TRC CONTINUATION PROPOSAL 2020- 2021
Liquid and Gas Impeller Rotordynamic Coefficients
Project Number: 258124-00059

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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 calculate flow field and rotordynamics of swirl brakes in presence of upstream and downstream components. Development of TRC Artificial Neural Network, "Pump Seal and Impeller Leakage Path (ANN-PSILP)" software for centrifugal pump rotordynamics has been started last year. Developed Artificial Neural Network (ANN) achieved over 95% accuracy to predict centrifugal pump face seal-front shroud stiffness, damping and mass 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 to also determine pump impeller dynamic coefficients. Deliverables will include artificial neural network ANN-PSILP software, 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) Artificial neural network ANN-PSILP software for pump seal and impeller leakage path stiffness, damping mass coefficients and leakage rate.
(b) ANSYS CFX CFD tutorials for quasi-steady and transient analysis of whirling impellers and non-axisymmetric seals in the presence of swirl-brakes.
(c) Pump impeller test rig to further validate CFD models for whirling impeller stiffness, damping and mass coefficients.
(d) Stand-alone MATLAB code for impellers (closed/open), diffusers and volutes with EXCEL GUI that appends to $XLTRC^2$ and utilizes general impedance curves for rotor stability and imbalance response predictions. The code utilizes vorticity based solver.
(e) Stand-alone FORTRAN CFD code evaluating the rotordynamic coefficients of a variety of seals.

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

STATUS OF 2019-2020 WORK

- Developed **Artificial Neural Network (ANN)** code for Centrifugal pump face seal front shroud to predict leakage, direct and cross-coupled **stiffness, damping and mass** coefficients. The ANN is trained by CFD results, and it achieved **over 95% fit**.
- Studied **centrifugal compressor** stage in CFX to extract rotordynamic coefficients for **labyrinth teeth front shroud**.
- Provided related **tutorials** for **steady state** and **transient CFD** modeling of centrifugal pump impellers and seals, centrifugal and axial compressor performance, compressor eye seal rotordynamics, compressor labyrinth teeth front shroud rotordynamics. Tutorials encompass design, grid generation, CFX-Pre setup, input files and video playback.
- Conducted Comparative study between rotordynamics of pump open impeller stage, closed impeller stage and Impeller Leakage Path Model (ILPM). **API level 2** analysis should include modeling of full pump stage.

- Delivered an efficient **transient multi-frequency CFD model** to find pump **open impeller** dynamic coefficients at **4-quadrant transient** operations.
- Studied pump open impeller **specific speed study** for all modes of 4-quadrant transient regimes.

PROPOSED WORK

Artificial Neural Network Software for Pump Seal and Impeller Leakage Path (ANN-PSILP)

- Artificial Neural Network (ANN) trained by 1000's of CFD results.
- Face seal impeller leakage path K, κ, M, m, C, c from input geometry and operating conditions.
- Capable of expanding training sets with additional data provided by the TRC members.
- MATLAB code with excel GUI.

Impeller and Seal – Swirl-brakes (CFX)

- Swirl-brake modeling for seals in presence of upstream and downstream components, such as impeller, leakage path, diffuser and volute.
- Structured grid generation and CFX CFD setup tutorials would be provided.

Impeller Test rig

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

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. For closed impellers a bulk-flow model will be developed. The code will provide impeller rotordynamic coefficients to $XLTRC^2$.

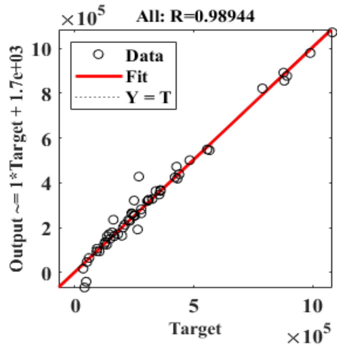
TRC CFD Solver Development (FORTRAN)

- Excel GUI driven quasi-steady model to obtain dynamic coefficients for seals with high quality structured mesh. Integrate hybrid bulk-flow model to the code as a quick solver option.

DISCUSSION

ANN Software for Pump Seal and Impeller Leakage path

ANN code has been developed for centrifugal pump face seal-front shroud utilizing Bayesian Regularization algorithm. The code predicted direct and cross-coupled stiffness, damping and mass coefficients with over 95% accuracy. The code would be enhanced by adding more parameters for better accuracy in any generic pump leakage path. Finally the software would be provided with an EXCEL GUI.

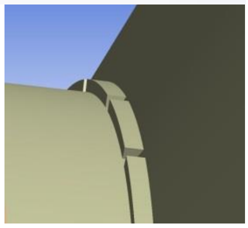


Pump Impeller Test Rig

The test rig is under development. Most of the components have been purchased to build the test rig measuring pump performance curve. Whirling motion would be imposed at the casing through shakers while the rotor would be instrumented. For parametric study, new features would be 3D printed and tested in the test rig.

Swirl-brakes (CFX)

Newly developed multi-frequency CFD approach would be utilized to calculate direct and cross-coupled stiffness, damping and mass coefficients for annular and labyrinth seals in the presence of swirl-brakes. The CFD model would contain all upstream and downstream flow components.



Theoretical Impeller Rotordynamic Model

Quick-estimate solutions for impellers can be found via 2D and meshless potential flow theory (vortex methods) of impeller primary flow passage. For closed impellers a bulk-flow model will be used to find the shroud forces.