Dynamics of Rotors on Hydrodynamic Bearings

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Engineering rotating machinery on hydrodynamic bearings is a challenge due to the risk of rotor instability caused by the rotor-bearing interaction. Coupled analysis of this problem enables the prediction of the critical performance criteria when developing new rotor bearing systems.

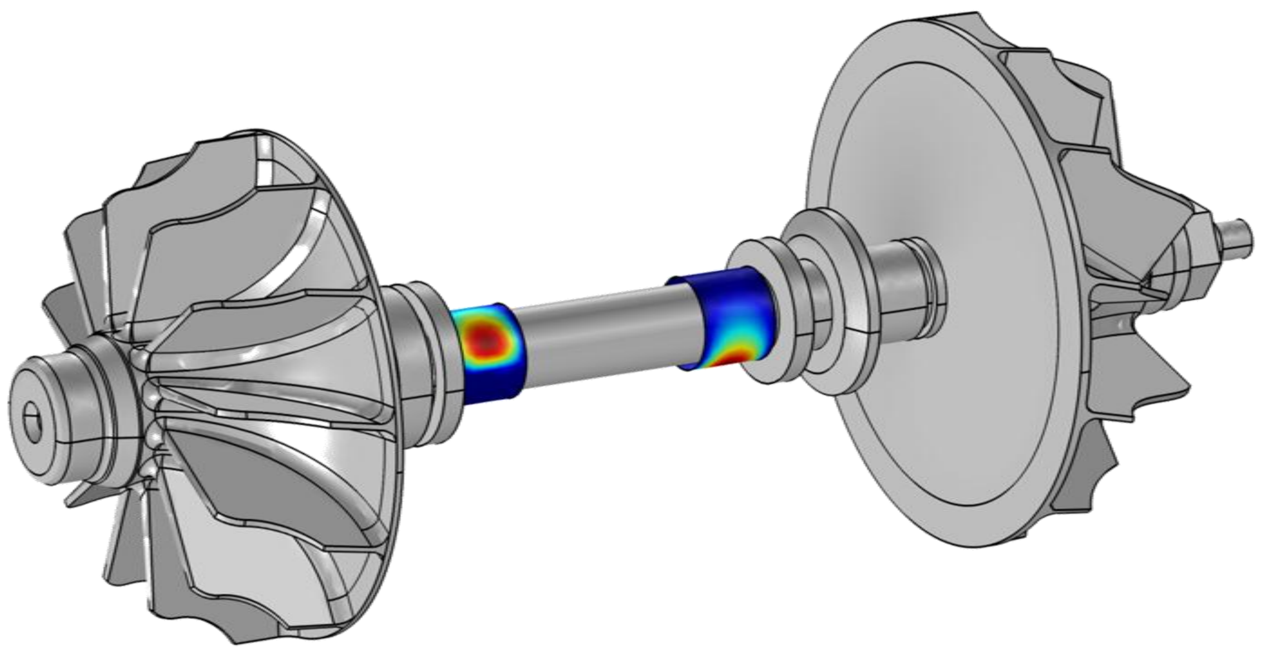

Figure 3. An automotive turbocharger rotor on hydrodynamic bearings

The fluid domain of the bearing is analyzed using the thin film Reynolds equation over the bearing surface:

$$\frac{\partial}{\partial t}(\rho h)+\frac{\partial}{\partial x}(\frac{\rho h}{2}U)=\frac{\partial}{\partial x}(\frac{\rho h^3}{12\mu}\frac{\partial P}{\partial x})+\frac{\partial}{\partial z}(\frac{\rho h^3}{12\mu}\frac{\partial P}{\partial z})$$

This equation describes the creation of a pressurized fluid film which carries the rotor load.

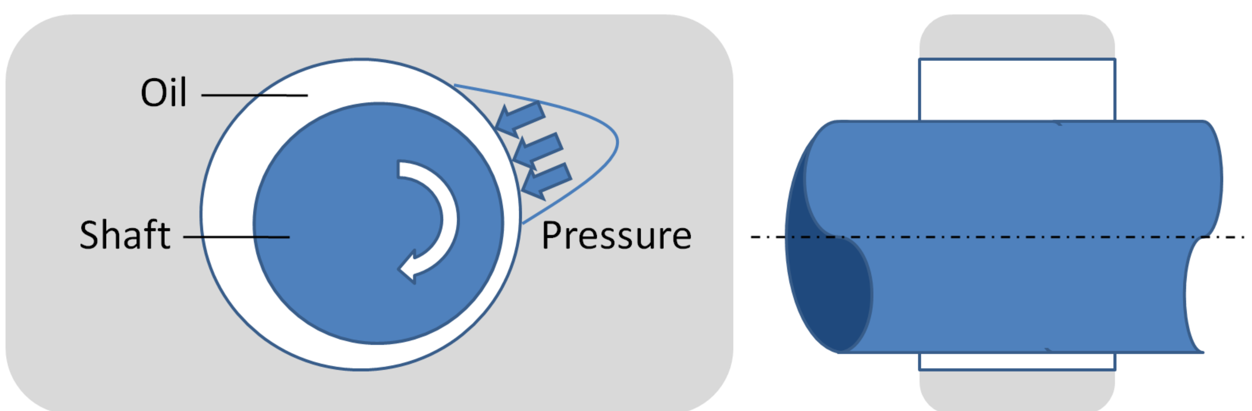

Figure 1. Schematic representation of a hydrodynamic bearing

The thin film Reynolds model predicts the pressure distribution as a function of shaft speed and location. Extensions to the fluid model are made to include cavitation and shear flow heating. The resulting bearing stiffness and damping behavior are highly non-linear and contain cross coupling terms.

The rotor can be reduced from a full FEM model to a simple beam element model. Gyroscopic terms are added for each of the beam and disk elements. The equations of motion for the coupled rotor bearing system become:

$$\mathbf{M}\ddot{\mathbf{q}}+\mathbf{C}\dot{\mathbf{q}}+\Omega\mathbf{G}\dot{\mathbf{q}}+\mathbf{K}\mathbf{q}=\mathbf{F}$$

$$with\ \mathbf{q}=[u_i\, v_i\, \theta_i\, \psi_i]^T$$

Where the external forces **F** originate from:

- Rotating unbalance on the rotor
- Fluid forces developed in the bearing

Figure 5. First bending mode from FEM model.

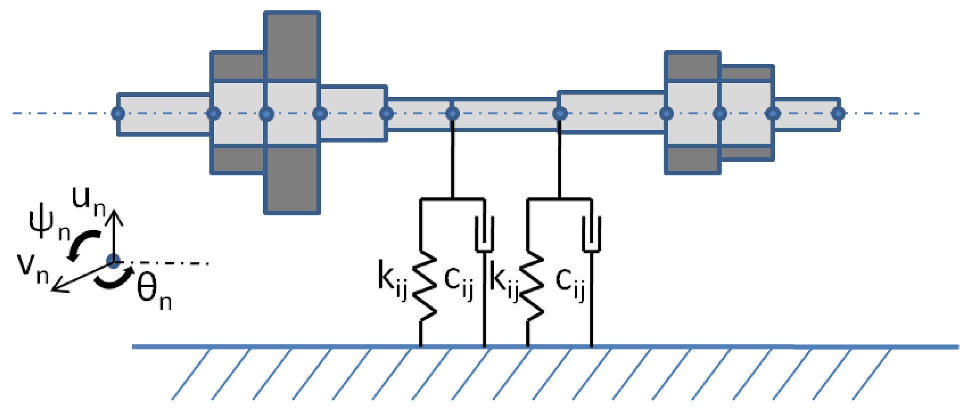

Figure 4. Equivalent model using beam and disk elements.

The resulting model evaluates the most important rotordynamic criteria:

•Rotor stability under run-up conditions, especially the non-linear whirling behavior

•Response to unbalance

•Friction losses in the bearings

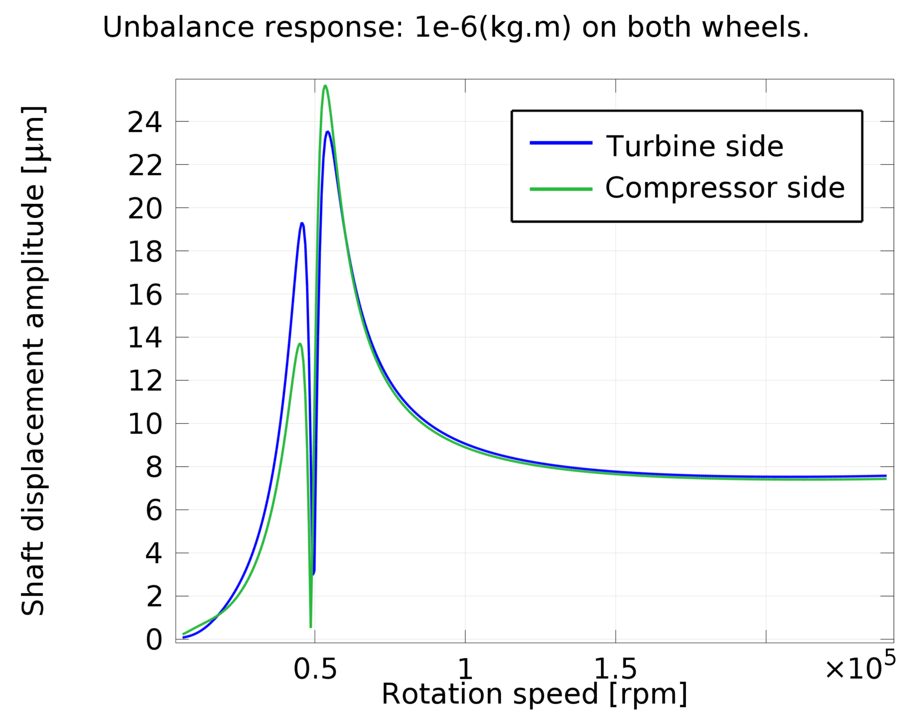

Figure 6. Unbalance response revealing two critical speeds.

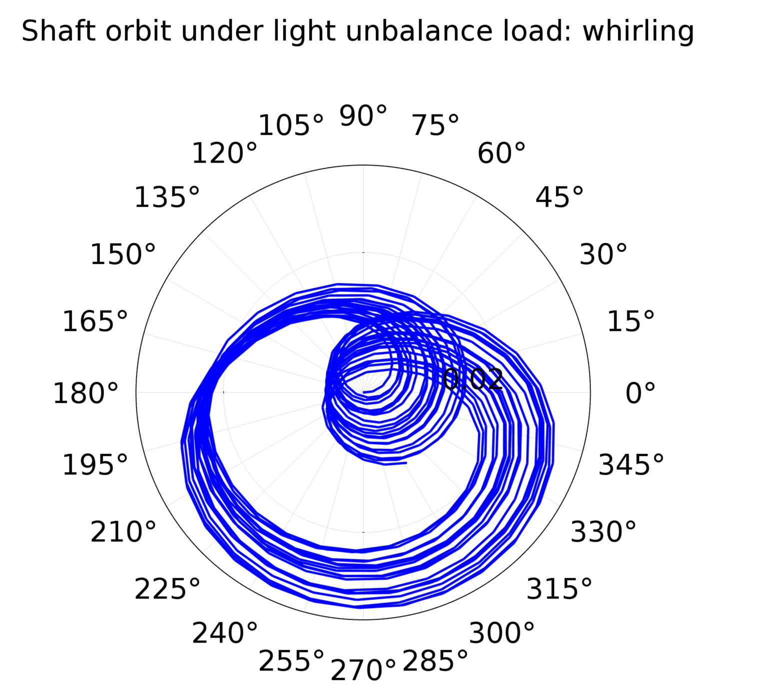

Figure 7. Shaft whirl caused by rotor-bearing interaction.

References:

1. Ishida, Y. Yamamoto, T., Linear and Nonlinear Rotordynamics