SIGNIFICANCE AND JUSTIFICATION

Seals leakage in centrifugal compressors and turbines represents a substantial loss in efficiency and power delivery with an increase in specific fuel consumption. Labyrinth seals (LS) are the most common and inexpensive means of reducing secondary leakage, albeit wearing out with operation and thereby penalizing performance and even affecting rotodynamic stability. Improperly designed and operated labyrinth seals can be the source of rotodynamic instabilities.

Pocket damper seals (PDS), adding baffles in (alternating) circumferential cavities of a LS and engineering the inlet and exit tip clearances, have demonstrated enormous benefits in system stability by providing physically large damping coefficients [1]. These seals, when properly designed, can act as damper bearings by offering also large stiffness coefficients. Bulk-flow analyses for pocket damper seals (PDS) are available [2] with predictions showing moderately good correlation with test data. However, the fully-partitioned PDS [3] lacks a proper physical modeling. This seal type, FPDS, has axial baffles covering the whole seal extent and the pockets are separated by thick small clearance regions (not sharp teeth) which can amount to 20% of the whole sealing area. In comparisons [4] with experimental results for a LS and a honeycomb seal, the FPDS showed the largest destabilizing cross-coupled stiffnesses. These coefficients are strong functions of the inlet preswirl and rotor speed. As a result, a LS with a swirl brake could still be a favored choice.

STATUS OF WORK 2012-2014

In 2012, the TRC funded a two-year project to develop a new computational tool for accurate prediction of the force coefficients and leakage of pocket damper seals. Note that commercial FPDSs [4] have thick walls rather than blades with sharp edges as in conventional LSs and early PDSs [2].

Weilian Shan, M.S. graduate student, studied an existing code, PDSEAL©, developed by Li et al. [2] for prediction of leakage and force coefficients in labyrinth seals and pocket damper seals with sharp blades, and constructed an EXCEL graphic user interface (GUI) for ready interface with the original Fortran code. XLPDS©, the GUI for pocket damper seals, is simple to use and obtains predictions for multiple cases varying the gas supply and exit pressures, rotor speed, and whirl excitation frequency. The tool will be soon available in the XLTRC© software suite. Technical report TRC-SEAL-0213 [6] reports the progress and delivers predictions of rotodynamic force coefficients for a test LS and a test FPDS in Ref. [4]. The predicted leakage and dynamic force coefficients correlate well with the test data for the labyrinth seal [4]. Predicted force coefficients for the FPDS are in gross error when compared to the experimental coefficients.

Hence, XLPDS© has severe limitations to predict the dynamic force performance of PDSs with thick walls. The physical model is a one-control volume, turbulent bulk flow model that includes the effects of circumferential flow velocity within a seal pocket and uses Neumann’s leakage equation across the seal blades. The model ignores the flow resistance along the circumferential direction, badly needed for PDS with blunt blades of sizable axial thickness. Needless to state that, it is in this region the seal develops a cross-coupled stiffness as the gas is whirled because of shaft rotation.
In 2013, Weilian Shan developed the physical model equations for FPDS by replacing the empirical leakage formulas with a bulk flow model that includes flow conservation and circumferential and axial momentum transport equations in the flow region under a thick blade and over the spinning rotor [6].

Unfortunately, last December, invoking health reasons, Ms. Shan withdrew from her research. Ms. Shan did leave good documentation and developed a useful GUI for XLPDS© available in the XLTRC² software suite. In January 2014, Ms. Maryna Ienina, Ph.D. student with experience in floating ring seals at KIST (Korea), began working in the research program. During the spring semester, Maryna read literature relevant to PDS, and learned gas dynamics and mechanical vibrations, i.e., the knowledge necessary to tackle the challenge ahead.

PROPOSED WORK 2014-2015 (YEAR III)

To develop computational models for prediction of leakage, drag power loss and force coefficients of fully partitioned PDSs and combined labyrinth-brush seals. In 2014-15, the tasks list includes:

- Solve the set of bulk-flow equation for FPDS to predict leakage and rotordynamic force coefficients.
- Perform further calibration of the physical model predictions against test leakage and force coefficients, in Ref. [4].
- Begin extensions of the bulk-flow model to include two-component mixtures (liquid in a gas) as in [7].
- The flow model will integrate real gas properties, including steam and supercritical CO₂. The analysis will be limited to a centered rotor thus giving force coefficients of the form \( K_{YY}=K_{XX} \) and \( K_{XY}=-K_{YX} \).

The research is important to advance accurate predictive tools to design, troubleshoot and validate the operation of pocket damper seals applied into high performance compressors and steam turbines. The deliverable will include a new GUI for the new computational program with examples of validation.

Note that current graduate students lack skills in scientific computing, having little mastery of linear algebra and differential equations. The learning curve is steep, however the future rewards and professional recognition merit the effort.

**BUDGET FROM TRC FOR 2014-2015**

<table>
<thead>
<tr>
<th>Description</th>
<th>YEAR III</th>
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<tbody>
<tr>
<td>Support for graduate student (20 h/week) x $ 2,200 x 12 months</td>
<td>$ 26,400</td>
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<tr>
<td>Fringe benefits (2.4%) and medical insurance ($118/month)</td>
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<tr>
<td>Tuition &amp; fees three semesters ($363 credit hour x 24 ch/year)</td>
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<tr>
<td>Other (Mathcad® and portable data storage)</td>
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<tr>
<td><strong>Total Cost:</strong></td>
<td><strong>$ 37,382</strong></td>
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**REFERENCES**