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

Paul Cizmas and Adolfo Delgado

Introduction and Background

There is a plethora of recent experimental investigations aimed at measuring the rotordynamic coefficients of a labyrinth seal (Wagner et al., 2009; Ertas et al., 2012; Vannini et al., 2014; Arthur and Childs, 2015). Almost always, however, some information needed for the computational fluid dynamic (CFD) simulation is missing either because it was not measured or because it was not reported. The chance of being able to obtain all the data needed for the CFD simulation decreases as the time interval between the experiment and the computational simulation increases, even if both activities are conducted in the same laboratory.

Significant advances were made recently in the CFD rotordynamic analysis of labyrinth seals using the Reynolds-averaged Navier–Stokes (RANS) equations (Moore, 2003) or Large Eddy Simulations (LES) (Tyacke et al., 2011). Irrespective whether one uses RANS or LES solvers, the CFD computations must be verified and validated. While the verification is done typically by proving the solution is grid independent, the validation must be done against experimental results. Ideally the generation of experimental and computational data for validation should be done simultaneously, to make sure that all required data are measured and available for the numerical simulation.

The goal of this final year of the project is to complete the experimental and computational investigation that will both measure and predict the rotordynamic coefficients of a labyrinth seal. The test matrix with the parameters investigated are shown in Table 1.

Inlet pressure [bar]	Speed [krpm]	Back pressure [%]
20	10	25, 50, 65
	15	25, 50, 65
	20	25, 50, 65

Table 1: Test matrix 2020-2021.

The geometry and operating parameters of the labyrinth seal were chosen as a compromise between the experimental and computational needs. For this reason, it was decided to test a seal with 6 teeth, so that the force is large enough without requiring a very large computational grid, currently between 16 and 37 million nodes.

The seal design and operating conditions were defined through preliminary CFD simulations. The experiments will include controlled-motion tests to obtain force coefficients for multiple inlet pressure ratios and operating speeds ranging from 10 krpm to 20 krpm. The seal inlet and outlet conditions, including flow velocity measurements using a 5-hole probe, temperature and static temperature, will be monitored and compared to the imposed CFD boundary conditions.

Delivered in 2020

1. Computer program `SealMesh`, written in Fortran, for generating labyrinth seals meshes. The code generates meshes for both sequential and parallel runs, shown in Fig. 1.
2. Computer program `SealStart`, written in Fortran, for generating an initial flow solution (shown in Fig. 2) needed for a CFD solver. This code is used prior to the CFD solver to reduce (1) the risk of solution divergence, and (2) the computational time.
3. General-purpose CFD solver `UNS3D` version 5.4.1, written in Fortran, for predicting internal and external flows. This is the computer program used for predicting rotordynamic coefficients. Updated User Manual for `UNS3D` version 5.4.1.
4. Labyrinth seal design, proposed test matrix and measurements, operating conditions of the labyrinth seal.

Proposed Work 2020-2021

The selected seal geometry will be tested in the component-level seal test rig (Childs and Hale, 1994). This facility is capable of testing annular seals up to 5 inches in diameter, at speeds up to 20,000 rpm with

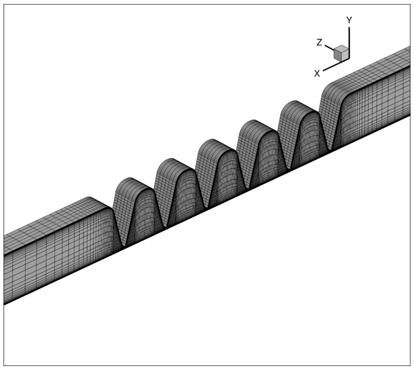

Figure 1: Two-degree sector of labyrinth seal being tested. Computational domain generated with `SealMesh`.

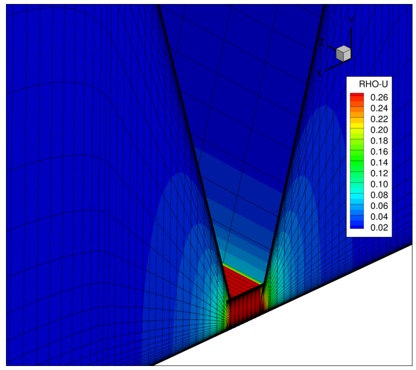

Figure 2: Initial solution generated with `SealStart` for CFD solver. Velocity vectors and axial velocity contour plots at tip.

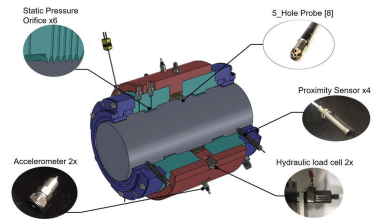

Figure 3: Partial cut-view of stator assembly showing critical measurement locations and instrumentation.

a maximum supply pressure of 70 bar, and multiple pressure ratios by controlling seal discharge pressure. Static and dynamic tests will be conducted to identify the seal force coefficients. 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.

Deliverables 2020-2021

1. Operating conditions and experimental measurements of the labyrinth seal.
2. Updated computational grids, updated UNS3D input files, simulation results, and accuracy assessment for the simulations of the labyrinth seal.
3. Comparisons between experimental and computational results.

Budget 2020-2021

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

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