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

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Introduction and Background

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 $\pm$ 0.01 degree.

Experimental results were obtained for a joint project aimed at validating CFD simulations. 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. 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 faulty pneumatic hose connections between the 5-hole probe and pressure transducers.

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.

Numerical simulations were completed for updated flow conditions: an inlet stagnation pressure of 14.5 bar and several pressure ratios, $p_{\text{exit}}/p_{0\ \text{inlet}}$, ranging from 0.2 to 0.4. These updated flow conditions were chosen so that they better match the current available testing range. The CFD flow solver `TRC-UNS3D`, which is used to solve the seal flow and predict the rotordynamic coefficients, has been updated. Two new capabilities are now available in the version 6.1.1 of `TRC-UNS3D`: (i) second rotating wall, and (ii) specified shaft displacement. The rotordynamic coefficients can now be calculated in two manners: (1) by keeping the shaft fixed, that is, not whirling, and assuming quasi-steady flow, and (2) by simulating unsteady flow while whirling or shaking the shaft on arbitrary paths. In the latter case, the grid is being deformed using either a linear interpolation or a radial basis functions algorithm.

Since the planned inlet stagnation pressure of 14.5 bar could not be used, the experiments are currently using an inlet stagnation pressure of approx. 13.1 bar. Consequently, a new set of cases are currently being computed for the inlet stagnation pressure of 13.1 bar.

Delivered in 2022

1. Updated computer program `SealMesh` version 1.2, written in Fortran, for generating labyrinth seals meshes.
2. General-purpose CFD solver `TRC-UNS3D` version 6.1.1, written in Fortran, for predicting internal and external flows. This is the computer program used for predicting rotordynamic coefficients. Version

6.1.1 now allows to calculate the rotordynamic coefficients by assuming either quasi-steady flow or unsteady flow. Updated User Manual for `UNS3D` version 6.1.1.

3. Updated test matrix and measurements, operating conditions of labyrinth seal.

Proposed Work 2022-2023

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 1. 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.

Table 1: Test matrix 2022-2023; inlet stagnation pressure 13.1 bar.

Case no	Pressure Ratio	Rotor RPM	Excitation RPM	Excitation Magnitude / Nominal Clearance
1	.2	10,000	3,000	.375
2			6,000	
3			9,000	
4	.3	10,000	3,000	.375
5			6,000	
6			9,000	
7	.4	10,000	3,000	.375
8			6,000	
9			9,000	

The measurements will include flow velocity, temperature, static and dynamic pressures, acceleration, displacement and input force. 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.

Deliverables 2022-2023

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 2022-2023

Support for graduate student (20 hours/week)	$26,400
Fringe benefits and insurance	$3,127
Tuition and fees	$17,186
Hardware and instrumentation	$2,287
Travel to technical conferences	$1,000
Total	$50,000