# Advanced Speed Control for the Air Turbine Motor of the NLR High Temperature Seal Test Rig

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## 1 Introduction

The NLR High Temperature Seal Test Rig is employed for the testing of seals for aircraft gas turbines. These seals are intended to prevent unintentional air flows between the primary and secondary air flows in the engine. The rotating part of this facility is driven by an air turbine motor. At the moment, a PID controller is used to keep the motor input pressure at a stable value. This method has a number of drawbacks, but many years of experience in wind tunnel models have proven that it is basically a safe and accurate way to control these types of motors. In order to overcome the disadvantages and to optimize the operation of the Seal Test Rig, a more advanced method for the motor control has been devised.

## 2 Control objectives

The fact that an operator has to adjust the input pressure setpoint, based on the reading of the motor speed from a display, has a number of drawbacks. First, the motor speed is dependent on a number of factors, in particular the load on the shaft and the upstream supply pressure. Second, the experience of the operator is critical in the operation of the facility.

To further automate the operation and to improve the performance of the Seal Test Rig a more advanced speed control algorithm must be developed. It must not rely on controlling the motor input pressure but directly on the motor speed. Moreover, it must be able to increase the number of ‘measurement points’ per day and to keep the motor speed constant between such points. Finally, the amount of the required compressed dry air must be minimized as much as possible.

## 3 System description

The Seal Test Rig is a complex installation, where a number of parameters that are important for the testing of the seals can be adjusted independently. Including the control of the motor speed, a total of seven control loops are implemented, which all interfere with each other. These parameters consist of upstream and downsteam pressures, temperatures, clearances and the radial velocity.

The most important factor that influences the air turbine motor speed is a phenomenon called windage heating. The windage effect is the viscous air drag on rotating components in e.g. gas turbine engines. It both represents direct power loss and adds energy to the air in the form of heat [1]. The equation for windage heating however has an inaccuracy of 25%, but more important is that not all relevant variables can be measured.

## 4 The control algorithm

Model Predictive Control has been selected as the most appropriate method for the control of the air turbine motor. In this case it has a number of advantages above other control methods. First, it has knowledge of the system by using a mathematical process model. Second, it is able to handle unmeasured disturbances such as the windage effect. Finally, constraints can be put on MPC variables. Latter is particularly important for optimal use of the compressed dry air, but also to protect the aluminum motor blades motor against input pressure gradients.

A Kalman filter was developed to further increase the performance in the noisy industrial environment of the facility. A mathematical model was obtained of the air turbine motor and for all relevant parts that contribute to its operation. This nonlinear model could however only be tested qualitatively. Simulations have shown that this virtual model behaves as expected. Linearized versions of the model were subsequently used to develop the MPC controller and the Kalman filter. The controller has not been implemented yet.

## References

[1] J.A. Millward, M.F. Edwards, “Windage Heating of Air Passing Through Labyrinth Seals”, Transactions of the ASME, Vol. 118, April 1996, pp. 414-419.