TRC CONTINUATION PROPOSAL 2022- 2023

Liquid and Gas Impeller Rotordynamic Coefficients
TEES Project Number: 00059

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INTRODUCTION AND JUSTIFICATION

API 617 level-II analysis requires detailed computed rotordynamic coefficients for each component of the flow path if level-I criteria fails. Thus, calculating more accurate rotordynamic dynamic forces and coefficients are crucial to satisfy the API standards. Proposed work includes use of the widely used, commercial CFD code CFX to model Alford force for axial turbomachines, design and optimize swirl brakes for damper seals, and model multiphase seal rotordynamics during laminar-to-turbulent transition. Development of TRC Artificial Neural Network, "Pump Seal and Impeller Leakage Path (ANN-PSILP)" software for centrifugal pump rotordynamics has been completed. Current version of the software has been delivered and developed Artificial Neural Network (ANN) achieved over 95% accuracy to predict rotordynamic coefficients. An in-house pump impeller test rig is under development that would be used to validate our whirling impeller CFD models for dynamic coefficients. A fast, simplified theoretical whirling impeller model, along with an impeller leakage path bulk-flow model, will be developed with a GUI. Deliverables will include CFD-based modified Alford force formulation, commercial code modeling tutorials for impellers, seals and swirl-brakes, an impeller test rig and stand-alone impeller and seal software with user friendly GUI.

DELIVERABLES

(a) CFD-based modified Alford force formulation for axial compressors, turbines, and pumps.
(b) Artificial Neural Network ANN-PSILP software for pump wear-ring seal and front shroud stiffness, damping, added mass coefficients and leakage rate.
(c) ANSYS CFX CFD tutorials for quasi-steady and transient analysis of whirling impellers, non-axisymmetric seals, swirl-brakes, and axial turbomachines.
(d) Analysis results and CFD tutorials for two phase (liquid-gas mixture) labyrinth seal rotordynamic coefficients in laminar-to-turbulent transition flow.
(e) Pump impeller test rig to validate CFD predicted whirling impeller rotordynamic coefficients.
(f) Design and analysis of centrifugal impeller, seal, and shroud for supercritical Carbon Dioxide (sCO_2) compressors.
(g) Stand-alone MATLAB code for impellers (closed/open), diffusers and volutes with EXCEL GUI. The code utilizes vorticity based solver.

COSTS ($50k): 1 PhD student, 12 mo., $2,200/mo., $2500 insurance & fringe, $13,000 Tuition and Fees, test rig and software subscription $8100

STATUS OF CURRENT WORK

- Developed **Artificial Neural Network (ANN)** code for Centrifugal pump face seal front shroud to predict leakage, direct and cross-coupled **stiffness, damping and added mass** coefficients.
- Conducted system-level analysis of **centrifugal compressor** stage in CFX to extract rotordynamic coefficients of **the eye-labyrinth seal and front shroud**. This model predicts stability of the whole system (accumulative contributions of seal, front shroud, diffuser and volute) instead of isolated seal model. It removes assumptions in boundary conditions and capture natural swirl formation.
- Designed and analyzed **five novel swirl-brakes** for centrifugal compressor eye-labyrinth seal. These swirl-brakes stabilize both the eye-labyrinth seal and front shroud.
- Provided **tutorials** for **steady state** and **transient CFD** modeling of centrifugal pump/compressor impellers, seals and swirl brakes rotordynamics, centrifugal and axial compressor performance.

- Developed CFD model to predict rotordynamic coefficients of multiphase labyrinth seal at laminar-to-turbulent transitional flow. CFX tutorial for this model is available in TRC SharePoint.

PROPOSED WORK

Tip Excitation Force in Unshrouded Axial Turbines, Compressors and Pumps (CFX)
- The transient multi-frequency approach CFD model will be used to predict the tip excitation force.
- A modified formulation for the Alford force will be developed utilizing parametric study and regression curve fit.
- CFX tutorials would be provided for tip excitation force prediction

Impeller and Seal – Swirl-brakes, Transitional Two-phase Flow (CFX)
- Swirl-brake design, modeling and optimization for damper seals. Tutorials will be provided.
- Two-phase flow seal rotordynamic coefficients during laminar-to-turbulent transition.

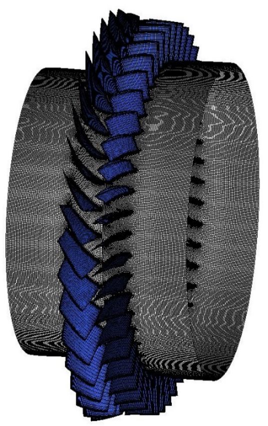
Artificial Neural Network Software for Pump Seal and Impeller Leakage path (ANN-PSILP)
- Pump wear-ring seal and front shroud geometry would be used to develop the new software.
- Artificial Neural Network (ANN) trained by 1000's of CFD results to predict dynamic coefficients.

Impeller Test Rig
- In-house validation of developed CFD models for flow vs head curve (characteristics curve).
- The test rig would be upgraded to measure stiffness, damping and added mass coefficients.

Rotordynamic Forces in Supercritical Carbon Dioxide (sCO_2) Impeller and Seals (CFX)
- Impeller, shroud and seals would be designed in Cfturbo. Cfturbo design tutorial would be provided.
- Prediction of Tip clearance force in open impeller, seal and shroud forces for closed impellers.

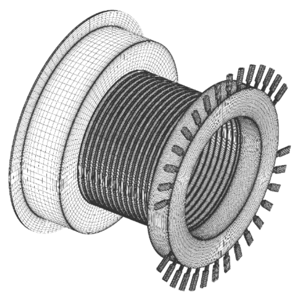
Impeller Code (MATLAB)
- Develop a theoretical MATLAB meshless vorticity-based code for impellers including the effects of diffusers, volutes and tip leakage for open impellers based on the available theoretical models.

DISCUSSION



Tip Excitation Force in Unshrouded Axial Machines

Tip excitation forces induce forward whirl (destabilizing) in axial turbines while it induces backward whirl (stabilizing) in axial compressors. Alford force model for tip excitation force neglects direct stiffness and direct damping, and it does not match well with experimental results in many turbomachines. Multifrequency whirling orbit CFD model would be utilized to model tip excitation force in axial turbines, compressors, and turbines. Proper scaling and regression curve fit will be done to have a more general modified formulation for a variety of impeller designs.



Two-phase Seal During Laminar-to-Turbulent Transition

The two-phase seal model has been developed and verified against experiment from literature. The test seal operates between 5 to 10 krpm and Reynolds number was in the transition flow range. The $\gamma - Re_\theta$ transitional model has been utilized to capture laminar-to-turbulent flow transition. Verifications for more gas volume fractions would be provided. The CFD model applied to both liquid-rich and gas-rich flows.

Novel Swirl-brakes- Design and Optimization (CFX)

Novel types of swirl brakes for damper seals, such as honeycomb seal with Swirl Reversing Ring (SRR), would be designed and modeled in CFX. The leakage and rotordynamic performance of honeycomb seals with the SRR would be predicted by employing the approach of Computational Fluid Dynamics (CFD) and multifrequency whirling model theory. Effect of its geometric parameters on the seal rotordynamics would be investigated to achieve design optimization.