Three dimensional, numerical analysis of an elasto hydrodynamic lubrication using fluid structure interaction (FSI) approach

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Abstract: This work is related to develop a methodology to model and simulate the TEHD using the sequential application of CFD and CSD. The FSI analyses are carried out using ANSYS Workbench. In this analysis steady state, 3D Navier-Stoke equations along with energy equation are solved. Liquid properties are introduced where the viscosity and density are the function of pressure and temperature. The cavitation phenomenon is adopted in the analysis. Numerical analysis has been carried at different speeds and surfaces temperatures. During the analysis, it was found that as speed increases, hydrodynamic pressures will also increases. The pressure profile obtained from the Roelands equation is more sensitive to the temperature as compared to the Barus equation. The stress distributions specify the significant positions in the bearing structure. The developed method is capable of giving latest approaching into the physics of elasto hydrodynamic lubrication.

1. Introduction

Journal bearings are used even today as very essential bearings in various rotating machines such as blowers, compressors, internal combustion engines, generators steam turbines, ship propulsion shafts etc. During rotation of the journals, the oil film forms a wedge and pressure is generated that supports the load. This generated hydrodynamic pressure distorts the bearing surfaces but by assuming of rigid bearing linear/bush fails to forecast the precise performance of the bearing and for this reason the combination of film lubrication with the structural analysis i.e. an elasto-hydrodynamic analysis must be considered. Even during rotation of the journals, the temperature of the lubricant rises which considerably affects the performance of the bearing for this reason thermal effects also considered. Hence, both structural deformation and thermal affects must be implemented during computational flow analysis of bearings. Such type of analysis is called as TEHD analysis. To conduct the TEHD analysis, FSI approach is required. The FSI involves, solving simultaneously combination of CFD and CSD techniques. Several numerical investigations on journal bearings have been done over a past few decades. K. P. Gertzos et. al., [1] were simulated journal bearing for Bingham lubricant under isothermal conditions. Mukesh Sahu et al. [2] and Amit Chauhan et. al., [3, 4] were conducted numerical analysis on journal
bearing by considering thermal effects. A. Ouadoud et. al., [5] were did thermal FSI analysis of journal bearings but not considered the effects of pressure and temperature on lubricant film. Even B. S. Shenoy et. al., [6] and Dinesh Dhande et. al., [7] were also conducted FSI analysis for isothermal condition. Samuel Cupillard et. al., [8, 9] were did numerical analysis on smooth and textured surfaces of the bearing. This work presents a method to model and simulate the TEHD analysis of the journal bearing by FSI approach.

2. Numerical Analysis

Flow analysis

Modeling and Meshing: The smooth journal bearing model was made by ANSYS Design modeler. The specifications of the journal bearing used in this work are given in Table 1. After modeling the flow domain, structured mesh was generated.

| Parameter | Values       | Parameter | Values       |
|-----------|--------------|-----------|--------------|
| D_J & L_J | 14.5 and 90 mm | T_0       | 20 °C        |
| T_L       | 5 mm         | T         | 10, 20 and 30 °C |
| c         | 0.00725 mm   | µ_0       | 0.16 Pa/s    |
| φ         | 60°          | ρ_0       | 922.5 kg/m³  |
| k         | 0.5          | C_p       | 1900 J/kg.K  |
| α         | 2x10^-8 m²/N | K         | 0.12 W/m².K  |
| β         | 0.03 K⁻¹     | D         | -0.00065 K⁻¹ |
| z         | 0.68         | p_0       | 1.19610⁸     |

2.1 Governing equations: The steady state, laminar, 3D Navier-Stokes with energy equations are solved using pressure based solver. For pressure-velocity coupling, coupled scheme is used. Cavitation phenomenon is considered hence for spatial discretization, PRESTO scheme is chosen to calculate pressure and QUICK scheme is chosen to calculate momentum and volume fraction.

When pressure is high, the liquid feature of a mineral oil will be dissipated and it behaves like a waxy solid. As working temperature of the lubricant increases, its viscosity will reduces. Therefore, effects of both pressure and temperature on the viscosity are important and essential in bearing analysis. In this analysis, combination of Barus and Reynolds equation (1) and Roelands equations (2) are used to evaluate the viscosity-pressure-temperature characteristics.

\[
\mu = \mu_0 e^{[\alpha P - \beta(T - T_0)]} \tag{1}
\]

\[
\mu = \mu_0 \exp \left\{ \ln \mu_0 + 9.67 \left[ -1 + \left( 1 + \frac{P}{p_0} \right)^z \times \left( \frac{T-138}{T_0-138} \right)^{-1.1} \right] \right\} \tag{2}
\]

Similarly to evaluate density-pressure-temperature characteristics, combination of Dowson-Higginson density-pressure and temperature-density relationship is used. Then equation for the density is given in Eq. 3.

\[
\rho = \rho_0 \left[ 1 + \frac{0.6P}{1+1.7P} + D(T - T_0) \right] \tag{3}
\]

The applications/uses of equations from (1) to (3) are not included in the FLUENT flow solver. So those equations are written in the udf’s and appended to the flow solver.
2.2 Boundary conditions: Journal and bearing surfaces are assigned as a rigid wall with No-slip. The journal surface is allotted as rotating wall and bearing surface as fixed wall. Pressure inlet and pressure outlet boundary conditions are chosen as the entrance and exit of the bearing respectively. In this simulation residual criterion is retained up to $1 \times 10^{-6}$ to reduce the approximation errors.

2.3 Structural analysis: The bearing liner model is made separately according to the specification is given in the Table 1. Then structure mesh was generated over the model. Boundary condition for the outer surface of the liner is specified as fixed support. For inner surface, hydrodynamic pressure force was assigned. Those forces are imported from the flow analysis as shown in Fig. 5.

3. Results and Discussions

Fig. 1 shows the pressure distribution on the journal surface by considering with and without cavitation effects. The cavitation effect imitates the half Somerfield boundary condition. This condition rejects all negative pressures in the diverging part of the fluid film. The obtained pressure contours are resembled with the K. P. Gertoz et. al., work [1]. At rotational speed of 200rpm, the pressure distribution on the circumference of the journal at mid plane for isothermal, isothermal with cavitation and thermal cases are plotted in Fig. 2. In isothermal analysis, maximum pressure is reached up to 3.65 M Pa while in isothermal with cavitation condition the maximum pressure reaches up to 4.1 M Pa. For Barus and Roelands equations the maximum pressure 4.25 M Pa and 4.10M Pa respectively at rotational speed of 200 rpm.

To study the characteristic of Barus and Roelands equations, analysis was carried out at different rotational speeds such as 200 rpm, 300 rpm and 400 rpm but initial and final surface temperature maintained as 293 K, the corresponding simulated results are taken from the circumference of the journal at mid plane and plotted in Fig. 3. From Fig. 3 it shows that, as rotational speed increases the hydrodynamic pressure also increases. In each rotation, the simulated results of pressure profile from the Barus equation dominates over the Roelands pressure profile.

![Figure 1. Pressure contours on the journal surface (a) without cavitation (b) with cavitation](image)
Further the analysis was conducted for different surface temperatures at rotational speed of 200 rpm to study the characteristic of Barus and Roelands equations. During this analysis the initial surface temperature is retained at 293 K but final surface temperature is maintained at 283 K, 293 K and 303 K respectively, finally the corresponding results are taken from the circumference of the journal at mid plane and plotted in Fig. 4. In 283 K of final surface
temperature condition, the maximum pressure obtained from the Roelands equation was 7.5 M Pa but for Barus equation was 5.75 M Pa and the pressure profile of the Roelands equation take over the Barus pressure profile. In 293 K of initial and final surface temperature case, the pressure profile of Barus equation is almost traced over the Roelands pressure profile. In 303 K case, 2.4 M Pa and 3.14 M Pa maximum pressure obtained from the Roelands and Barus equations respectively but in this case Barus pressure profile dominates over the Roelands pressure profile. Figure 6 shows the stress distributions on bearing liner. That stress is created is due to the action of generated hydrodynamic forces.

4. Conclusion
The complete “THD” and “TEHD” analysis of full journal bearing has been carried out using the sequential application of CFD and CSD i.e. FSI approach. This method gives the deformation of the bearing due to the action of generated hydrodynamic forces. This approach is essential for
predicting the performance of the bearings and also selecting of the bearing materials. In this work, the analysis was conducted for static load condition but this approach can also extended to dynamic load condition. The characteristics of Barus and Roelands viscosity-pressure-temperature were studied. The pressure profile obtained from the Roelands equation is more sensitive to the temperature as compared to the Barus equation. Finally inclusion of FSI approach, cavitation and thermal effects may be useful in forecasting the performance of bearing in real working conditions.

Nomenclature

- $D_J$ & $L_J$: Diameter and length of the journal
- $c$ & $k$: Radial clearance and Eccentricity ratio
- $\varphi$: Attitude angle
- $T_L$: Thickness of bearing liner.
- $T_0$: Initial temperature
- $T$: Temperature of the surfaces
- $\rho$ & $\mu$: Density and viscosity of lubricant
- $K$: Thermal conductivity of lubricant
- $C_P$: Specific heat of lubricant
- $p_0$: Pressure–viscosity coefficient
- $z$: Coefficient of viscosity-pressure in Roelands viscosity–pressure formula
- $\alpha$: Coefficient of viscosity pressure in Barus viscosity–pressure formula
- $\beta$: Viscosity–temperature coefficient in the Barus formula in K$^{-1}$
- $D$: Density–temperature coefficient in K$^{-1}$
- CFD & CSD: Computational fluid dynamics and Computational structural dynamics
- TEHD & THD: Thermo- elastohydrodynamic and Thermo- hydrodynamic

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