3-D CFD ANALYSIS OF HYDROSTATIC BEARINGS

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ABSTRACT

The hydrostatic bearing promises life and speed characteristics currently unachievable with rolling element bearings alone. In order to achieve the speed and life requirements of the next generation of rocket engines, turbopump manufacturers are proposing hydrostatic bearing to be used in place of, or in series with, rolling element bearings.

The design of a hydrostatic bearing is dependent on accurate prediction of the pressure in the bearing. The stiffness and damping of the hydrostatic bearing is very sensitive to the bearing recess pressure ratio. In the conventional approach, usually ad hoc assumptions were made in determining the bearing pressure of this approach is inherently incorrect.

In the present paper, a more elaborate approach to obtain the bearing pressure is used. The bearing pressure and complete flow features of the bearing are directly computed by solving the complete 3-D Navier-Stokes equation.

The code used in the present calculation is a modified version of REACT3D code.

Several calculations has been performed for the hydrostatic bearing designed and tested at Texas A&M. Good agreement has been obtained between computed and test results. Detailed flow features in the bearing will be also described and discussed.
3-D CFD Analysis of Hydrostatic Bearings

by

Robert Hibbs, Jr., and Shyi-Jang Lin

Benefits of Hydrostatic Bearings in High Power Density Turbomachinery Led Rocketdyne to Pursue Aggressive IR&D Initiative to Improve Analysis Capability
HPOTP Pump End Bearing Conversion

Flight Configuration

Hydrostatic Bearing Retrofit

Ball Bearings

Rotor

Hydrostatic Bearing

Bearing Support
Benefits:

- Low-Wear/ No Known Life Limit
- Reasonable Hardware Cost
Significantly Improved Life & Power Level Margin With Hydrostatic Bearing

No Known Limit Life (component tests)

Hydrostatic Bearing

Bearings Life (hr)

Ball Bearing Wear Life

Engine Power Level Percent

No Limit
Analysis Requirement:

- Improve Accuracy of Rotordynamic Model Input
  - Direct Stiffness
  - Cross-Coupled Stiffness
  - Direct Damping
  - Added Mass
Analysis Method:

- Bulk-Flow Analysis Operational and Anchored
  - Film-averaged Navier Stokes Eqn Across Lands
  - Recess Pressure Constant / Including orifice
  - Loss Coefficient Used to Determine Pressure at Entrance to Bearing Land
- Currently Improving with Steady-State 3-D CFD
  - Anchor Loss Coefficients for Bulk Flow Model
- Full Bearing Perturbation Solution of 3D Steady-State Solution
- Steady Solution with Eccentric Shaft
- Unsteady Solution with Whirling Shaft
COMPARISON OF THEORY AND EXPERIMENT
TEXAS A&M HYDROSTATIC BEARING TESTING

**Difference**

<table>
<thead>
<tr>
<th></th>
<th>MIN</th>
<th>AVG</th>
<th>MAX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct Stiffness ($K_{xx}$)</td>
<td>-5%</td>
<td>+7%</td>
<td>+20%</td>
</tr>
<tr>
<td>Cross-Coupled Stiffness ($K_{xy}$)</td>
<td>-26%</td>
<td>+2%</td>
<td>+16%</td>
</tr>
<tr>
<td>Direct Damping ($C_{xx}$)</td>
<td>-22%</td>
<td>-5%</td>
<td>+13%</td>
</tr>
<tr>
<td>$WFR = K_{xy} / (\omega C_{xx})$</td>
<td>-15%</td>
<td>+1%</td>
<td>+8%</td>
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Rockwell International
Rocketdyne Division
**Grid Generation Challenges:**

- Circular Orifice to Square Recess
- Circular Orifice Matching Recess Curvature
- Aspect Ratio in Bearing Land

- Solved Through Multi-Zone Approach

<table>
<thead>
<tr>
<th>Zones</th>
<th>Dimensions</th>
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<tbody>
<tr>
<td>Entrance</td>
<td>22X8X8</td>
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<tr>
<td>Orifice</td>
<td>10X8X8</td>
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<tr>
<td>Recess</td>
<td>6X20X20</td>
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<tr>
<td>Land-1</td>
<td>6X32X17</td>
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<tr>
<td>Land-2</td>
<td>6X32X17</td>
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</tbody>
</table>

- Total in Model - 10976
Methodology

- 3 D Steady-State Accurate Finite Volume Formulation in Generalized Coordinates

- Full Navier-Stokes (FNS) 1st and 2nd Order Upwind/Central Spatial Discretization

- Simple Based Velocity-Pressure Coupling

- $k-\varepsilon$ Turbulence Modelling with Wall Function

- Multiple Zone Approach
Boundary Conditions

- No-slip at stationary wall
- Specify velocities at the inlet
- Extrapolate the flow velocity variables from the interior point at the outlet
- No slip relative to the rotating shaft
- Periodic conditions between recesses
- Consistent formulation of interface Zonal conditions
Results:

- Within 5% of Recess Pressure Loss
- Qualitative Agreement of Flowfield
- Matches Assumptions of Bulk Flow Model
Code Development and Verification
TAMU Data Compared to CFD Solution

Orifice Pressure Drop (MPa)

Supply Pressure (MPa)

- CFD
- Experiment

Speed = 10200 rpm
Clearance = 0.126 mm
Pressure Contour at Clearance Radial Plane

Axial Direction

Rotation

Pressure

0.0

0.5

1.0
Conclusions:

- REACT3D Successfully Predicted Hydrostatic Bearing Solution on Actual Concentric Geometry

- 3-D CFD Solution Supports Main Assumptions of Bulk-Flow Model
  
  - Flow Variables Constant Across Bearing Clearance
  
  - Recess Pressure Constant

- Improvements to Bulk-Flow Solution will be Determined by Evaluation of Differences
  
  - Pressure Recovery at Entrance to Recess and Land