TRC CONTINUATION PROPOSAL 2019- 2020

CFD-Based Impeller and Seal Rotordynamic Force Coefficients

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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 impedance curve, stiffness, damping and mass for entire flow paths of pumps/compressors including impeller, seal, diffuser and volute in presence of labyrinth seal swirl brakes and cavitation. TRC Machine Learning, "Teeth on Stator Seal "and "Impeller Leakage Path (ML-TSSILP)" software will predict stiffness, damping and mass, based on training sets of 1000's of CFD simulations. A small in-house impeller test rig will be built to further 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 impeller dynamic coefficients. Deliverables will include parameter effect studies, commercial code modeling tutorials for impellers and seals, artificial neural network ML-TSSILP software, an impeller test rig and stand-alone impeller and seal software with user friendly GUI.

DELIVERABLES

(a) ANSYS CFX CFD tutorials for quasi-steady and transient analysis of whirling impellers and non-axisymmetric seals in the presence of cavitation (pump) and swirl-brakes (compressors/turbines).
(b) Artificial neural network ML-TSSILP software for teeth on stator labyrinth seal and impeller leakage path impedance curve, stiffness, damping and mass.
(c) Impeller test rig to further validate whirling impeller stiffness, damping and mass predictions.
(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 database is a mixture of Bulk-flow, CFD-based and theoretical models.
(e) Stand-alone FORTRAN CFD code evaluating the rotordynamic coefficients of a variety of seals.

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

STATUS OF CURRENT WORK

- Studied the translational and tilting motion effects on dynamic coefficients of **shrouded impellers**.
- Developed a general, **transfer function curve-fit** approach to provide an accurate description of non-quadratic impedance curves for use in stability and response simulations.
- Developed systematic approach to include **non-axisymmetric components** such as **volutes** and **diffusers** in the impeller model. Models include extended upstream and downstream components.
- Dynamic coefficients, leakage, and roughness analysis for **hole-pattern and grooved seals**.
- Provided related **tutorials** for **steady state** and **transient CFD** modelling of impellers and seals. Tutorials for **meshing** of turbomachinery are also provided.
- Developed standalone laminar and turbulent CFD solver for **plain annular seals**. The code has gained 100x speed-up through linear and non-linear **multigrid solver** and **MPI parallelization**.
- Delivered an efficient **transient multi-frequency CFD model** to find **unshrouded** and shrouded impeller impedance and dynamic coefficients at **four-quadrant** operation namely pump, turbine, brake and turbining.
- Delivered open impeller **specific speed study** for all modes of four-quadrant/**transient regimes** enabling prediction of dynamic coefficients for any open impeller based on specific speed.

PROPOSED WORK

Impeller and Seal – Swirl-brakes & Cavitation (CFX)

- CFD modeling tutorials for quasi-steady and transient analysis of impellers and seals.
- Swirl-brake modeling for seals including effects of impeller, leakage path, diffuser and volute.
- Destabilizing forces and dynamic coefficients of whirling impellers under cavitation.

ML-TSSILP Software for teeth on stator seal and impeller leakage path

- MATLAB code with excel GUI. Artificial Neural Network (ANN) trained by 1000's of CFD results.
- Teeth on stator seal & impeller leakage path K, κ, M, m, C, c from input geometry and operating conditions.

Impeller Test rig

- In-house validation of developed CFD models for stiffness, damping and mass.

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 $XLTRC^2$.

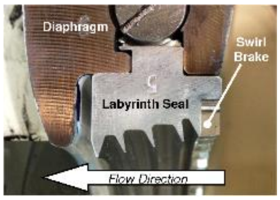
TRC CFD Solver Development (FORTRAN)

- Excel GUI driven quasi-steady, hybrid bulk-flow model for seal dynamic coefficients.

DISCUSSION

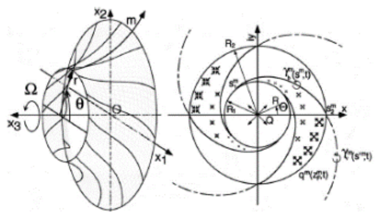
Swirl-brakes & Cavitation (CFX)

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 model would include upstream and downstream flow paths, full circle model of the geometry and appropriate real gas model. Rayleigh-Plesset model and Volume of Fluid (VOF) multiphase model would be utilized for dynamic coefficients calculation in presence of cavitation.



ML-TSSILP Software

Parametric study would be done utilizing CFD to train ML-TSSILP ANN. Impeller leakage path parameters are inlet pressure, inlet pre-swirl, flow rate, suction diameter, outlet diameter, wear ring clearance, wear ring alignment and other important geometric and operating parameters. Some teeth on stator seal parameters are teeth numbers, inlet flow rate and pre-swirl, inlet pressure, teeth numbers, teeth thickness, teeth height, surface roughness, teeth spacing.



Theoretical Impeller Rotordynamic Model

Quick-estimate solutions for impellers can be found via 2D and meshless potential flow theory (vortex methods) to impeller primary flow passage. For closed impellers a bulk-flow model will be used to find the shroud forces. The effects of diffuser vanes, volutes and rotating stall will be included from the earlier theoretical works in this area.

Impeller Test Rig

The CAD model for a commercial centrifugal pump has been achieved from OEM. Whirling motion would be imposed through piezoelectric. Instrumentation through load cells, pressure taps and flow meters. For parametric study, new features would be 3D printed and tested in the test rig.