An Experimental and Computational Investigation of the Rotordynamic Coefficients of a Labyrinth Seal (Continuation)

Paul Cizmas and Adolfo Delgado

Introduction and Background

Experimental results were obtained for a joint project aimed at validating CFD simulations. Air flow velocity data obtained through use of a 5-hole probe did not agree with predictions or alternate measurements. Investigation into the cause of the discrepancy is ongoing, but the suspected cause is expected to be associate with the instrumentation.

The proposed seal and test rig modifications where made and the rig was assembled for testing. Two labyrinth seals were machined to remove all but 6 teeth left in the center of the seal. This was done to reduce the computational complexity and to provide a smoother transition into and out of the active seal section. The stator housing and one of the seals was modified by drilling ports for pressure taps in each tooth cavity, upstream of the teeth, and at the seal exit and milling a slot to hold a block containing the tooth cavity pressure taps. A 5-hole probe was mounted near the start of the teeth facing the oncoming leakage. This configuration was chosen to provide accurate measurement of the velocity and flow direction of the air as it enters the active section of the seal. Before assembling the rig, the 5-hole probe was aligned with the stator by means of a digital inclinometer. The angle of the probe was set at zero degrees relative to the flow path ± 0.01 degree. Data were collected for dynamic characteristics, temperature, pressure distribution along the seal length, and leakage. The measurement of the flow velocity was much smaller than predicted and did not agree with the leakage rate measured with a flow meter.

It initially appeared that the compounded error of the pressure sensors and data acquisition system combination employed was masking the readings. To eliminate this as a cause, a differential pressure sensor was used in place of the gauge sensors to test the pressure difference with more sensitivity. The data acquisition system was bypassed, and the reading taken with a process meter to reduce chance of error. The pressure difference was still much smaller than predictions. The differential pressure sensor was checked for proper function by connecting the pressure ports to a device that can direct a stream of compressed air at various angles. In this airstream the differential pressure sensor registered a pressure difference of a pitot-static tube combination an order of magnitude larger than the measurements taken during the seal tests despite the velocity being much lower than that predicted for the test.

With the sensors confirmed to be working properly, it is suspected that a problem exists with the myriad of nylon tubing used to connect the 5-hole probe to the pressure sensors. The next step is to troubleshoot the probe tubing and installation in order to complete these critical flow measurements.

The computational investigation of the seal started assuming that the stagnation pressure upstream of the seal would be 20 bar. The variation of seal leakage as a function of the pressure ratio, $p_{\text{static exit}}/p_{\text{stagnation inlet}}$ is shown in Table 1. Since the planned inlet stagnation pressure of 20 bar could not be used, the experiments are currently using an inlet stagnation pressure of approx. 14.3 bar. Consequently, a new set of cases are currently being computed for the inlet stagnation pressure of 14.3 bar. The results given in Table 1 show that the leakage mass flow rate calculated is different from the measured value. The calculated leakage mass flow rate decreased with the increase of pressure ratio, as expected. The measured leakage mass flow rate was approximately constant, although the flow was not chocked.

Inlet pressure [bar]	Pressure ratio [-]	Seal leakage [kg/s]	Source
20	0.4	0.1719	Computation
20	0.5	0.1623	Computation
20	0.65	0.1378	Computation
14.49	0.4	0.1231	Computation
14.29	0.2	0.1829	Experiment
14.35	0.3	0.1831	Experiment
14.49	0.4	0.1816	Experiment

Table 1: Seal leakage vs. pressure ratio.

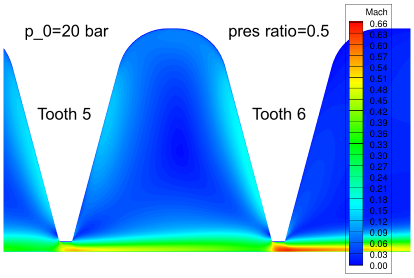

Figure 1: Mach number contours over last two teeth.

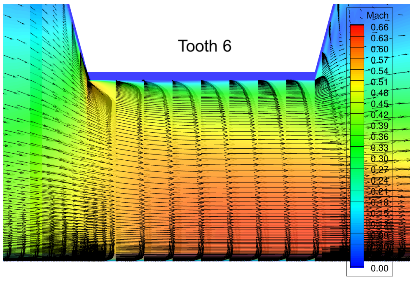

Figure 2: Velocity vectors over last tooth.

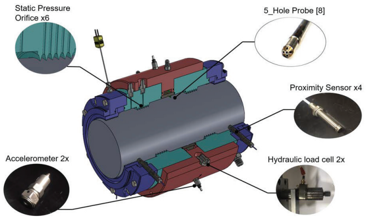

Figure 3: Stator assembly showing critical measurement locations and instrumentation.

Delivered in 2021

1. Updated computer program `SealMesh`, written in Fortran, for generating labyrinth seals meshes.
2. General-purpose CFD solver `UNS3D` version 5.4.3, written in Fortran, for predicting internal and external flows. This is the computer program used for predicting rotordynamic coefficients.
3. Labyrinth seal design, proposed test matrix and measurements, operating conditions of labyrinth seal.

Proposed Work 2021-2022

The goal of this year of the project is finish troubleshooting the 5-hole probe and to complete the experimental and computational investigation that will both measure and predict the rotordynamic coefficients of a six-tooth labyrinth seal. The test matrix with the parameters investigated are shown in Table 2. Once these tests are completed, the test matrix will be repeated after installing a swirl brake. These additional experiments will allow to benchmark CFD predictions for evaluating the effectiveness of swirl brakes and optimizing their geometry. The measurements will include flow velocity, temperature, static and dynamic pressures, acceleration, displacement and input force, as shown in Fig. 3. Subsequently, the measured parameters will be directly compared to CFD simulations. The benchmarked CFD model will then be used to optimize labyrinth seal and swirl brake geometries leveraging additive manufacturing.

Inlet pressure [bar]	Speed [krpm]	Back pressure [%]
14.3	10	20, 30, 40
	15	20, 30, 40
	20	20, 30, 40

Table 2: Test matrix 2021-2022 without and with swirl brake .

Deliverables 2021-2022

1. Operating conditions and experimental measurements of the labyrinth seal.
2. Numerical simulation results, and accuracy assessment for the simulations of the labyrinth seal.
3. Comparisons between experimental and computational results.

Budget 2021-2022

Support for graduate student (20 hours/week)	$26,400
Fringe benefits and insurance	$3,127
Tuition and fees	$17,186
Hardware and instrumentation	$3,287
Total	$50,000