Effects of Structural Forces on the Dynamic Performance of High Speed Rotating Impellers.

Gowrava Shenoy B, Manipal Institute of Technology
Dr. B S Shenoy, Manipal Institute of Technology
Dr. Raj C Thiagarajan, ATOA Scientific Technologies
ATOA Scientific Technologies (ATOA)

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- Bridge Atom to Application to Proliferate Simulation (Multiphysics, Multiscale & multimaterial) for cost effective Innovation.

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- ATOAST Global with HQ’s in Bangalore

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Introduction

• Rotor dynamics- Applied Mechanics-Study of Behavior and Diagnosis of Rotating Structures.

• Includes Rotating Structures - Jet engines, Gas Turbines, Pumps- Computer Storage Disk, Micro Turbines.

• Rotating-Rotor, Supporting Stationary-Stator.

• Campbell Diagram-Plot of Whirl Freq. vs Spin Speed.
ROTOR DYNAMICS LOADS

• Traditional Rotor dynamics - Linear Structural Loads - Dominant.
  For safe and efficient performance
• Nonlinear Structural Loads
• Thermal Loads
• Fluidic Load
Application- Micro and High Performance Turbines

• Objective- “To Evaluate Dynamic And Vibration Performance Of High Speed Rotors Efficiently Considering Coriolis Forces With Centrifugal Force”.
Multiphysics Rotor Dynamics

- Beam and Shell elements used in Most common Traditional Rotor Dynamics softwares.
- For Complex Geometry - 3D Rotor Dynamics- For improved accuracy. Eg. Impeller
- 3D rotor dynamics
  - The stress stiffening and softening effects
  - Coupling effects of shaft and rotor
  - Actual and Accurate geometry based modelling can be leveraged.
- 3D CAD geometry based Multi Body Rotor Dynamics - for accurate performance prediction.
Governing Equations

- Fundamental Physical Law governing Vibration - Newton’s Second Law.
- Linking The Inertial, Damping, Elastic And External Forces, Along With Mass, Damping And Stiffness Properties, As Given Below

\[ m\ddot{x} + c\dot{x} + kx = f(t) \]

\[ [M][\dddot{x}][t] + [C][\dot{x}][t] + [K][x][t] = [R] \]

Where,
- \([K]\), Global stiffness matrix
- \([x]\), Displacement vector of all the nodes
- \([C]\), Global Damping matrix
- \([\dot{x}]\), Velocity vector
- \([\dddot{x}]\), Acceleration vector
- \([R]\), Global force or load vector, where, \(R = f(t)\)
Comsol Implementation

• To calculate Centrifugal Force ($F_{\text{cent}}$) and Coriolis Forces ($F_{\text{cor}}$) following eqn

\[
F_{\text{cent}} = -\rho \Omega^2 e \times e \times (r - r_0) \\
F_{\text{cor}} = -2\rho \Omega e \times v
\]

Where

• ‘\(\Omega\)’ fixed angular velocity for a system rotating about a fixed unit-length axis ‘\(e\)',

• ‘\(r\)’ and ‘\(v\)’ are the position and velocity of a material element, respectively,

• ‘\(\rho\)’ is its density and ‘\(r_0\)’ is any point on the axis of rotation. The model rotational axis is ‘\(z\)' for this simulation.
Design of Experiment

- Case a: Single disk rotor,
- Case b: Micro single disk rotor,
- Case c: Double disk rotor,
- Case d: Counter Rotating Rotor

- Assumption-Rigid Bearing and Flexible Shaft/Rotor.

- The vibration characteristics for a rotational speed about 15000 RPM. (75000RPM-MicroTurbine).
Design of Experiment

• Determine the natural frequency and mode shapes for critical speeds. Effect of Coriolis force, Scale Effect investigated.

• Total of 8 DOE runs considered for vibration performance evaluation and comparison.

• Using Campbell diagram-Vibration Performance investigated as function of rotating speed.

• These cases were selected to finalize the concept for a new turbine.
Result and Discussion

Mode Shapes of 4 Cases
Campbell Diagram of single disk rotor

- Change in Behavior - High Speed with effect of Coriolis Forces

a) without effect of Coriolis forces

b) with the effect of Coriolis forces.
Campbell Diagram of micro single disk rotor

a) without effect of Coriolis forces

- Natural frequency almost constant - lower rotational speed without the effect of Coriolis forces.
- With effect of Coriolis forces - significant changes in pattern - increased rotational speed.

b) with the effect of Coriolis forces.
Campbell Diagram of Counter Rotating disk rotor

- Dual frequency behavior observed.
- Coriolis effects observed at high speed.
Campbell Diagram of Double disk rotor

- The natural frequency increases with rotation speed.
- The Coriolis force effect at high rotational speed.

a) without effect of Coriolis forces
b) with the effect of Coriolis forces.
Conclusions

• The overall vibration characteristics as a function of structural forces were investigated and reported.
• The single disk rotor was shown to increase frequency with rotation speed.
• The Coriolis forces were shown to lower the frequency at higher rotational speeds.
• The counter rotating disk was shown a dual frequency vs rotation speed behaviour.

Scope for Future Work

• The effect of fluidic (aero and hydro) and thermal forces along with structural forces will be investigated in the future work.
Thank You

Questions??