EFFECT OF THE DIAMETER OF THE LONG-PULSE TUBE ON THE PULSATOR CURVE

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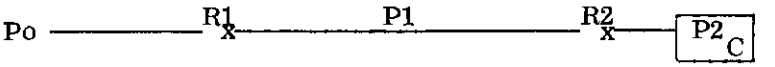
INTRODUCTION

Different makes of milking machines use long-pulse tubes with various inside diameters.
At the request of the ISO Technical Committee 23/SC 11/WGv2 "Milking Machine Installation", we examined the effect of the diameter of the long-pulse tube on the pulsator curve.
The measurements were carried out in a laboratory on an artificial udder with both pipeline and bucket installations.

THEORETICAL

Theoretically we can consider the vacuum variation in the pulsation chamber as follows:
Increasing vacuum phase



Po = vacuum in vacuum line
P1 = vacuum in pulsator
P2 = vacuum between teat cup and liner
R1 = resistance of tube between vacuum line and pulsator
R2 = resistance of pulsator and pulse tube
C = capacity of room between teat cup and liner + capacity of pulse tubes.

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To ensure that there would be no variation in Po, we used a vacuum pump with a large capacity.
We can make the following equations:

$$\phi = \frac{P1-Po}{R1} = \frac{P2-P1}{R2} = -C\frac{dP2}{dt} \quad \ldots (1)$$

$$(P1-Po)R2 = (P2-P1)R1 \text{ or } P2\frac{R1}{R1+R2} + Po\frac{R2}{R1+R2} = P1 \quad \ldots (2)$$

$$P2 - P1 = -CR2\frac{dP2}{dt} \quad \ldots (3)$$

Substitude (2) in (3),

$$P2 = Po - C(R1 + R2)\frac{dP2}{dt} \quad \ldots (4)$$

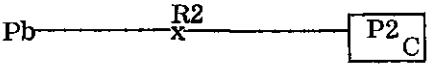
If we accept that the sliding valve of the pulsator opens in a very short time, then Po changes as a step function

$$P2 = Po(1 - e^{\frac{-t}{\tau}}) \quad \ldots (5)$$

This formula shows that the time it takes for P2 to reach the value of Po depends on the resistance R1 and R2 and the capacity C.

DECREASING VACUUM PHASE

The air under atmospheric pressure can flow via the pulsator and the pulse tubes in the space between the teat cup and the liner.



Pb = atmospheric pressure

$$\emptyset = \frac{Pb - P2}{R2} = C \frac{dP2}{dt} \quad \ldots (6)$$

$$P2 = Pb - CR2 \frac{dP2}{dt} \quad \ldots (7)$$

This formula shows that the time taken for P2 to reach the atmospheric pressure Pb depends on the resistance R2 and the capacity C.

MEASUREMENTS

For the measurements the following variables were introduced.

MILKING PIPELINE MACHINE

Pulsator	A	Alternative	pulsation
	B	"	"
	C	"	"
	D	Simultaneous	"
	E	"	"

Pulse tube diameter
- 6 mm
- 7 mm
- 8 mm
- 9 mm, all 2400 mm long

Capacity
- teat cup large
- small

We can combine the variables as follows:

	6 small	6 large		6 small	6 large
A	7 small	7 large	B	7 small	7 large
	8 small	8 large		8 small	8 large
	9 small	9 large		9 small	9 large
	6 small	6 large		6 small	6 large
C	7 small	7 large	D	7 small	7 large
	8 small	8 large		8 small	8 large
	9 small	9 large		9 small	9 large

E This pulsator is placed on the claw so that no long-pulse tubes can be used
E large
E small
E without teat cups

BUCKET MILKING MACHINE

Pulsator A, B, C } alternative pulsation
D simultaneous pulsation

Pulse tubes

diameters 6 mm, 920 mm long
7 mm, " "

Capacity

teat cups: large
small

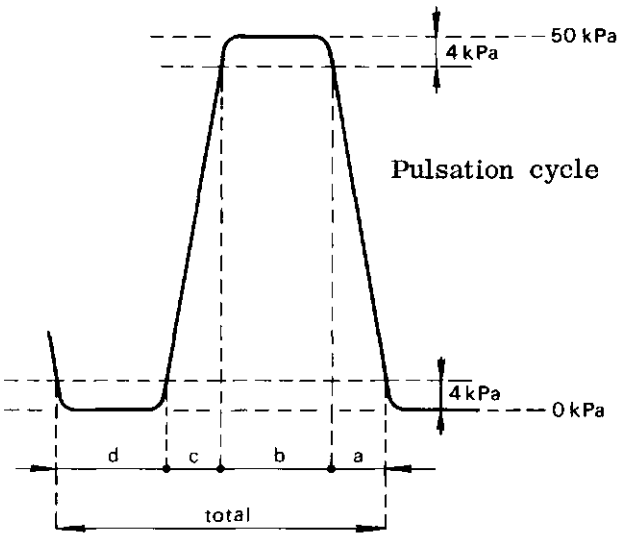
We can combine the variables as follows:

A	6 small	6 large
	7 small	7 large
B	6 small	6 large
	7 small	7 large
C	6 small	6 large
	7 small	7 large
D	6 small	6 large
	7 small	7 large

During the measurements the teat cups were connected to an artificial udder. The pressure variation was measured with pressure transducers and recorded with a recorder which had a satisfactory frequency response (0-100 Hz). The air consumption was measured with a gas volume meter (Drawings 1 and 2). The results of the measurements are presented in Tables 1, 2 and 3 and in the Figs. 1-50.

From the graphs the following data can be obtained:

total pulsation cycle
a. increasing vacuum phase
b. maximum vacuum phase
c. decreasing vacuum phase
d. minimum vacuum phase



These data are expressed in % of the total pulsation cycle (tables 1, 2 and 3).
These tables also show the pulsator rate, air consumption in litres of expanded air per min, and the air consumption in l expanded air per 60 cycles.

CAPACITY C

The capacity of the installation:
- capacity of space between teat cup and liner (4 x by simultaneous and 2 x by alternative)
- capacity of long pulse tube
- capacity of short pulse tubes (4 x by simultaneous and 2 x by alternative pulsation).

The capacity of the pulsation chamber was measured by pouring water into the chamber with a vacuum inside the liner.

Capacity of small teat cup: 105 cm^3 (by alternative)
135 cm^3 (by simultaneous)
Capacity of large teat cup: 165 cm^3

Capacity of pulse tubes

diameter	l = 2400 mm	l = 920 mm	l = 25 mm
6 mm	67.0 cm^3	26 cm^3	4.2 cm^3
7 mm	92.4 cm^3	35.4 cm^3	
8 mm	120.6 cm^3		
9 mm	152.9 cm^3		

Total capacity in litres with different tube diameters, pulsators and teat cups

Milking pipeline machine

diameter of pulse tube	small alt.	small sim.	large alt.	large sim.
6 mm	0.29	0.62	0.41	0.74
7 mm	0.31	0.65	0.43	0.77
8 mm	0.34	0.68	0.46	0.88
9 mm	0.37	0.71	0.49	0.83

Bucket milking machine

diameter of pulse tube	small alt.	small sim.	large alt.	large sim.
6 mm	0.24	0.58	0.36	0.70
7 mm	0.25	0.59	0.37	0.71

We can conclude that the teat cups have more influence on the total capacity than the diameter of the pulse tubes.

Table 1 Milking pipeline machine

pulsator type	teat cup	tube diam. mm	$\frac{a+b}{tot}$x100%	$\frac{a}{tot}$x100%	$\frac{b}{tot}$x100%	$\frac{c}{tot}$x100%	$\frac{d}{tot}$x100%	pulsation rate	time of pulsation cycle, sec.	l/min	in l/60 cycles	Fig.
A	small	6	67.9	11.3	56.6	9.4	22.6	44.38	1.35	39.37	53.23	1
		7	62.2	11.3	50.9	9.4	28.3	44.38	1.35	41.32	55.86	2
		8	67.9	11.3	56.6	9.4	22.6	44.38	1.35	42.02	56.81	3
		9	62.2	11.3	50.9	9.4	28.3	44.38	1.35	44.05	59.55	4
	large	6	62.3	17.0	45.3	11.3	26.4	44.38	1.35	48.30	64.8	5
		7	66.6	14.8	51.8	11.1	20.4	43.60	1.38	49.20	67.2	6
		8	66.0	15.1	50.9	11.3	22.6	44.38	1.35	51.30	68.9	7
		9	62.3	15.1	47.2	11.3	26.4	44.38	1.35	52.60	70.6	8
B	small	6	60.5	11.6	48.8	9.3	30.2	54.70	1.10	50.00	54.84	9
		7	60.5	11.6	48.8	9.3	30.2	54.70	1.10	51.02	55.96	10
		8	72.1	11.6	60.4	9.3	18.6	54.70	1.10	50.51	55.40	11
		9	55.8	11.6	41.9	25.6	18.6	54.70	1.10	52.91	58.04	12
	large	6	45.5	20.5	22	27.3	27.3	53.45	1.12	56.90	63.87	13
		7	45.5	18.2	27.3	25	29.5	53.45	1.12	56.90	63.87	14
		8	46.5	16.3	30.2	25.6	27.9	54.70	1.10	60.60	66.66	15
		9	46.5	16.3	30.2	25.6	27.9	54.70	1.10	62.50	68.75	16

Table 2. Milking pipeline machine

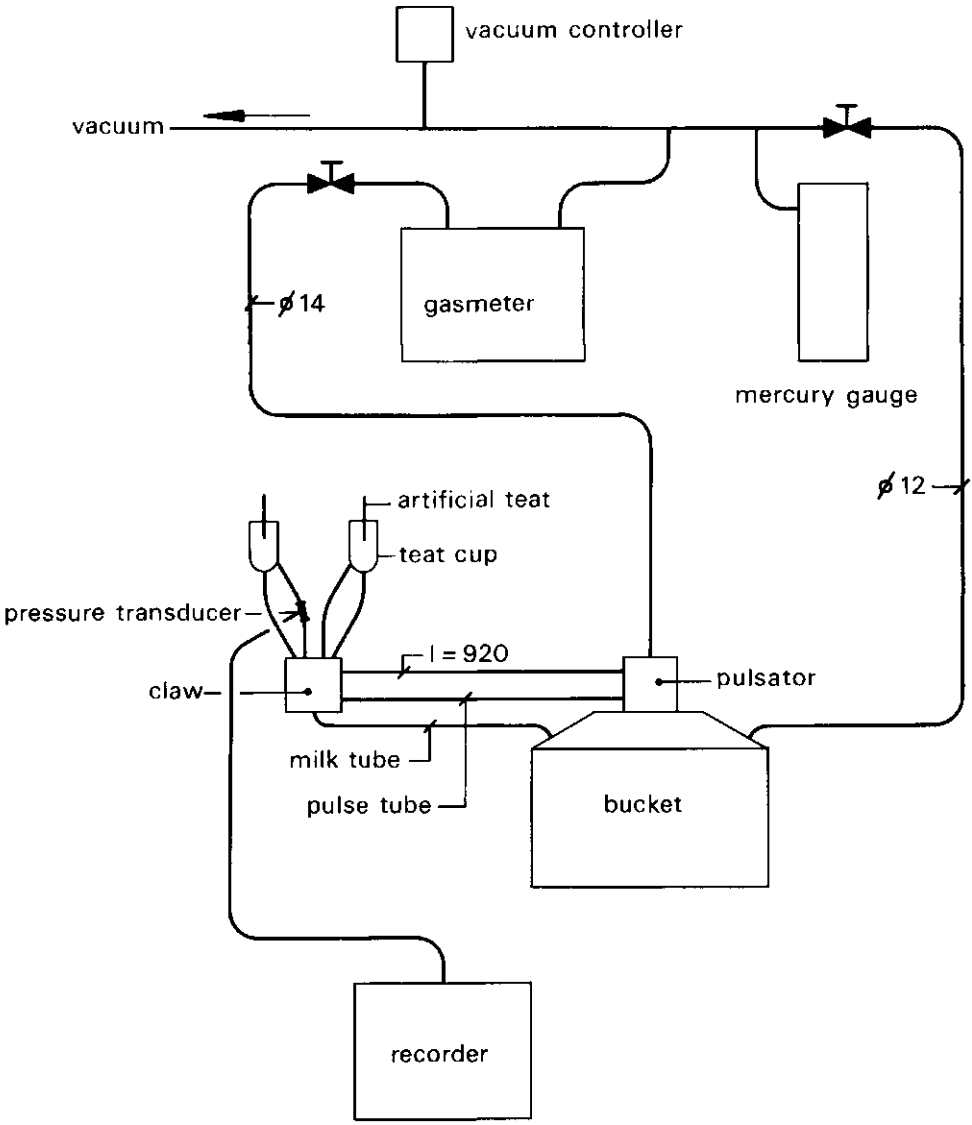
pulsator type	teat cup	tube diam. mm	a+b / tot x 100%	a / tot x 100%	b / tot x 100%	c / tot x 100%	d / tot x 100%	pulsation rate	time of pulsation cycle, sec.	l/min	in l/60 cycles	Fig.
C	small	6	73.0	13.5	59.5	10.8	16.2	64.0	0.94	64.90	60.80	17
		7	73.0	13.5	59.5	10.8	16.2	64.0	0.94	68.20	63.40	18
		8	75.0	13.9	61.1	8.3	16.7	65.8	0.91	67.80	61.30	19
		9	73.0	13.5	59.5	10.8	16.2	64.0	0.91	73.20	68.60	20
	large	6	73.0	18.9	54.1	10.8	16.2	64.0	0.94	78.40	73.50	21
		7	70.3	21.6	48.6	16.2	13.5	64.0	0.94	79.40	74.40	22
		8	73.0	18.9	54.1	13.5	13.5	64.0	0.94	82.40	77.30	23
		9	70.2	18.9	51.3	13.5	16.2	61.9	0.97	83.30	81.30	24
D	small	6	50.0	25.0	25.0	22.9	27.1	49.0	1.22	43.48	53.24	25
		7	50.0	20.8	29.2	16.7	33.3	49.0	1.22	45.04	55.15	26
		8	50.0	20.8	29.2	20.8	31.3	49.0	1.22	45.45	55.65	27
		9	50.0	20.8	20.2	20.8	31.3	49.0	1.22	46.29	56.68	28
	large	6	51.1	34.0	17.0	23.4	25.5	50.0	1.20	50.63	60.80	29
		7	51.1	29.8	21.3	23.4	25.5	50.0	1.20	50.42	60.50	30
		8	50.0	29.2	20.8	22.9	27.1	49.0	1.22	49.58	60.70	31
		9	50.0	35.4	14.6	22.9	27.1	49.0	1.22	50.00	61.20	32
E	small	-	65.4	28.8	36.5	11.5	23.1	45.5	1.32	42.95	56.70	33
	large	-	69.2	38.5	30.8	13.5	17.3	45.5	1.32	44.44	58.70	34
	none	-	75.0	2.5	72.5	2.5	22.5	58.8	1.02	-----	----	35

Table 3. Bucket milking machine

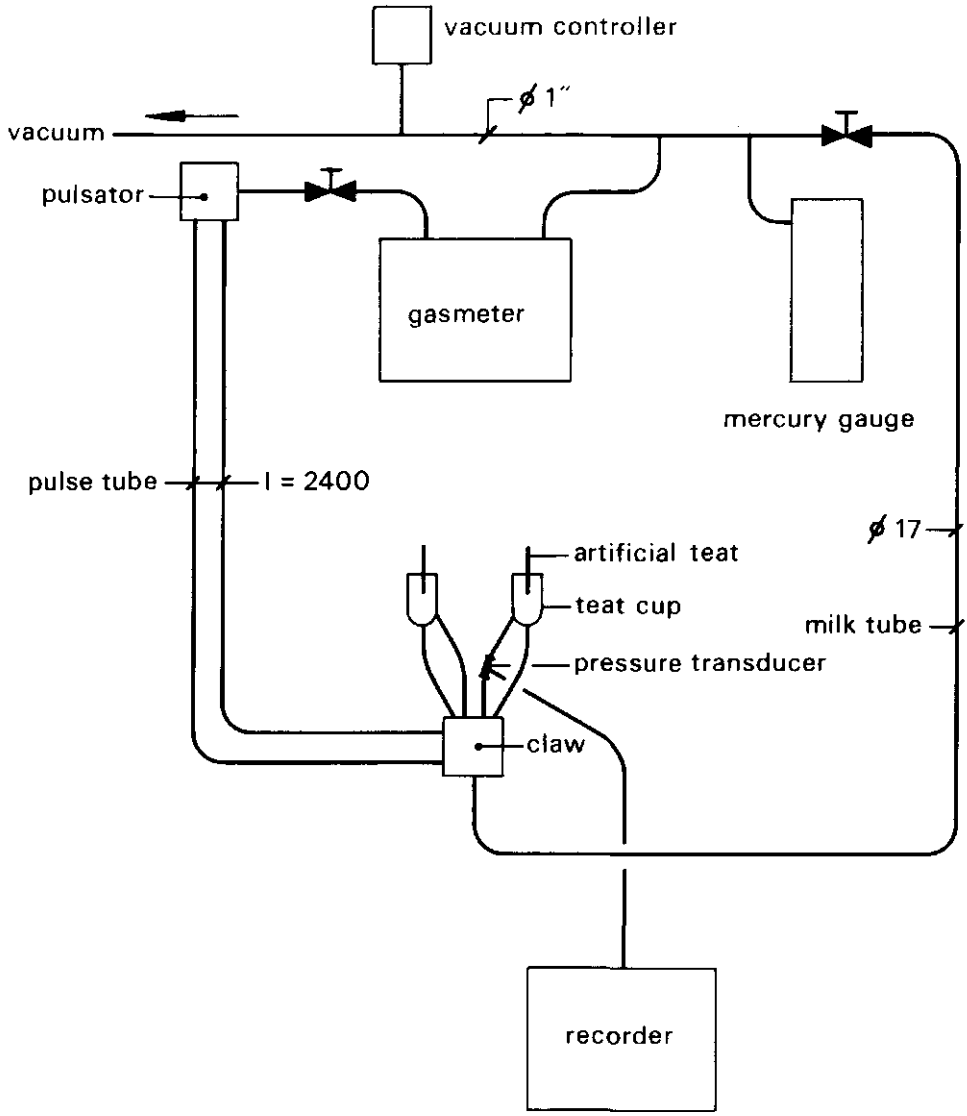
pulsator type	teat cup	tube diam. mm	$\frac{a+b}{tot}$ x 100%	$\frac{a}{tot}$ x 100%	$\frac{b}{tot}$ x 100%	$\frac{c}{tot}$ x 100%	$\frac{d}{tot}$ x 100%	pulsator rate	time of pulsation cycle, sec	l/min	in l/60 cycles	Fig.
A	small	6	63.8	10.6	53.2	8.5	27.7	50.0	1.20	45.5	54.6	35
		7	68.1	12.8	55.3	6.4	25.5	50.0	1.20	45.5	54.6	36
	large	6	66.7	16.7	50.0	10.4	22.9	50.0	1.20	57.7	69.2	37
		7	59.6	17.0	42.6	12.8	23.4	50.0	1.20	63.8	76.6	38
B	small	6	60.5	14.0	46.5	9.3	30.2	54.7	1.10	43.9	48.3	39
		7	60.5	9.3	51.2	7.0	32.6	54.7	1.10	44.4	48.8	40
	large	6	58.1	18.6	39.5	14.0	27.9	54.7	1.10	46.2	50.8	41
		7	67.4	16.3	51.2	14.0	18.6	54.7	1.10	56.6	62.3	42
C	small	6	73.0	13.5	59.5	10.8	16.2	64.0	0.94	62.5	58.8	43
		7	73.0	10.8	62.2	8.1	18.9	64.0	0.94	61.9	58.2	44
	large	6	73.0	21.6	51.4	13.5	13.5	64.0	0.94	75.0	70.5	45
		7	72.2	16.7	55.6	13.9	13.9	65.2	0.92	76.9	70.7	46
D	small	6	50.0	22.9	27.1	18.8	31.3	49.0	1.22	42.5	51.9	47
		7	47.8	21.7	26.1	19.6	32.6	51.3	1.17	45.5	53.2	48
	large	6	50.0	30.4	19.6	21.7	28.3	51.3	1.17	48.1	56.3	49
		7	50.1	28.3	21.7	21.7	28.3	52.2	1.15	51.0	58.7	50

CONCLUSIONS

The values of (a) and (c) are affected by the resistance in the system and the capacity of this system (this is also shown by the formulas). Although we do not know the effect of these factors on the milking, we assume that the effect of the diameter of the pulse tubes must be small. From the tables the effect of the capacity seems fairly great compared with that of the tube diameter.
For a pipeline milking machine with an alternative pulsator and teat cups of not too large capacity, a long-pulse tube with a diameter of 6 mm is sufficient: with teat cups of a larger capacity this diameter slightly lengthens the increasing and decreasing vacuum phase so that a tube with an inside diameter of 7 mm gives a better result.
With a simultaneous pulsator it is clear that an inside diameter of 6 mm is too small and the diameter must be at least 7 mm.
For a bucket milking machine with an alternative pulsator and a pulse tube 920 mm long, a diameter of 6 mm is sufficient.
For a simultaneous pulsator a pulse tube with an inside diameter of 7 mm gives better results.



Drawing 1 Diagram of the laboratory installation for measuring the pressure drop in the long-pulse tube by bucket installations.



Drawing 2 Diagram of the laboratory installation for measuring the pressure drop in the long-pulse tube by pipeline installations.

Fig. 1-50 show the pressure variations in the different situations between teatcup and liner.

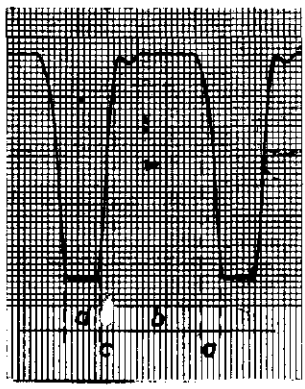


fig. 1

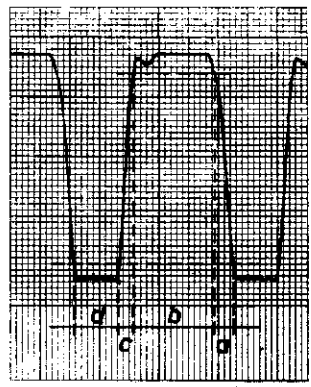


fig. 2

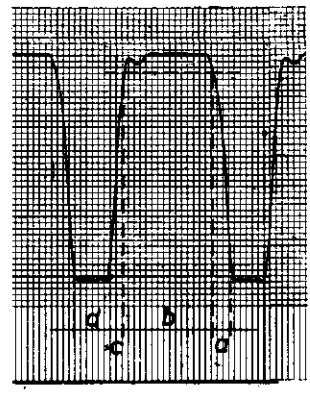


fig. 3

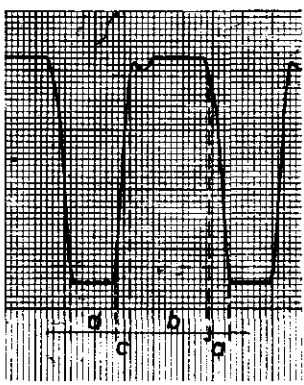


fig. 4

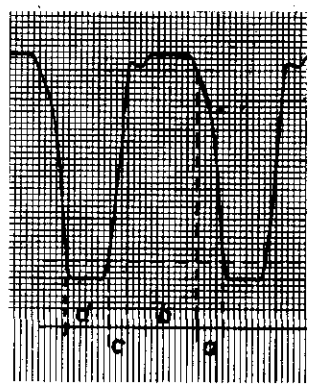


fig. 5

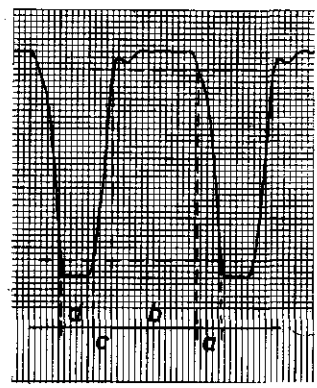


fig. 6

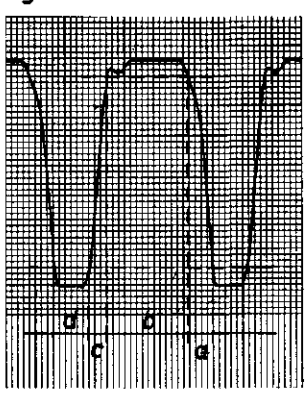


fig. 7

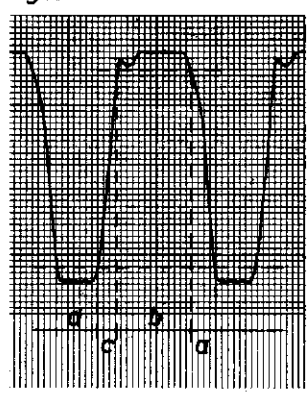


fig. 8

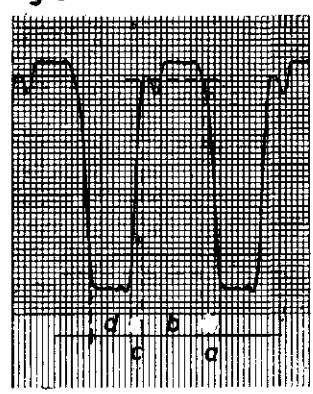


fig. 9

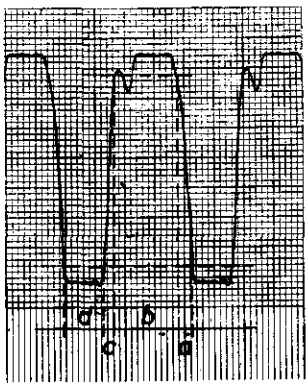


fig. 10

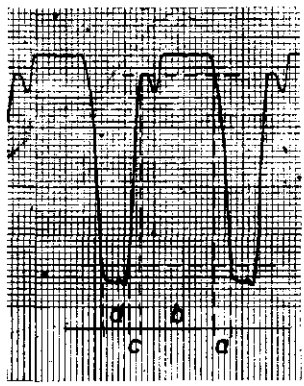


fig. 11

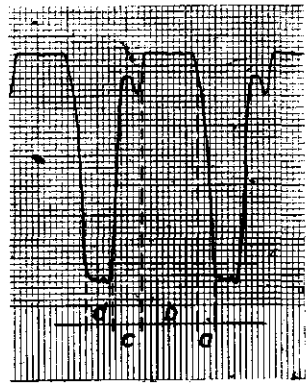


fig. 12

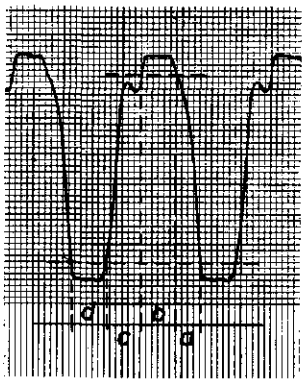


fig. 13

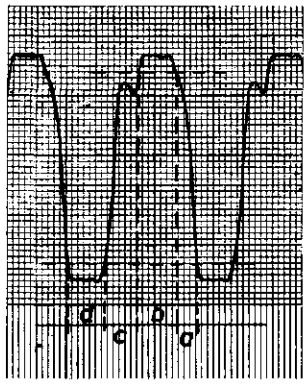


fig. 14

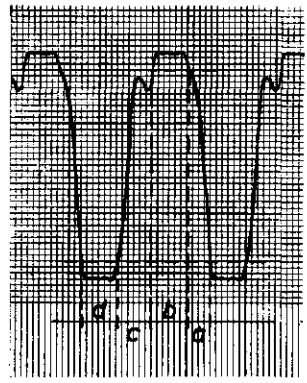


fig. 15

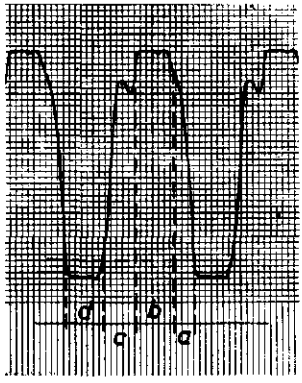


fig. 16

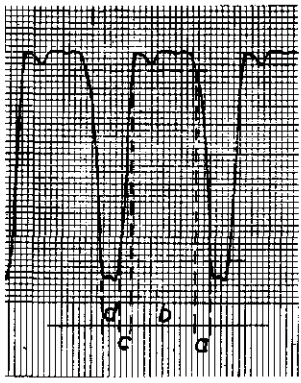


fig. 17

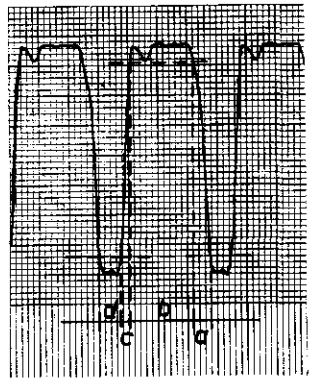


fig. 18

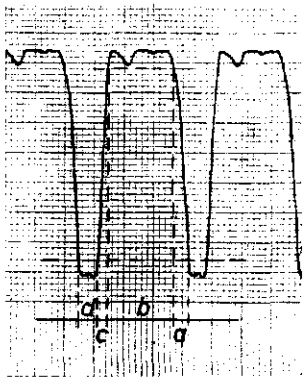


fig. 19

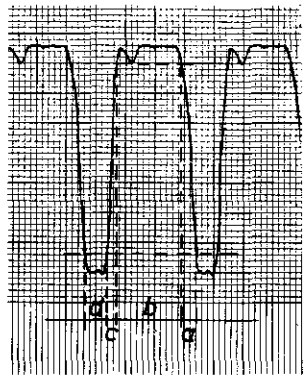


fig. 20

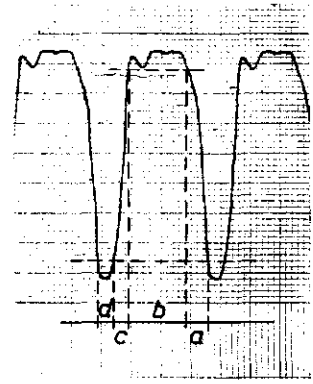


fig. 21

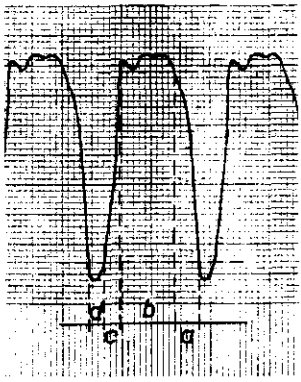


fig. 22

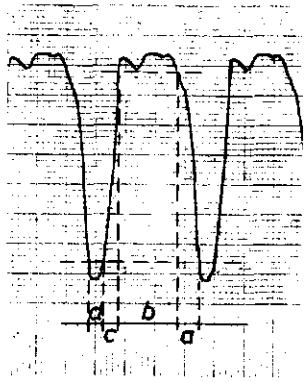


fig. 23

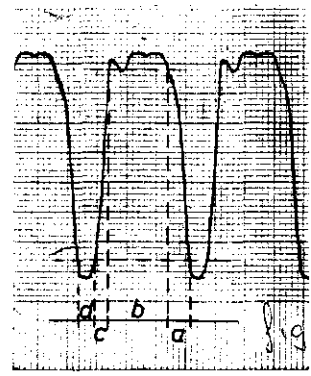


fig. 24

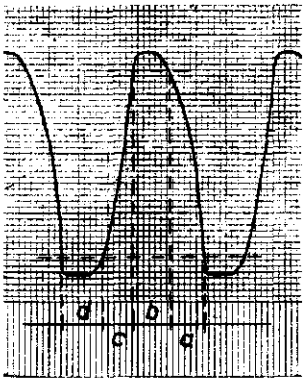


fig. 25

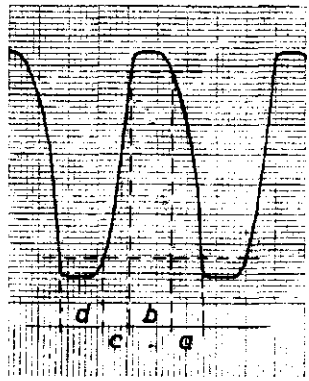


fig. 26

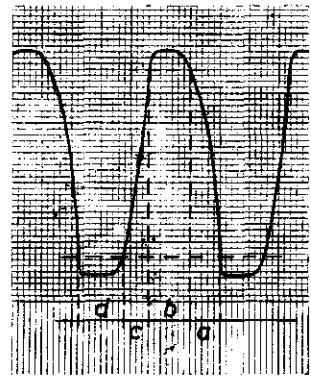


fig. 27

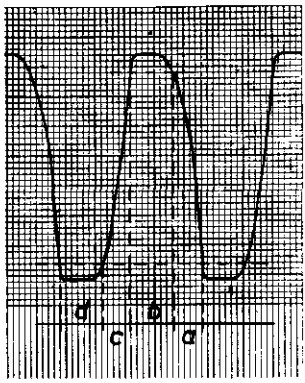


fig. 28

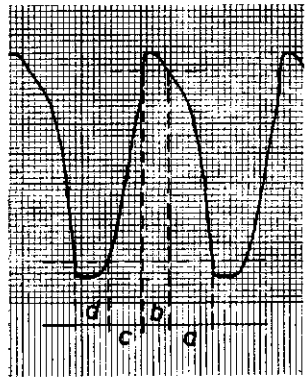


fig. 29

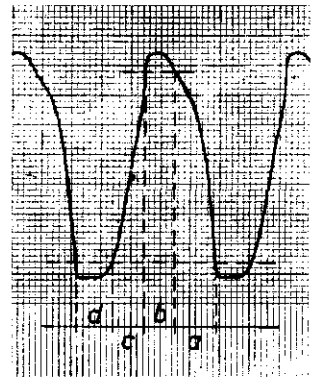


fig. 30

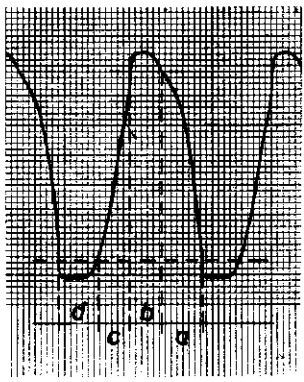


fig. 31

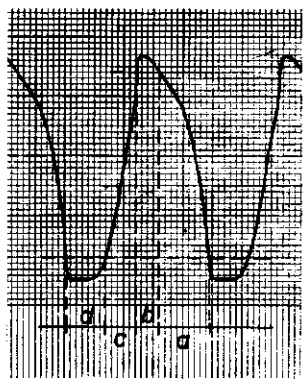


fig. 32

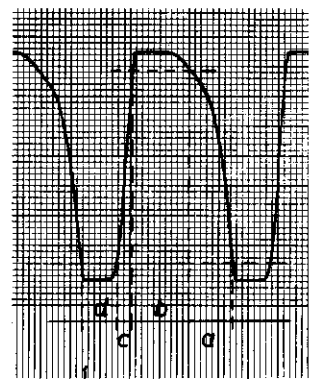


fig. 33

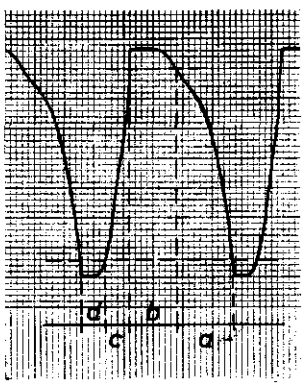


fig. 34

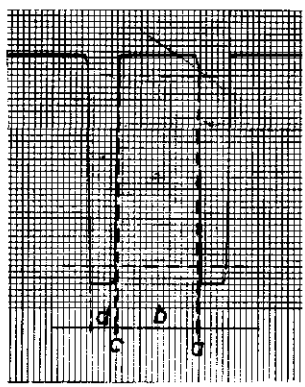


fig. 34 a

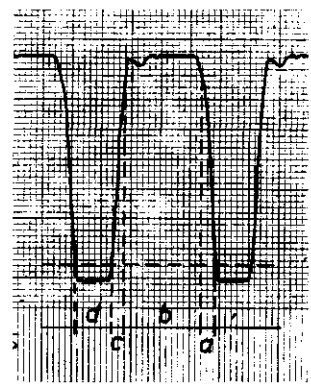


fig. 35

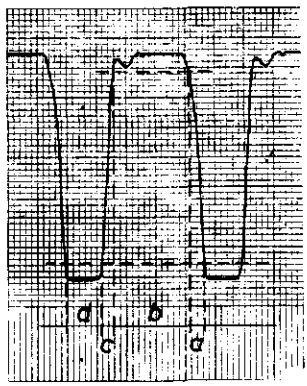


fig. 36

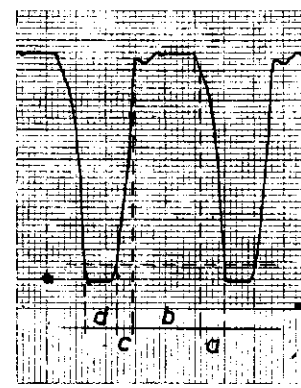


fig. 37

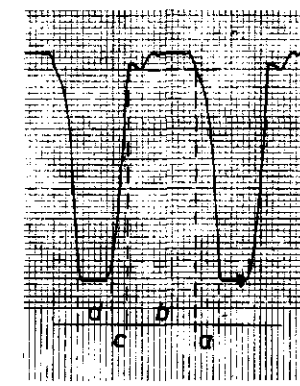


fig. 38

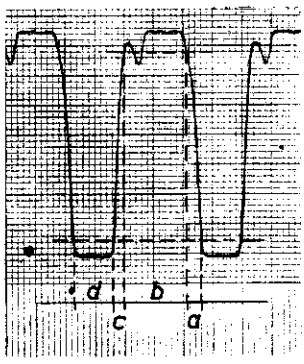


fig. 39

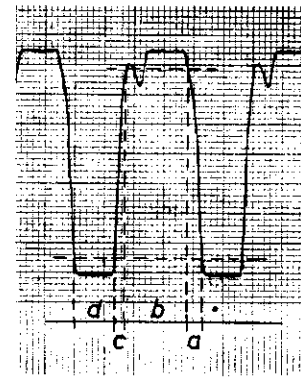


fig. 40

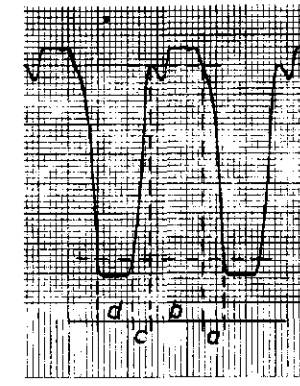


fig. 41

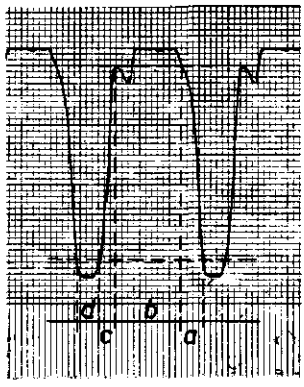


fig. 42

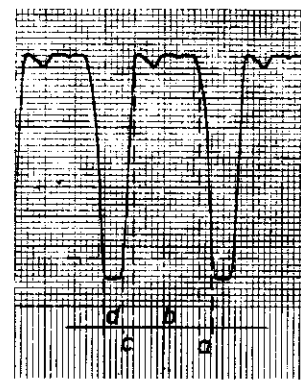


fig. 43

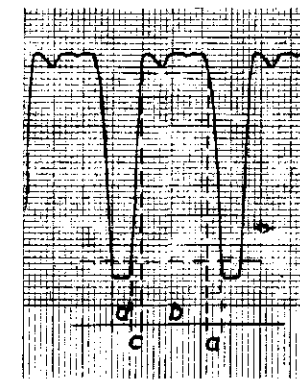


fig. 44

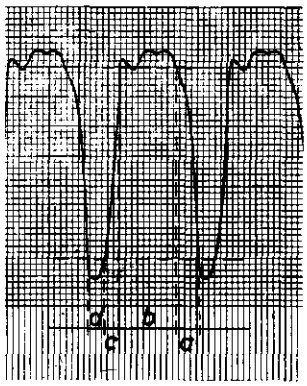


fig. 45

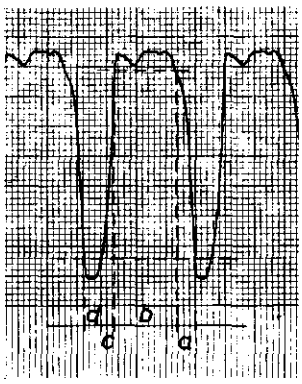


fig. 46

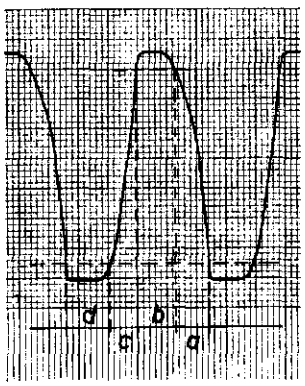


fig. 47

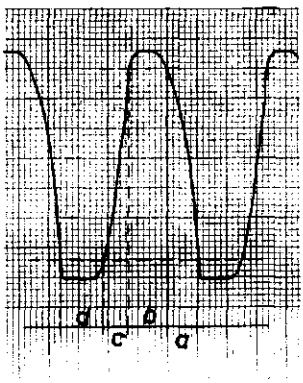


fig. 48

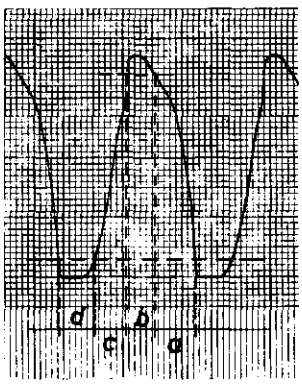


fig. 49

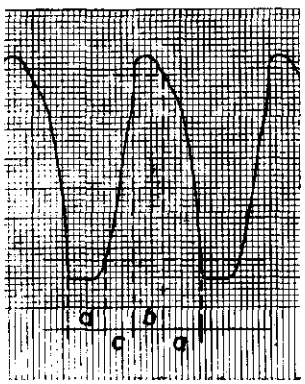


fig. 50