can now be used to optimize farm management e.g. optimizing grassland production. With the same labour input the farmer can now keep a larger number of cows or do the same work without the help of a farm labourer. In this last case a reduction in labour costs is achieved (Verwaaijen, 1988). The time now available can be used to start up a new branch at the farm. As usual the investments, the labour requirement, the prospects, the costs and profits, etc. have to be considered. As the saying goes "look before you leap".

Conclusions

In this paper we described the structure of problems associated with organization associated with the introduction of the AMS on a dairy farm. Research will need to be carried out to estimate the consequences for labour- and social-organization and to attribute a precise value to the labour and to possible labour savings. Research has already started at the Institute of Agricultural Engineering (IMAG-DLO, Wageningen) at the time of presenting this paper.

References

Anonymous, 1970. Taaktijden in de Landbouw, deel 1. ILR, Wageningen, The Netherlands.

Anonymous, 1971. Taaktijden in de Landbouw, deel 2. ILR, Wageningen, The Netherlands.

Anonymous, 1991. Ontwikkeling geautomatiseerd melkveebedrijf. Verslag van de werkgroep Ontwikkeling van een Modern Melkveebedrijf. IMAG-DLO, Wageningen, The Netherlands, Report 91-10.

Belt, A.H.M., 1984. Een verkennend onderzoek naar de mentale belasting in de melkveehouderij. IMAG, Wageningen, The Netherlands, Publication 206.

Belt, A.H.M. & D.H.A. Zegers, 1984. De arbeidsomstandigheden tijdens het melken. Bedrijfsontwikkeling 4:309-311.

Frost, A.R., 1990. Robotic milking: a review. Robotica 8:311-318.

Middel, R. & R. Oenema, 1985. Automatic apply of teat cups. International Patent Application PCT/NL84/00044, Int. Publication No. WO 85/02973.

Montalescot, J.B., 1984. Robot equipé de palpeurs cherche-trayons (Robot equipped with sensing element for teat-searching). Journal of Agricultural Engineering Research 30:65-70.

Notsuki,I. & K. Ueno, 1977. System for managing milking cows in stanchion stool. U.S. Patent 4010714.

Ordolff, D., 1987. Safety considerations for Automatic Milking Systems. Journal of Agricultural Engineering Research 38:91-98.

Sonck, B., J. Daelemans, A. Maton, & A. Ghesquiere, 1991. Arbeidsorganisatie in geautomatiseerde visgraat- en autotandemmelkstallen. Landbouwtijdschrift 44(3):447-460.

Stål, M. & S. Pinzke, 1991. Working environment in dairybarns. Musculoskeletal problems in Swedish milking parlour operators. Swedish University of Agricultural Sciences, Department of Farm Buildings, Report 80.

Verwaaijen, H., 1988. Van koeboer naar "veemanager by exception". Afstudeeropdracht Christelijke Agrarische Hogeschool, Dronten, The Netherlands.

Practical experiences with automated electronic animal identification using injected identification transponders

S.L. Spahr & R.S. Surber

University of Illinois, Department of Animal Sciences, 1207 West Gregory Drive, 132 ASL, Urbana, Illinois 61801, U.S.A.

Summary

Two trials were conducted with injected animal identification transponders. In Trial 1 fifty heifers were injected at 12 to 18 months of age with glass-enclosed transponders under the triangular cartilage at the base of the left ear. Transponders were read periodically for 6 months with a portable reader or a stationary antenna placed at a waterer. High reading efficiency was found with the stationary antenna at about 45 cm from the injected transponders; reduced reading efficiency occurred when the read range was extended to about 65 cm. All 50 transponders remained operational for 5 months; one transponder failed during month 6. In Trial 2 fifty baby calves were injected with transponders at 3 to 7 days of age. Forty-one transponders remained intact and operational for 6 months; loss within a few days after injection was the primary cause of failure with the injectable transponders in baby calves.
Keywords: electronic animal identification, electronic transponders, dairy automation, injectable identification devices.

Introduction

Progressive programs for dairy herd management are highly dependent upon animal identification. Traditional criteria for animal identification include permanent identity, being legible at a distance, inexpensive, easy to apply, minimum pain or discomfort to the animal, conform to coding for retrieval, and be difficult to alter, destroy or lose. For an injectable electronic identification system, additional criteria are:

1. the identification device should be capable of being read and recorded automatically;

2. the system of coding should meet international protocols for standardization of information.

A single standardized national system of electronic identification for dairy cattle would increase the percentage of genetic records that are useable for genetic evaluations and facilitate the monitoring of carcasses for traceback of disease and chemical residues at time of slaughter.

The U.S.A. does not have a national regulatory agency with a responsibility specifically for animal identification or animal registration. Individual animal databases for control of animal diseases, traceback of carcasses at time of slaughter, and production records are decentralized. Only registered purebreds and those animals enroled in voluntary milk records programs are listed in regional or national databases. The U.S. Holstein Association (HA) and the National Dairy Herd Improvement Association (NDHIA) have formed an alliance to coordinate and implement injectable electronic identification in the U.S. dairy industry. This report presents the results of the first testing, in co-operation with HA/NDHIA, to provide assurance to U.S. dairy producers that the commercial systems have the capability to perform well in on-farm situations.

Materials and Methods

Trial 1

Fifty heifers (Holstein, Ayrshire, Brown Swiss, Jersey and Guernsey) from the University herd were injected at 12 to 18 months of age with glass enclosed transponders (4×29 mm, Texas Instruments, Attleboro, MA) under the triangular (scutiform) cartilage at the anterior base of the left ear. Each transponder was read with a portable reader at 2-week intervals for 8 weeks, and at least monthly thereafter until the units had been in place for 6 months. Automated scanning was tested by installing a 51×76 cm stationary antenna at a waterer in such a way that it was well within the range of the injected transponders for one group of 20 heifers (approximately 45 cm from the base of the left ear), Pen 7, and marginally within the range of the transponders in a second group of 20 heifers in an adjacent lot served by the waterer, Pen 8, (right ear was closest to the antenna for this group). A modem was used to transmit the data about 400 m via a buried communication cable to a personal computer for real time recording. The following details were recorded: time, electronic number and herd number when a transponder was read, and the time when the transponder stopped being read. An "entry" was defined when a new transponder of an animal in the same lot was read. Time of exit was recorded by maintaining the time and identification of the last transponder read in each lot in a temporary register, and recording that time as an exit for the previous animal when a new transponder was read in the same lot. Times when the reader started and stopped reading an individual animal between the entrance and exit times also were recorded. Animal entries to the waterer were recorded continuously in a temporary register. The identification number of animals recorded in the register was written to datafile and the temporary register reset to zero every 30 minutes.

Trial 2

Fifty calves were injected, at 3 to 7 days of age with the same type transponders as were used in Trial 1. Heifers were identified with a portable electronic reader at 2-week intervals initially and approximately monthly thereafter.

Results and Discussion

Trial 1

The pattern of usage for the waterer recorded for a 26-day time period in January 1992 is shown in Figure 1. These data demonstrate that the technology of injected identification transponders and a stationary antenna can be used successfully for recording routine animal events, in this case the presence of an animal at an automatic waterer during a specific 30-min period.

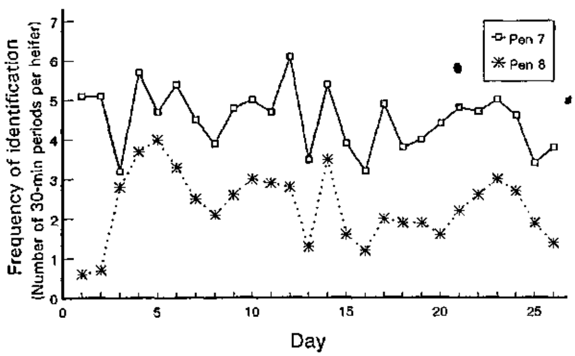


Figure 1. Number of 30-min periods during which individual heifers were identified daily. Data are means for 20 heifers in each pen.

The data also were analyzed to characterize the pattern of usage by individual animals. For the 26-day experimental period the heifers in Pen 7 were identified an average of 4.5 times daily (S.D.=0.8) while those in Pen 8 were identified an average of 2.3 times daily (S.D.=0.9). These results indicate both the capabilities and limitations of the recording system since the management of the heifers was the same in each pen. A greater number of real time identifications in Pen 7 than in Pen 8 is attributed to the transponders being closer to the antenna for those heifers housed in Pen 7 since their left ear was closest to the antenna. Those heifers housed in Pen 8 had their right ear closest to the antenna resulting in substantially greater distance between the antenna and their transponder, causing a lower percent of trips to the waterer to be recorded than occurred in Pen 7. The success of real time recording takes into account the fact that the transponders are somewhat directional, and the heifers will not have their transponders in optimal orientation continuously. Thus, the effective real time range with a high percentage of reads as demonstrated in Pen 7 (about 45 cm), was somewhat less than the range with optimum orientation of the transponder (about 0.70 cm).

Means for recorded usages of the waterer by half-hour periods for heifers in Pen 7 from midnight to midnight during a 26-day experimental period in January 1992 are shown in Figure 2. The data show that wide variations existed in the frequency with which heifers visited the waterer at various times of the day. The results also demonstrate the success of the injected ID transponder system for recording patterns of animal events.

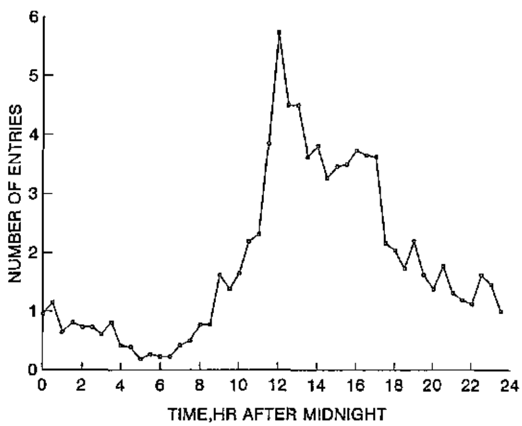


Figure 2. Number of recorded entries to a waterer at various times of the day (20 heifers, 26 days).

Other methods for characterizing the efficiency of the reading and recording system are in Table 1. For this analysis we recorded every time that a transponder came in or went out of the field of interrogation.

Table 1. Characteristics of real time recording of visits to a waterer by dairy heifers.

	Day 1	2	3	4	Mean
	Number of times reader started and stopped per occupancy				
Pen 7	6.9±3.9[1] (1 to 19)[2]	11.6±5.2[1] (2 to 49)[2]	7.7±4.7 (2 to 24)[2]	4.5±2.7[1] (1-15)[2]	7.6±4.1[1]
Pen 8	8.1±5.3 (1 to 57)	11.1±2.6 (2 to 23)	2.3±0.7 (1 to 3)	2.5±0.5 (1 to 5)	6.1±2.3
	Percent of occupancy time that transponder was being read				
Pen 7	69.3±20.8[1] (2.2 to 100)[2]	70.1±11.3[1] (5.0 to 100)[2]	58.0±17.4[1] (8.6 to 95.0)[2]	72.1±15.7[1] (15.0 to 100)[2]	67.5±16.3[1]
Pen 8	28.4±19.4 (1.2 to 100)	39.5±9.2 (0.2 to 86.7)	51.4±9.2 (11.1 to 100)	46.8±46.7 (6.3 to 100)	42.8±13.5
	Time per occupancy (seconds)				
Pen 7	174±174[1] (2 to 1513)[2]	201±110[1] (18 to 1366)[2]	135±101[1] (8 to 673)[2]	64±39[1] (4 to 320)[2]	143±106[1]
Pen 8	299±278 (3 to 1567)	534±266 (7 to 2076)	12±6 (2 to 18)	38±13 (3 to 80)	186±138

[1] Within-day standard deviation.
[2] Range of values. Single values are included if entry time was > 1 sec.

The top section of Table 1 shows that wide ranges and large standard deviations relative to the mean existed in the number of times that a reader started and stopped during an entry. These values are attributed to the heifer moving her head in and out of the field of interrogation, sometimes by changing the orientation of the transponder.

The centre section of Table 1 shows that sometimes the transponder read the entire time between the first time it was detected and the last time it was detected for a specific occupancy. The transponders injected in the heifers in Pen 7 read a larger percentage of the occupancy time than did the transponders injected in the heifers in Pen 8. The difference between pens in the percent of occupancy time that the transponder was being read is attributed to the greater distance between the reader and transponder in Pen 8 due to the left ear being on the side away from the reader.

The bottom section of Table 1 shows that a large variation existed in the time per occupancy. Such variation is to be expected since some occupancies were leisurely with no interruptions; other times a second heifer might displace the one at the waterer after only a short visit.

All fifty transponders continued to operate for 5 months. One unit failed during month 6. It was concluded that the system tested was capable of successful automated identification of heifers in a real time environment over an extended period.

Trial 2

Three units injected into baby calves came out and were recovered in the bedding before the heifer was one month of age; units in six heifers could not be read (lost, broken or some other fate) by the time the heifers were two months of age.

Conclusions

It was concluded that the scutiform cartilage was a less secure location in baby calves than in yearling heifers. In addition, the cartilage was softer, resulting in proper injection being more difficult in baby calves than in older heifers. There was no evidence of infection or tissue reaction at the site of injection. No evidence of migration away from the site of injection was noted. The injection process was learned quickly and was accomplished readily. Interrogation of an injected transponder with a portable reader generally was successful on first try at 30 cm or less. Loss of injected units before complete healing occurred in baby calves was the greatest cause of failure; one unit also failed in yearling heifers after 5 months, and 6 units could not be located within 2 months after injection in baby calves. The range of interrogation was acceptable for automated recording of management events. This system of injectable electronic identification appears promising for commercial use in on-farm automated electronic identification applications for cattle.

Effects of local pre-stimulation versus post-stimulation on milk production and milk composition

K. Svennersten

Swedish University of Agricultural Sciences, Department of Animal Nutrition and Management, P.O. Box 7024, S-750 07 Uppsala, Sweden

Summary

Local regulatory mechanisms within the mammary gland of importance in milk production have been identified. In previous experiments, where the cows were exposed to enhanced stimulation during the complete milking, milk and fat production increased. The aim of the present study was to find out if similar effects on production could be achieved by enhanced pre-stimulation or post-stimulation. An experiment was performed on nine dairy cows in mid-lactation. The cows received extra stimulation on one front teat. This was done by handmilking in the first minute of milking versus the last minute of milking. Pre-stimulation increased daily milk yield and fat content by 2%, while post-simulation increased milk yield by 7% and fat content by 3%. The results demonstrate that post-stimulation is of importance in the milking routine.
Keywords: milk production, pre-stimulation, post-stimulation.

Introduction

Local regulatory mechanisms of importance in milk production have been identified. Enhanced stimulation by handmilking on one teat during the complete milking increased milk yield by about 3%, while fat production increased by about 7% in the teat receiving extra stimulation (Svennersten et al., 1990). Since the effect was only detected in the extra stimulated teat, it was postulated that the effect was due to the activation of local regulatory mechanisms, which increased activity within the milk secreting cells. Furthermore, the finding demonstrated that the type of teat stimulation is of importance in activating these mechanisms.

The aim of the present study was to find out if enhanced stimulation during the complete milking could be replaced by either enhanced pre-stimulation or post-stimulation.

Materials and methods

The experiment was divided into three periods. Each period included three different treatments. The treatments were:

1. handmilking one front quarter during the first minute of milking while the other teats were machine milked
2. handmilking one front quarter during the last minute of milking while the other quarters were still being machine milked
3. control treatment where all teats were machine milked during the complete milking.

When the experiment started the cows had passed peak lactation. Daily milk yield ranged from 15 to 26 kg.

The cows were milked twice a day at 8.5 and 15.5 hours milking intervals. The milking routine was as follows: the teats were cleaned with a paper towel, control milk was drawn from each teat and then the teat cups were applied. In treatment including pre-stimulation, one front quarter was handmilked during the first minute of milking while the other teats were machine milked. During treatment including post-stimulation, one front teat was handmilked during the last minute of milking while the other teats were machine milked. After milking had been completed, 10 ml of milk was drawn from each teat (sample of post-milk) and then the teats were dipped in iodophor disinfectant solution. Samples from the bucket milk were also collected. The milking machine was an Alfa Laval quarter milking machine. The vacuum level was set at 50 kPa, the ratio at 70:30 and the rate at 60 per min.

The collected samples of milk were analysed using the infrared (IR) technique. The milk was analysed for fat, protein and lactose content. All data were subjected to the least square analyses of variance using the General Linear Model (GLM) procedure of SAS (Anonymous, 1985). The results were expressed as least square means. The statistical model included cow, period, day within period, morning and evening, treatment and teat within treatment. Results are presented for the treated and untreated front teats.

Results

Pre-stimulation

During evening milking, the fat content increased significantly in the treated teat and a tendency was also seen in the control teat. During morning milking, there were no effects on milk yield or fat production following pre-stimulation. Neither were any effects detected in the last 10 ml milk fraction which could be ascribed to the treatment (Table 1).

Post-stimulation

During evening milking, fat content in the bucket milk and last 10 ml milk fraction increased in the treated teat, while milk yield increased significantly in both the control and the treated teat. During morning milking, yield of milk and fat content in the last 10 ml milk fraction tended to increase in the treated teat (Table 1).

Table 1. Results (means and standard error) of the experiments on 9 cows.

	Morning control teat mean	Milking treated teat mean	SE	Evening control teat mean	Milking treated teat mean	SE
Milk yield						
pre-stimulation	3.80	3.52	0.08	2.04	1.97	0.08
control	3.81	3.46	0.08_1	2.02_2	1.92_2	0.08
post-stimulation	3.95	3.66	0.08^1	2.23^2	2.10^2	0.08
Fat content						
pre-stimulation	3.95	3.95	0.09	5.63^1	5.85^3	0.09
control	3.99	4.05	0.09	5.40	5.51_2	0.09
post-stimulation	3.81	4.07	0.09	5.42	5.77^2	0.09
Fat content in last 10 ml milk						
pre-stimulation	12.01	11.55	0.22	10.68	10.47	0.21
control	11.95	11.55	0.22_1	10.91	10.32_2	0.21
post-stimulation	12.01	12.13	0.22^1	10.89	11.06^2	0.21

Significant differences within teat between treatments:
$^1 = P<0.1$; $^2 = P<0.05$; $^3 = P< 0.01$.

Discussion

In this experiment it was observed that as a result of enhanced stimulation at the end of milking milk production increased to almost the same level as was achieved with enhanced stimulation during the complete milking (Svennersten et al., 1990). That post-stimulation is of importance for activating local regulatory mechanisms has also been demonstrated in other species. For example the more piglets suckle after milk let down, the more milk is produced in that specific teat (Algers & Jensen, 1989).

Pre-stimulation resulted in increased fat production in both treated teat and control teat during evening milking. It is likely that pre-stimulation resulted in a more efficient oxytocin release and thereby the other not treated udder quarters were also affected by the treatment. That manual pre-stimulation influences milk production and oxytocin secretion has been observed in earlier studies (Mayer et al., 1985).

Conclusion

This study shows that post-stimulation is valuable in the milking routine. However, the greatest effect would be achieved if both enhanced pre-stimulation and enhanced post-stimulation could be performed by the milking machine during milking.

References

Algers, B. & P. Jensen, 1989. Teat stimulation and milk production in early lactation of sows. Effects of continuous noise. In: vocal and tactile communication during suckling in pigs. Thesis. Swedish University of Agriculture Sciences.

Anonymous, 1985. SAS user's guide: Statistics. Version 5 Edition. SAS Institute Inc., Cary, N.C., U.S.A.

Mayer, H., H. Worstorff, D. Schams & M. Klein, 1985. Secretion of oxytocin and milking characteristics in cows as affected by several modes of tactile teat stimulation. Milchwissenschaft 40:1-5.

Svennersten, K., C.O. Claesson & L. Nelson, 1990. Effect of local stimulation of one udder quarter on milk production and milk components. Journal of Dairy Science 73:970-974.

Practical application of Milkodat palettes for early detection of mastitis and mastitis monitoring during lactation period

P. Tongel & S. Mihina

Research Institute of Animal Production, Hlohovská 2, 949 92 Nitra, Czechoslovakia

Summary

The practical use of Milkodat palettes for monitoring mastitis in the herd by measuring milk electrical conductivity from individual udder quarters before milking is described. The palletes tested were developed in Czechoslovakia. Their practical applicability was evaluated. First, the relationship between measured value of electrical conductivity of milk and udder health status was investigated. The health status of the mammary gland was estimated from bacteriological and SCC analyses of quarter samples. Samples from single quarters and from the entire udder were collected and their electrical conductivities were measured and compared with udder health status. It was found, that the electrical conductivities of milk samples from the entire udder were not as useful for indicating udder health status as samples from individual quarters. A threshold value of electrical conductivity in quarter milk was established, for indication of mastitis. In addition, relationships were found between the value of electrical conductivity of foremilk samples before morning and evening milking and between the first, second and subsequent foremilk stripping samples. Within the experiment the measuring accuracy and reliability of the palettes, accuracy of the milk samples collected by the milker from individual quarters, speed the milker's adaptation to the new activity, and time needed for collection were also observed.
Keywords: electrical conductivity, bovine mastitis, detection.

Introduction

The inflammation of the mammary gland i.e. mastitis is an important disease of dairy cows. The main causes of udder inflammation are poor hygiene in the cowshed, the low standard of control of the spread of infectious agents and unsatisfactory maintenance of milking machines. It is generally known that it is necessary not only to treat the mastitis but first of all to prevent it. Many programmes have been introduced to prevent mastitis. Some have introduced aids to hygiene that protecting against the spread of infection. The monitoring of mastitis is crucial in the programme of prevention. It is generally known that the value of the electrical conductivity of milk from an inflamed mammary gland is higher than in milk from healthy udder (Janal, 1986). Measuring the value of the electrical conductivity of milk before every milking enable both new and established inflammations of the mammary gland to be recorded. The stage of development of contemporary electronics and PC's is such that electronic diagnostic systems can be designed for use on farms. Two systems for measuring the electrical conductivity of milk have been developed: off-line (Mielke et al., 1981; Rysanek, 1989) and on-line (Paul et al., 1984; Rossing et al., 1987). In our paper we deal with an off-line system that is specially suitable for tie-housing with milking in a stall. In Czechoslovakia more than 80% of cows are kept in this type of housing at present.

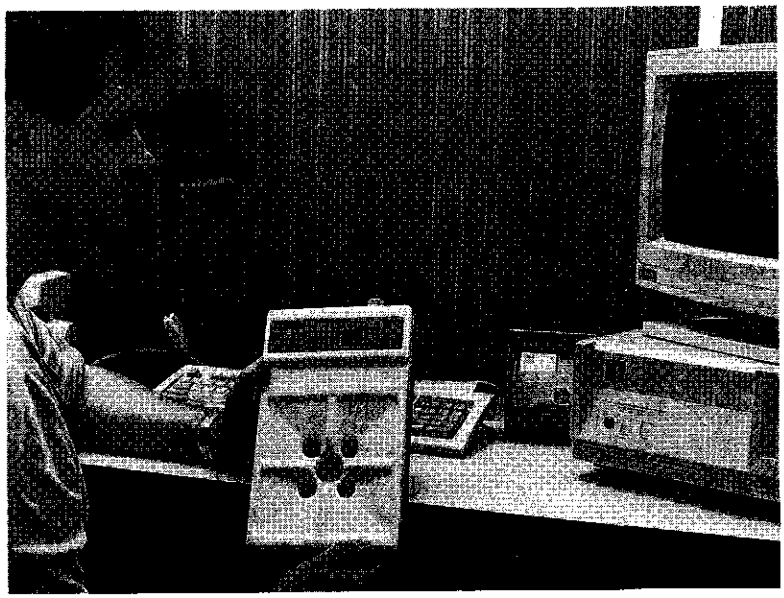


Figure 1. Milkodat Palette.

Features of the equipment

Several years ago Milkodat palettes were developed in Czechoslovakia. These devices allow the electrical conductivity of milk from individual quarters of the udder to be measured before every milking and the recorded data to be transferred to a PC after milking. The palette has four slanting areas for milk stripping from individual quarters. These slope into the chambers equipped with conductivity sensors. When the chambers are full the milk flows to the fifth central common chamber equipped with temperature sensor. Afterwards the measurement is started by pressing the control button. The measured values of electrical conductivity from individual quarters are processed, corrected in accordance with the temperature and the average value is stored in the memory of the palette. It is possible to program a threshold value of electrical conductivity of milk into the palette. If this threshold value is exceeded in any of the quarters, the warning light belonging to that quarter starts to flash on the control display. The diagnostic palette can also be used like a notebook. The keyboard of accessory data allows the milker to input data on the occurrence of oestrus, clinical mastitis and other systemic disease. All these measured and stored data are transferred from palettes to the personal computer and are processed automatically.

Testing the palette

Before beginning the experiment to study the relationship between milk conductivity and health state of the udder we had investigated the accuracy and reliability of the palettes in practice. First, we verified the accuracy of the palettes under laboratory conditions. We performed manifold measurements on salt solutions of known values of electrical conductivity at 20 °C. After each collection of milk samples we checked the accuracy of the measurement of palettes with the calibration solution. The accuracy of 0.02 $S.m^{-1}$ guaranteed by the manufacturer was satisfactory. The accuracy in practical use was tested by repeated measurements using two palettes together. When collecting samples the skill of the milker is very important. He must be careful to fill all the four chambers until they are full and the milk overflows to the common chamber equipped with temperature sensor. He must streak the milk only to the chamber which belongs to the quarter. He must also ensure that the correct number of the stall is displayed on the control panel. Our measurements demonstrated that the milker is able to collect the samples of milk into the palette with complete accuracy, if he is familiar with the equipment. The milker usually discards the first squirts of milk before every milking anyway, and the time needed to collect milk samples in the palette is not much more (though it requires more concentration). Once the milker has learnt the routine he performs all operations well and automatically. We found the technical reliability of the palettes to good. Failure occurred only when the palette fell on the floor when the cow kicked it. This is another reason why it is important to train the milker. We trialled the palette for one year.

Verifying diagnostic reliability of the measurement with Milkodat palettes

The relationship between electrical conductivity (EC) of milk and health state of the udder was observed in a randomly selected group of 20 dairy cows. The cows were in various stages of lactation and were of various ages. Samples were collected from individual quarters and from the whole udder. The health status of individual quarters was estimated on the basis of repeated bacteriological examinations and SCC analyses. The variation in the measured values of the EC in samples from the whole udder was 0.12 $S.m^{-1}$ between cows and the values of EC showed only slight indications of changes in udder health status. At the same time samples were collected from the individual quarters of the udder. The variation of the measured values between all sampled quarters was twice as large (0.26 $S.m^{-1}$). The EC values of quarter samples correlated more with the health status of the mammary gland. As mentioned earlier, a threshold EC value can be given which, if exceeded, indicate probable mammary gland inflammation. The palette can be programmed to alert the milker if this threshold is exceeded. In our case the threshold value of EC for quarter foremilk collection was experimentally fixed as 0.56 $S.m^{-1}$ at 20 °C, based on the threshold value of 0.556 $S.m^{-1}$ at 20 °C found by Rysanek et al. (1980). Starting the absolute threshold value is only the first step for mastitis indication. The second step the differences between the quarters are important (Maatje et al., 1992).

The samples collection

In a second experiment the relationship between first, second and subsequent foremilking stripping samples was observed. The samples were collected consecutively after washing of the udder. The measurements with one palette in randomly selected group of cows were also performed consecutively. We found that the first samples did not differ from second and third samples. In a few cases, mainly among ill cows, the first foremilk samples had a higher EC. Therefore the first squirts were discarded in the next part of experiment in which we studied the differences between the morning and the evening milkings (normally it is not necessary to do this). The measurements were obtained with the same palette which was calibrated after the second measurement. We found that the morning values of EC samples were, on average, 0.012 $S.m^{-1}$ higher than the evening ones. The variation was 2.5% from mean value. Rossing et al. (1987) found a figure of 0.64%. On the basis of our experiment we recommend collecting the samples before every morning milking. It is not necessary to discard the first squirts of milk. If the palette signals an inflammation in a previous healthy cow, then the sampling must be repeated. If the second or third samples do not signal an inflammation then we can assume there was some dirt in the teat canal.

Discussion and conclusion

The palettes enable mastitis to be monitored in herds during the whole lactation period. Then, at drying off, only the infected quarters are treated. Economic analyses have shown that treating all cows in the drying off period has no expected benefit (Howard et al., 1990; Miller et al., 1991). If all quarters are treated without regard to the health status of noninfected quarters there is a greater risk of new mastitis occurrence than if they are not treated (Browning et al., 1990). The Milkodat palettes could be used as a hand-held instrument for prevention of the spread of infectious mastitis in herds. If the milker sees that the light diode of a certain quarter is flashing then he must disinfect teat cups thoroughly after this milking to prevent the infection spreading to other cows. The measurements of EC of milk from individual quarters with the Milkodat palettes have shown that the palettes are a good instrument for diagnosing the origin of inflammations of the mammary gland. They help prevent mastitis from spreading in the herd. The record on mastitis occurrence in the lactation period can be used as information for dry cow treatment or for culling if necessary.

References

Browning, J.W., G.A. Mein, M. Barton, T.J. Nicholls & P. Brightling, 1990. Effects of antibiotic therapy at drying off on mastitis in the dry period and early lactacion. Australian Veterinary Journal 67:440-442.

Howard, W.H., R. Gill, K.E. Lesslie & K. Lissemore, 1990. Monitoring and controlling mastitis on Ontario dairy farms. Canadian Journal of Agricultural Economics 39:299-318.

Janal, R., 1986. Milk conductivity measuring and its utilisation in the praxis. MF VSZ Prague, Czechoslovakia, p. 160.

Maatje, K., P.J.M. Huijsmans, W. Rossing & P.H. Hogewerf, 1992. The efficacy of in-line measurement of quarter milk electrical conductivity, milk yield and milk temperature for the detection of clinical and subclinical mastitis. Livestock Production Science 30:239-249.

Mielke, H., J. Shulz, W. Beuche & H. Labitzke, 1981. Zur Uberwachung der Euter-gesundheitdurch Messung der elektrischen Leitfagichkeit von Viertelanfangs gemelkproben. Archiv für Experimetelle Veterinarmedizin 35:259-276.

Miller, G.Y. & P.C. Barlett, 1991. Economic effects of mastitis prevention strategies for dairy producers. JAVMA, Food Animal Economics 198:227-231.

Paul, W. & H. Speckman, 1984. Die Messung der Leitfahigkeit beim Milchenzug--Messtechnik und erste Ergebnise. Grundl. Landtechnik Bd. 34:192-198.

Rossing, V., E. Benders & P.M. Hogewerf, 1987. Practical experiences with realtime measurements of milk conductivity. Proceedings of the third Symposium Automation in dairying, IMAG, Wageningen, The Netherlands, p. 138-146.

Rysanek, D. & P. Olejnik, 1980. Diagnostic effectiveness of the measurement of electric conductivity of milk. Veterinarni Medicinina 25:464-474.

Rysanek, D., 1989. Rapid diagnostic test for the detection of mastitis based on electrical conductivity of milk. Publication of Veterinary Research Institute, Brno, Czechoslovakia, p. 27.

Modification of suction-pressure pulsation ratio

L. Tóth & J. Bak

Hungarian Institute of Agricultural Engineering, Tessedik Sámuel utca 4,
2100 Gödöllő, Hungary

Summary

The modifying effect of formal change proves that while the suction period does not change significantly in the cylindrical liner, when there are higher or lower vacuums a 20-30% change can be experienced at the conical liner. Therefore, if a different liner is used in the given milking equipment instead of the original one, then the technical and milking parameters of the equipment will also change significantly.
Keywords: teat cups, liner, suction period increasing.

Introduction

Research (Norlander, 1973) carried out twenty years ago indicated that well-constructed milking machines in good working order, used under optimum conditions do not make the animals sick. But that milking machines that do not work well and contaminated milking equipment can cause mastitis (Whittlestone & Jaspers, 1979). Therefore the role milking equipments plays in the spread of infection has to be moderated, especially when it is being used in large herds of cows.

The liners touch the living organism directly (the teats). Therefore their effects can be particulary harmful. Presumably, changing certain elements in a given milking machine effect the operating characteristics of the total unit. The movement of the liner will be modified if another pulsator with different parameters is used. This is also true if the same pulsator is fitted with liners which have different features (liner thickness, form, flexibility, etc.). Therefore, different liners have been tested in order to determine the change of movement and with this, the change of effective pulsation ratio, related to the theoretical, characteristic curves of the pulsator.

Materials and methods

The theoretical sketch of measurement and signal processing are shown in Figure 1. Settings and observations during the test were:

- The peak vacuum of pulsator was 50 kPa and it has not changed in the measurings.
- The pulsation frequency and pulsation ratio have not changed during the experiment.
- The vacuum change at the tip of the teat was measured during the tests.

By setting the teat-end vacuum to 32-34 and 50, 62 kPa the moving mechanism could be well studied at extreme values. These situations occur in practice in case of traditional and double-vacuum milking machines.

The liner movement were observed using a film camera at a speed of 150 and 300 pictures per second. The film can be studied picture by picture in the evaluating equipment.

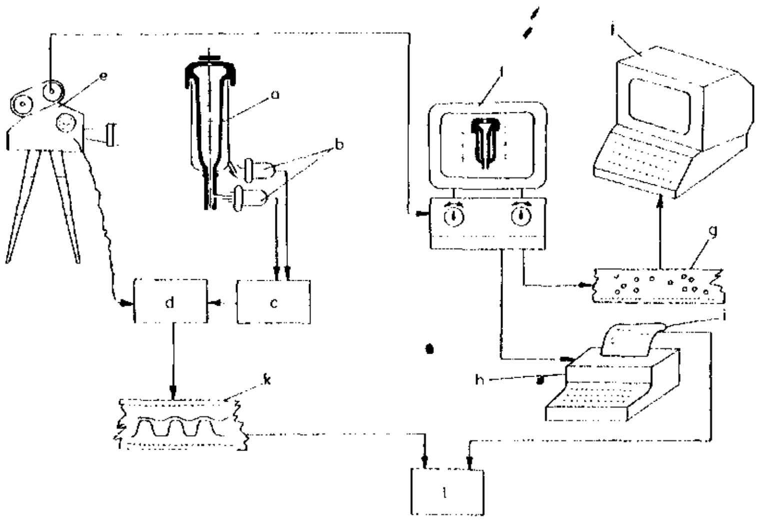


Figure 1. Theoretical sketch of measuring and the primary signal processing equipment.

The theoretical accuracy of the evaluation, apart from 0.006 mm of picture resolution, can be assured to three decimal points (measured in mm). The accuracy of timing (0.03-0.07 s) is characterized by the picture speed.

Table 1. The main technical parameters of the tested liners.

Type	symbol	d_1	d_2	d_3	D	l	F	Characteristics of materials: Hardness (Sb°A)	Breaking strength	Tensile strength
Bou-Matic oval	b	21	21	7	56	146	28	42	550	8.8
Bou-Matic cylindrical	c	21	21	21	56	146	28	41	550	14.8
Conical	d	25	30	22	59	147	50	53	500	14.8
Cylindrical	e	23	25	24	59	133	42	55	555	11.0
Conical-cylindrical	f	22	27	22	60	95	28	45	470	8.6
Silicon [1]		24	26	23	60	140	53	40	590	7.3

[1] Note: the liner marked with "d" is similar to the conical form.
Hungarian standards were applied.

The cross-sectional drawings of the tested liners are shown in Figure 2. The more important parameters can be seen in Table 1. Several other types of liners are known but their basic parameters do not differ from each other significantly, as far as the moving parts are concerned. Figure 2-a shows the measuring planes. In Figure 2-b and Figure 2-c the Bou-Matic liners can be seen.

A rubber ring was placed on the upper part of the liners in order to prevent bulging, thus the liners are less able to climb up the teats. Climbing was reduced in the modified versions by the oval form of the lower part.

Figure 2-d shows a liner that is conical at full length. With this type the diameter, d_2 is greater than diameter d_1 of the mouth opening. Figure 2-e shows a widely used cylindrical liner. Figure 2-f shows a specially formed liner the upper part of which is conical and lower part cylindrical.

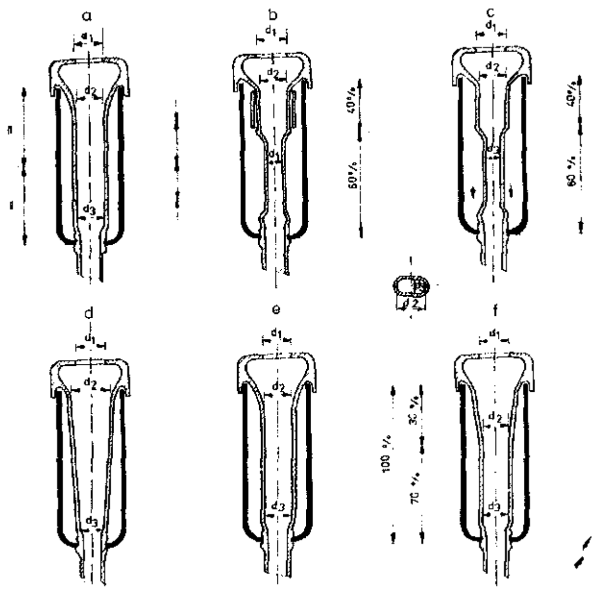


Figure 2. Cross-sectional drawings of the tested liners.

Results

Diagrams were made of changes in liner diameter (Figure 5). The diagram shows how the suction-pressure pulsation ratio changes in relation to the theoretical one because of changes in the milking vacuum and the effect of other factors. The following symbols were used to denote the change of suction period (Figure 3).

t_c	=	the total pulsation cycle (ms).
t_0	=	period of time of pulsator peak vacuum. The liner is in an under-formed condition if the milking vacuum correspond to the pulsator peak vacuum. This can be called a theoretical suction period (ms).
a	=	vacuum.
b	=	time.
t_m	=	the liner finished its movement,when the teat channel closes and there is no milk flowing (it can be called a practical suction period) (ms).
$(t_a;p_0)$, $(t_m;p_m)$	=	co-ordinates of curve $f_n(x)$.
$\Delta t_{a,b}$	=	increments of the suction period starting from t_o(ms).

p_0	=	peak vacuum of pulsator but it is also the milking vacuum if there is no vacuum decrease (kPa).
p_f	=	the vacuum which forms under the teats during milking (milking vacuum, kPa).
p_v	=	milking vacuum decrease due to losses in flow (p_o - p_f = p_v) (kPa).
p_{kr}	=	pressure difference required for starting the teat deformation (by calculation or measuring) (kPa).
p_g	=	value needed to close the teat channel calculated from the value of p_{kr} (10mm) (kPa).

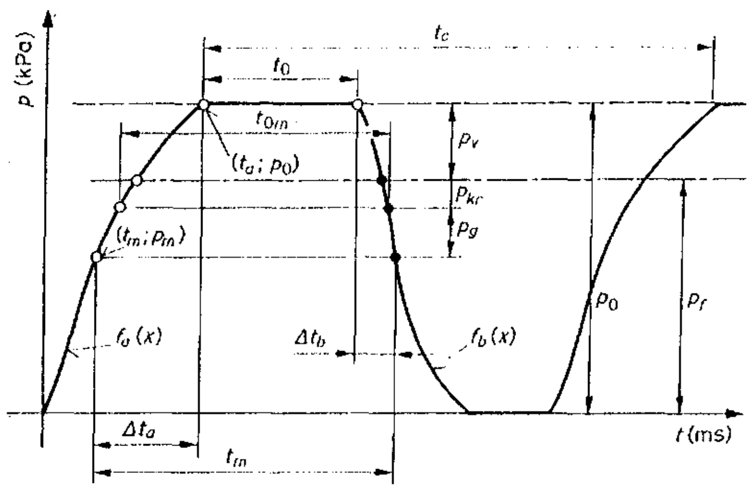


Figure 3. Symbols used in the calculations to denote sections in the pulsation chamber vacuum record.

In general, the value of the outer diameter of closed liner (d_g) is approximately 10 mm in the case of normal liners. On the basis of this data, the variation of pressure pulsation can be calculated as function of milking vacuum decrease and liner characteristics.

According to dynamic measuring:

$$\frac{t_0}{t_c} < \frac{t_m}{t_c}$$

or the rate of suction period increases during milking.

In the computation it is necessary to know the intensity of vacuum change (pulsation) between the wall space of the pulsator. The interim suctions (practical calculation) can be calculated with approaching straight lines but more precisely it can be characterized by functions of a higher degree.

If the transition to suction is characterized by:

$$p = A_1 + B_1 \times \ln t$$

and the transition to pressure is expressed by:

$$p = A_2\, e^{-B_1 t}$$

then the increments of suction elements can be written. In the equations the letters A and B denote the constants of curves fitted to measuring data.

At the transition to suction, the increment of suction period is (we disregard the long demonstration based on Figure 3):

$$\Delta t_a = e^{\frac{1}{B_1}(A_1 + p_0)} - e^{\frac{1}{B_1}\left(A_1 + p_0 - p_t - p_{kr} - \frac{d_0 + d_g}{m_g}\right)}$$

At transition to pressure the increment is:

$$\Delta t_h = \frac{1}{B_2} \ln A_2^{-1} \left(p_0 - p_t - p_{kr} - \frac{d_0 - d_g}{m_g}\right)$$

m_g = the radial spring constant of the liner which is computed from the deformation diagram of the liner (mm/kPa)

As an example, calculations have been made for liners of 24 and 27 mm diameter:
- p_v = 15 kPa
- at ϕ 24: $p_{kr} + p_g$ = 10.1 kPa
- at ϕ 27: $p_{kr} + p_g$ = 5.5 kPa
- t_o = 570 ms; t_c = 1250 ms

So:

- at ϕ24: $t_a + t_b + t_o$ = 155.7 + 101.4 + 570 = 827.1 (ms)
- at ϕ27: $t_a + t_b + t_o$ = 146.14 + 89.3 + 570 = 805.4 (ms)

The starting suction rate is:

$$\frac{t_0}{t_c} = \frac{570}{1250} = 0.45$$

The changed suction rates based on the calculation are:
- at ϕ24: 0.66
- at ϕ27: 0.64.

Values obtained during the dynamic tests are:
- at ϕ24: 0.66 (5 measurements)
- at ϕ27: 0.63 (4 measurements)

The length of the suction period can be well approximated by calculations based on these relations. Because the measurable suction and pressure rate at the pulsator does not give reliable information on the milking machine, the results of the measured parameters of pulsator characteristics can be only informative.

The vacuum conditions can also change significantly at the end of life-time of a liner due to the formal and material change of the liner. Figure 4 shows the moving characteristics of the new (RF) and the used (LR) liners. In the case of a well-used liner the moving conditions change due to loss of flexibility. The suction period also increases and the opening speed of the liner rises.

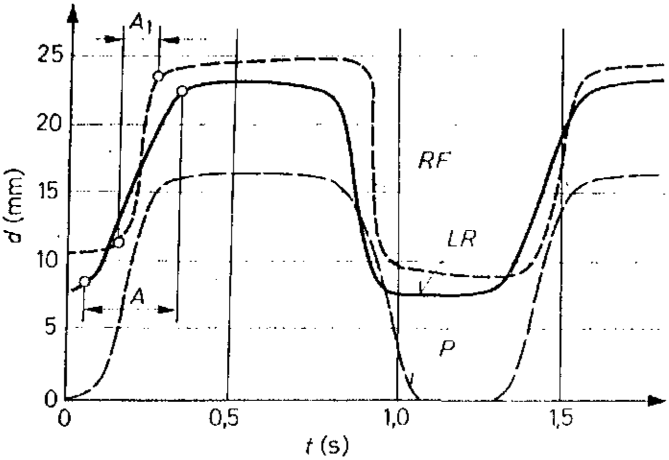


Figure 4. Movement of the new and used liners.
p: pulsator chamber vacuum record; A, A_1: opening times of diameter.

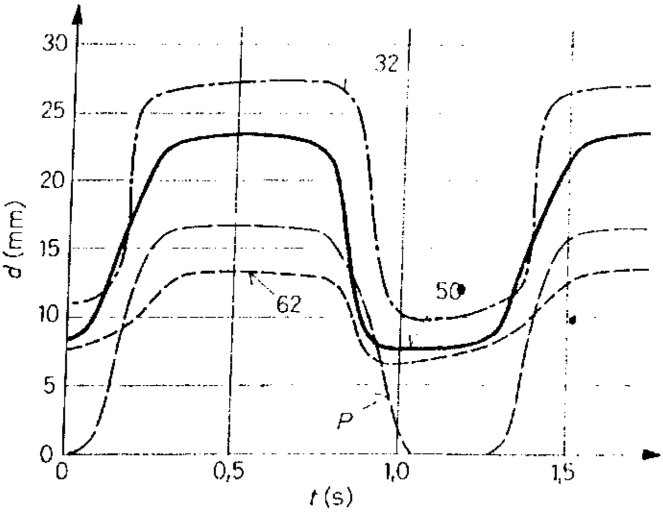


Figure 5. Movement diagram of liner conical at full length on the three tested vacuum levels in the second measuring plane.

References

Norlander, D.O., 1973. Bovine mastitis is a man-made problem. Colorado, U.S.A.

Whittlestone, V.G. & D.E. Jaspers, 1979. The movement of infective substances between milk-hoses, milking cups and teats. Ruakura Animal Research Station, New-Zealand.

The Hungarian milking robot

L. Tóth, J. Bak & T. Liptay

Hungarian Institute of Agricultural Engineering, Tessedik Sámuel utca 4, 2100 Gödöllő, Hungary

Summary

At the Hungarian Institute of Agricultural Engineering research was done to develop a milking robot for the extensive Hungarian dairy farms. This contribution describes the results of a study on the variety in teat locations in a representative Hungarian herd, and the premise adopted to develop the robot.
Keywords: robotics, automatic milking, milking robot, teat cup attachment, teat location, udder sizes.

Introduction

On the extensive dairy farms in Hungary milking machines often work 8-12 hours per day. If milking robots were introduced on these farms they would be intensively exploited. Therefore at the Hungarian Institute of Agricultural Engineering a milking robot is being developed. Studies have been done to find which premise should be adopted when developing such a robot. This article describes the study on teat location and the technical development of the robot.

Finding the teats

If a milking robot is to be able to attach teat cups automatically, first of all the exact location of the teats has to be known (Bak et al., 1989). In this respect the following points have to be considered:

1. The dimensions of the udder and location and size of the teats differ between cows.
2. For each cow the exact location of the teat and the distances between the teats change during lactation.
3. When in the milking stall a cow will move when the teat cups are being attached. Consequently, the locations of the teats will not be fixed.

The working area of the robot arm has to take account of the above-mentioned points. In a study we investigated teat size and location in a herd of Hungarian spotted variety × Holstein Frisian cows. This herd is characteristic of herds on Hungarian dairy farms.

The length of teats in our herd varies from 47 to 56 mm. The deviation in the length of the teats was 17% for the front teats and 22% for the rear teats. In general the front teats are longer than the rear teats (11-21 mm depending on the breed). Cross-breeding can be applied to create new genotypes which may have longer or shorter teats. Normally, cross-breeding reduces the diameters of teats at first, but they may extend during lactation. The teat diameters in the experimental herd observed range from 22 to 27 mm.

The distances between teats range from 110 to 300 mm. The average distances measured between the rear teats are significantly smaller than those measured between the front teats (120 mm and 175 mm on average respectively). Cross-breeding can reduce the distance between the front teats. The average distance between the front teats and rear teats is 126 mm. The distances measured between the udder and ground level vary from 460 to 560 mm. This distance decreases during lactation.

Technical development of the robot

The premise adapted for the technical development of the milking robot is that the milking robot itself and its accompanying features have to be simple and cheap (Tóth, 1990). A prototype of a milking robot has been developed that can be incorporated into a conventional tandem milking stall.

The size of the stall can be adjusted to fit the body size of the individual cow by moving the feeder. When a cow enters the milking stall, the feeder drives back the cow until her hindquarters touches a body sensor. The feeder is driven by a pneumatic cylinder.

The robot approaches the cow from the rear between her legs. A leg opener provides space for the movement of the robot arm and protects the robot arm from being damaged. It also minimizes the possibilities for the cow to move. The leg opener is put in position by a pneumatic cylinder after the size of the milking stall has adjusted to the length of the cow.

The robot arm (Figure 1) has two linear axles and one rotary axle. Its task is to bring 'working heads' (e.g. washing head, milking head) into position. The central computer provides the coordinates for positioning the working heads under the udder of the cow to be milked. As regards the milking head, the robot arm will bring the teat cups 20 to 30 mm underneath the teats at the point where the central point of the teat cups and the central point of the udder coincide (global approach). After this basic position has been reached a controlling device directs the teat cups to their desired locations (fine adjustment). In the basic situation the teat cups are in their central position where the distances between the teat cups correspond with the average distances between the teats as described before (175 mm between the *front* teats, 120 mm between the rear teats and 126 mm between the *front* teats and the rear teats). The controlling device, a double eccentric mechanism, can adjust each teat cup up to 90 mm from its central position. The desired locations for the teat cups are calculated from the coordinates of the teats as registered the previous day. Finally when the teat cups are in position, they are attached in one motion. For this purpose each teat cup is equipped with a small pneumatic cylinder that moves the teat cup upwards.

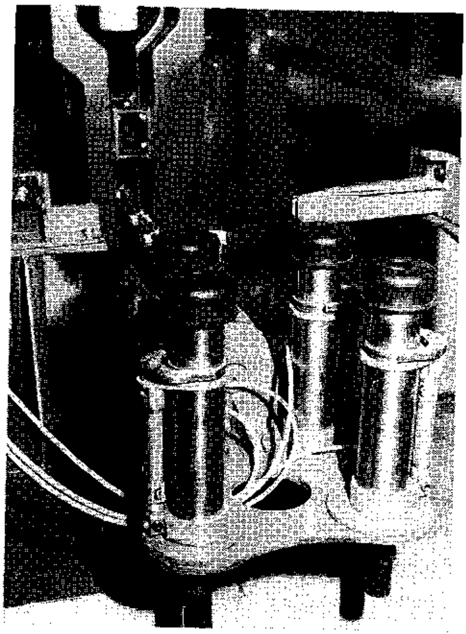


Figure 1. The robot arm with the milking head.

First trials with the robot have taken place in the laboratory. Further development and testing of the robot has been suspended, as further funding for this project is unsure.

References

Bak, J., T. Liptay & L. Tóth, 1989. Investigation of biological parameters aiming the development of computer controlled feeding and milking robots. Report on thesis. Technical Institute of Agricultural Engineering, Gödöllő, Hungary.

Tóth, L., 1990. The automatization and electronization of animal keeping. Technical Institute of Agricultural Engineering, Gödöllő, Hungary.

An alternate paradigm for fostering collaborative research and technology transfer

M.A. Varner* & R.A. Cady**

* *University of Maryland, Department of Animal Sciences, College Park, Maryland 20742-2311, U.S.A.*
** *Washington State University, Puyallup, U.S.A.*

Summary

The objectives were to establish DAIRY-L, an electronic information exchange network for professionals advising dairy producers and then summarize the usage rate and type of communications. The LISTSERV software package on an IBM 3081 mainframe computer was used to maintain a list of the electronic mail addresses, and process submitted electronic mail for distribution. Subscribers were classified according to job description. Recorded logs of messages were examined and classified. The amount of time between questions and responses was determined. DAIRY-L had over 250 subscribers from 42 states/territories and 21 countries. Most subscribers were from academic institutions, but many were from private industry, demonstrating the potential for involvement of private industry. Over 725 messages were sent, most being questions and associated responses. Few questions went unanswered. Most questions received a response in less than one day. Electronic computer networks appear to be useful in fostering collaborative technology transfer among public and private-sector dairy scientists.
Keywords: electronic mail, computer networks, dairy production.

Introduction

Electronic information exchange networks (EIEN) can be used to facilitate communications among individuals dispersed over long distances. Linking public and private sector professionals who advise dairy producers by using local and wide-area computer networks to establish a dairy-related EIEN is now possible and can have significant advantages. Communication by electronic networks like BITNET (LaQuey, 1990b) or INTERNET (LaQuey, 1990a) has advantages over other telecommunication technologies. Communication is rapid and inexpensive. Access to INTERNET E-mail for a private individual currently costs US$ 10 to US$ 20 per month (Varner, M.A.; personal communication) through a private sector computer host. There is an extreme paucity of agriculturally-oriented EIEN's. The objective of this study was to establish DAIRY-L, an electronic information exchange network for professionals advising dairy producers and then summarize the usage rate and type of communications to determine its utility to dairy science programs.

Results and discussion

A dairy-related discussion group, entitled DAIRY-L was established in 1991 using the LISTSERV (Thomas, 1987) software package on an IBM 3081 mainframe computer. The INTERNET electronic mail address of the discussion group is DAIRY-L@UMDD.UMD.EDU. The LISTSERV software maintains a list of the electronic mail addresses for all subscribers. When an electronic mail message is received by the LISTSERV software at the DAIRY-L address, the LISTSERV software stores a copy in a log of all messages. The software then sends out a copy of the message to all subscribers in a manner that optimizes the BITNET/INTERNET mailing efficiency. The amount of time between a question and response(s) was calculated in one day intervals. For responses that came within one day, the number of hours between question and response was calculated. The average number of responses per question, mean number of hours to first response (for first responses that came in 24 hour), and the associated standard error of the mean were calculated (Steel & Torrie, 1960). Ranges and proportion of messages in various categories were calculated. The number of messages sent per month was summarized. The number of subscribers who sent messages was determined.

DAIRY-L started with 2 subscribers, and as of 31 March 1992, over 250 individuals were subscribers to DAIRY-L. Subscribers were from 42 United States states/territories and 21 countries. Of the subscribers, 81% are dairy or veterinary scientists in academic institutions, 12% are in private industry, 3% are in federal, state or provincial governments, and the professional association of the rest is unknown. Most subscribers are currently in academic positions, but the potential for private sector participation has been demonstrated.

Over 725 messages were sent, with 22% being questions, 42% responses, 14% announcements and 17% miscellaneous messages. Responses to questions became rapid and frequent. Questions and responses came from all types of subscribers. The mean number of responses per question (± SEM) was 1.9 ± 0.1. Less than 10% of questions had no responses. Over 60% of questions received at least one response in less than one day, and over 25% received 2 or more responses in less than one day. For first responses received in less than one day, the response was received in 6.5 ± 1.0 hours. Approximately 50% of subscribers have sent messages, providing an unexpected educational opportunity for the participants who have not sent messages. The number of messages per month is in Figure 1.

The volume of messages did not increase until after direct contact by the authors' personal letter. The number of subscribers was not recorded regularly, however, a trend similar to the number of messages appeared to exist in the number of subscribers to DAIRY-L. These results suggest that direct contact is needed to stimulate participation in an EIEN like DAIRY-L. During the early start-up period, it was incumbent on the moderators to insure all requests received some response. Upon reaching a critical mass, encompassing a broad range of specialties, responses from other users were of sufficient number to relieve the moderators from responding to the majority of requests for information. Moderators provided 51% of the responses for the first 40 questions and provided only 31% of the responses for the last 40 questions.

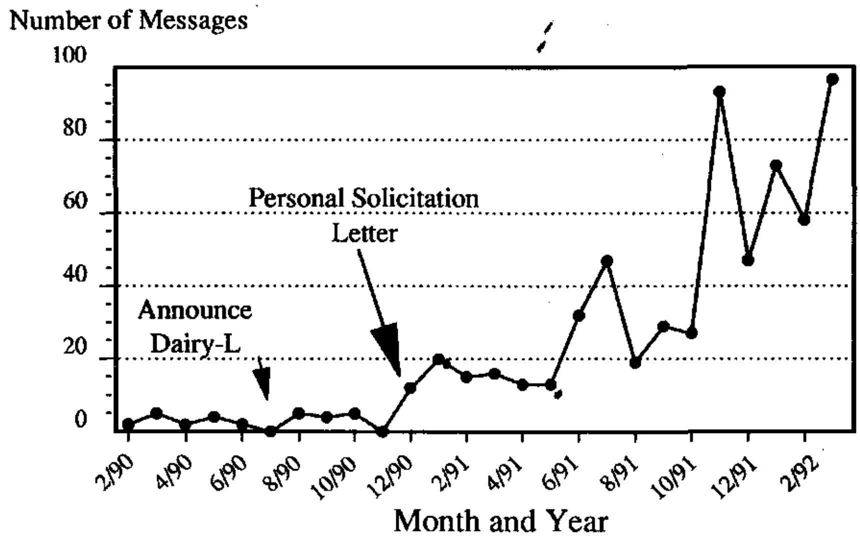


Figure 1. Number of messages sent by DAIRY-L.

Remote retrieval of files is a popular DAIRY-L feature. A total of 29 files were stored, and 470 requests were made by 86 different individuals using LISTSERV software. Some files received more requests than others, even though the files were stored in response to just one question or request for information. Text files related to dairy cow nutrition appeared to be the most popular. Only one binary file was encoded for BITNET mail transfer and the number of requests for that specially encoded file was only half that of the most popular text file. As more subscribers obtain availability to all INTERNET features, the exchange of binary computer files may become even more important.

The success of DAIRY-L suggests that development of EIEN's for other agriculturally-related disciplines will likely become more common in the future. Some features of DAIRY-L or the moderators' operating approach may have application to individuals interested in establishing an EIEN. Those features include: 1) appropriate breadth or narrowness of EIEN focus, 2) potential subscribers have some common bond or easily identifiable mutual need, 3) subscribers are recruited in an appropriate and efficient manner by EIEN moderators, 4) useful information is exchanged and 5) an effort is made initially by the moderators to ensure a response to all requests until the subscriber base becomes large enough to support the system.

Successful and effective use of the electronic communication paradigm in collaborative technology transfer for professionals advising dairy producers was demonstrated. Research and development on automated milking equipment is conducted by scientists who are physically distributed. Use of an electronic communication paradigm similar to DAIRY-L may prove useful in fostering collaborative research on automated milking systems.

References

LaQuey, T.L., 1990a. INTERNET. In: T.L. LaQuey (Ed.): The User's Directory of Computer Networks. Digital Press, The University of Texas System. p. 194.

LaQuey, T.L., 1990b. BITNET. In: T.L. LaQuey (Ed.): The User's Directory of Computer Networks, Digital Press, The University of Texas System. p. 2.

Steel, R.G.D. & J.H. Torrie, 1960. Principles and Procedures of Statistics, McGraw-Hill, New York, NY, USA.

Thomas, E., 1987. Revised List Processor (LISTSERV@FRECP11), Release 1.5m. Ecole Centrale de Paris.