Determining Dynamic Stiffness of a Pressurized Bearing Using 3D CFD Code with Experimental Verification
Problem Statement

- Existing Methods of Pressurized Bearing Dynamic Stiffness Prediction Not Generally Applicable for All Geometries

- 1-D, 2-D Bulk Flow Methods Require Analytical/Geometric Approximations

A Generalized 3D Approach Applicable to All Geometries and Operating Conditions is Highly Desirable
CFX-TASCflow

• General 3-D Navier-Stokes Fluid Flow Solver Developed By AEA Technology Engineering Software

• Applicable to Laminar/Turbulent, Compressible/Incompressible, Steady/Transient Flow

• Flexible Fluid Properties (Constant, Variable)

• Uses Multi-block, Locally Structured Grids with Arbitrary Block Connectivity

• Unique “Moving Grid” Feature Allows Motion of Walls in Computational Model. Modeling of Positive Displacement Pumps, Hydrostatic Bearings, and Seals Now Possible
“Moving Grid” Approach

- User Provides Mathematical Model of Time-Dependent Position of Each Node On Moving Boundary Via User-FORTRAN Subroutine

- User Defines Nodes in Model Which Will Not Move (Frozen Nodes)

- All Other Nodes Will Move Based On A Laplacian Diffusion Solution

- The Entire Grid is Smoothly Adjusted In A Shape-Preserving Manner

- A Transient Solution is Created Based on The Time-Dependant Position of the Moving Boundary
Moving Grid Example:

“Piston” Grid
Pressurized Bearing Model

- Four Pocket Fixed-Ring Orifice-Compensated Bearing
- Half Bearing Modeled (No Mis-alignment Assumed)
- Model Size: 177K Nodes
- Fluid: ISO 32 Oil at T=89 deg F
- Rotational Speed: 8000 RPM
Bearing CFD Model

- Multi-Block Structured Grid
- Generalized Grid Interface (GGI) Allows Arbitrary Block Connections, Reduces Overall Node Count

Boundary Conditions
- Symmetry Plane
- Rotor (Spinning Wall)
- Outlet (Ps=14.7 psia)
Bearing CFD Model - “Moving Grid” Feature

- User Specifies Two Nodal Regions:
  - “Moved” Nodes - Nodes which follow a user-prescribed motion as a function of time (e.g. elliptical orbit)
  - “Frozen” Nodes - Nodes which are fixed

“Frozen Nodes” - Feed Tube, Recess

“Moved” Nodes - Rotor Surface

All Other Nodes (Land Region, Region Between Rotor and Recess) Will Move To Accommodate Motion Of The Rotor
“Moving Grid” Boundary Conditions

• Four Perturbation Speeds Analyzed: 1500, 3000, 4500, 6000 RPM

• Circular Orbit of Journal Center Specified:

\[ \begin{align*}
X_{\text{NODE}} &= \text{X(INODE, JNODE, KNODE)} + \text{RO} \times (\cos(\Omega \times \text{STIME}) - \\
&\quad \cos(\Omega \times (\text{STIME}-\text{DTIME}))) + \text{OFF} \\
Y_{\text{NODE}} &= \text{Y(INODE, JNODE, KNODE)} + \text{RO} \times (\sin(\Omega \times \text{STIME}) - \\
&\quad \sin(\Omega \times (\text{STIME}-\text{DTIME})))
\end{align*} \]

\( X_{\text{NODE}}, Y_{\text{NODE}} \): New Position of Nodes on Journal Surface [in]
\( \text{RO} \): Journal Eccentricity [in]
\( \Omega \): Perturbation Circular Frequency [sec]
\( \text{STIME} \): Current Solution Time [sec]
\( \text{DTIME} \): Time Step Size [sec]
\( \text{OFF} \): Journal Offset At Time=0
Pressurized Bearing CFD Results

Bearing Static Pressure as a Function of Time
Pressurized Bearing CFD Results

Bearing Static Pressure as a Function of Time
Pressurized Bearing CFD Results

Time-Dependant Journal Forces Used to Calculate Direct and Quadrature Dynamic Stiffness

X-DIRECTION
N perturb=3000 rpm

Y-DIRECTION
N perturb=3000 rpm
Calculation of Bearing Dynamic Stiffness from CFD Solution

The diagram illustrates the relationship between force and displacement in a dynamic stiffness calculation. The equation for dynamic stiffness is shown as:

\[ \text{Dynamic stiffness} = \frac{\text{Force}}{\text{Displacement}} \]
Bearing
$K = 370 \text{ Lbf/mil} = 6.5 \times 10^7 \text{ N/m}$

**Direct Dynamic Stiffness**

EXPAND
Direct Dynamic Stiffness

- Experimental stiffness
- Points calculated from cfd analysis
- Calculated values corrected for modal mass effects

N/m

- 8000
- 8K PostStruct
**Quadrature Dynamic Stiffness**

\[ D = 0.53 \text{ Lbf s/mil} = 9.28 \times 10^4 \text{ Ns/m} \]

**Graph**

- **Axes:**
  - **Perturbation Speed (RPM)**
  - **Quad Stiffness (Lbf/mil)**

- **Legend:**
  - 8000
  - 8K PostStruct

**Note:**
- EXPAND

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**Explanation:**

The graph illustrates the relationship between perturbation speed (in RPM) and quadrature dynamic stiffness (in Lbf/mil). The data points are color-coded for distinction between different conditions or datasets. The notable equation provided highlights a conversion factor from Lbf s/mil to Ns/m, crucial for understanding the dynamic behavior under varying perturbation speeds.
Quadrature Dynamic Stiffness

Points calculated from cfd analysis
Summary

• A New Method of Simulating Pressurized Bearing Operation using Computational Fluid Dynamics was Presented

• “Moving Boundary” Feature Allows Time-Accurate Modeling of Journal Motion Within Bearing

• Good Comparison of Predicted vs Measured Dynamic Stiffness

• New Approach is Applicable to Any Bearing/Seal Geometry