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CFD Based Thermo-Hydrodynamic Analysis of Circular Journal Bearing

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Abstract

Hydrodynamic journal bearings are used in machineries which are rotating at high speeds and carries heavy loads. This results in high temperature rise in the lubricant film which significantly affects the performance of bearing. Thermo-hydrodynamic analysis should be carried out in order to obtain the realistic performance parameters of journal bearing. Thermo-hydrodynamic analysis of circular journal bearing has been simulated by using Computational Fluid Dynamics approach. This approach solves the three dimensional Navier-stokes equation to predict the bearing performance parameters such as the pressure and temperature of the lubricant along the profile of the bearing. The CFD technique has been applied through ANSYS Fluent software. The oil flow is assumed to be laminar and the steady state condition has been assumed in the current work. The effect of variation of pressure and temperature on the lubricant film has been considered during the study. Thermo-hydrodynamic analysis has been carried out at an eccentricity = 0.6 and rotational speed = 2500 rpm. During the analysis, authors have found that due to the consideration of viscosity variation fewer rises in temperature has been observed in thermo-hydrodynamic analysis as compared to iso-thermal analysis.

Keywords: Computational Fluid Dynamics; Circular journal bearing; Thermo-hydrodynamic

Introduction

Circular Journal Bearing profile is the most commonly used to support the rotating shaft extensively in high speed machinery, example turbines, electric motors etc. These bearing support the external load and the presence of thick film of lubricant between the clearance spaces avoid the metal contact of rotating part of machinery with the surface of bearing. High speed of rotation causes the considerable rise in the temperature of the lubricant which significantly affects the performance of the bearing. Therefore the investigation of bearing performance based on a thermo-hydrodynamic (THD) analysis requires simultaneous solution of the complex equations of flow of lubricant, the energy equation for the lubricant flow and the heat conduction equations in the bearing and the shaft. Previously, the researchers investigate the performance of the lubricant by solving the Reynolds Equation through Finite Difference Method approach. With the progress of computer technology many researchers uses commercial computational fluid dynamics (CFD) software to solve these complex equation. CFD codes provides a solution to flow problems by solving the full Navier-Stokes equations instead of Reynold's Equation. Also, CFD software solve the three dimensional energy equation to predict the temperature distribution in the fluid film where most of the researchers does THD analysis by solving the two dimensional energy equation for finding the temperature variation in the lubricant and two dimensional Reynolds Equation for pressure variation by neglecting the variations across the film thickness.

First a remarkable work on Thermo-hydrodynamic study of journal bearing was done by Hughes and Osterle [1]. The authors found out a relation between viscosity as a function of temperature and pressure of the lubricant inside the journal bearing for adiabatic conditions. The authors have presented a numerical example to illustrate the method. Basri and Gethin [2] have investigated the thermal aspects of various non-circular journal bearing using adiabatic model. Hussain et al. [3] have presented a work, on the prediction of temperature distribution in noncircular journal bearings: two-lobe, elliptical and orthogonally displaced bearings. The authors have presented the results for these geometries including the conventional circular bearing. Cupillard et al. [4] have presented an analysis of lubricated conformal contact to study the effect of surface texture on bearing friction and load carrying capacity using computational fluid dynamics. The authors have reported that the coefficient of friction can be reduced if a texture of suitable geometry is introduced. Gertzos et al. [5] have investigated journal bearing performance with a Non-Newtonian fluid i.e. Bingham fluid considering the thermal effect. Liu et al. [6] have used computational fluid dynamics and fluid structure interaction method to study rotor-bearing system. The authors have investigated the dynamic response of the system with both the rigid and flexible bodies with an assumption of isothermal behaviour for all the models. Further, the author have considered the cavitation within the fluid film and reported that the elastic deformation and dynamic unbalanced loading of the rotor have significant effects on the position of its locus. Chauhan et al. [7] have presented a comparative study on the thermal characteristics of elliptical and offset-halves journal bearings. It has been reported by the authors that the offset-halves bearing run cooler when compared with elliptical bearing with minimum power loss and good load capacity. Ouadoud et al. [8] have considered the finite volume which is used to determine the pressure, temperature and velocity distributions in the fluid film through Computational Fluid Dynamic (CFD) and Fluid Structure Interaction (FSI). The authors have analyzed the influence of the operating conditions on the pressure, temperature and displacement. Sahu et al. [9] have carried out THD analysis of a journal bearing as a tool. The authors have presented 2-dimensional distribution and 3-dimensional pressure of the lubricating film. Li et al. [10] have presented a new method for studying the 3D transient flow of misaligned journal bearings in a flexible rotor-bearing system. The results presented by the author indicate that the bearing performances are greatly affected by misalignment and method presented by them can effectively predict the transient flow filed of the system under consideration. Panday et al. [11] have done the numerical unsteady analysis of thin film journal bearing using ANSYS fluent software and calculated the various bearing parameters like pressure distribution, wall shear stress at different eccentricities ratios. The effect of thermal analysis on the pressure distribution is reported by few of the researchers using CFD as a tool but the variation of temperature has not been analyzed. An effort has been made to analyze the thermohydrodynamic effect on variation of temperature in the lubricant of the journal bearing.

Analysis

The geometry and the co-ordinate system of the journal bearing is shown in fig 1. The journal rotates with a angular velocity ω. The journal remains in equilibrium position under the action of external load, W and developed hydrodynamic pressure. The journal centre O is eccentric to the bearing centre O'. The film thickness h(θ) varies from its maximum value h_{max} at bearing angle θ = 0 to its minimum value, h_{min} at θ = 180. The film thickness of an aligned bearing can be expressed by [3]:

$$h(\theta) = C + e\ Cos\theta\ = C(1 + \epsilon\ Cos\theta) \qquad (1)$$

Where, C and ε represent the radial clearance, eccentricity ratio of the journal bearing, θ coordinate in the circumferential direction, being measured from the maximum film thickness.

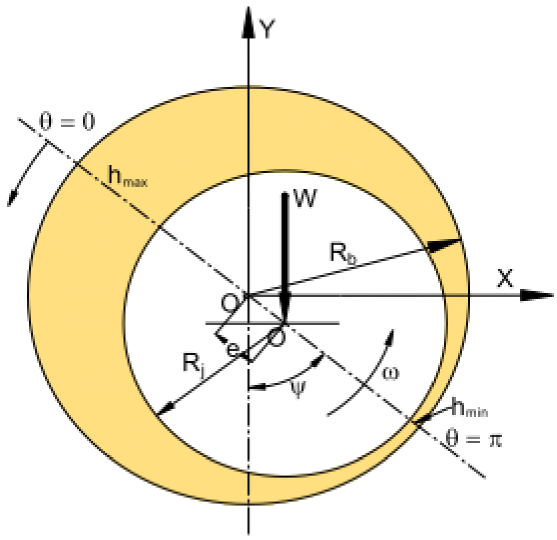

Fig. 1: schematic diagram of circular journal bearing

Governing Equations

For all types of fluid flow problems, the CFD software FLUENT solves conservation equation of mass and momentum for computation of pressure and velocity of the fluid. In order to compute the temperature or heat transfer along the fluid or from fluid to bearing surface energy equation is being solved. For thermal considerations energy conservation equation is solved. Mass conservation equation is written as [5]

$$\frac{\partial \rho}{\partial t} + \nabla\,(\rho\vec{v}) = 0 \tag{1}$$

Momentum conservation equation is written as [5]

$$\frac{\partial}{\partial t}(\rho\vec{v}) + \nabla(\rho\vec{v}\vec{v}) = -\nabla p + \rho\vec{g} + \vec{F} \tag{2}$$

where, $\rho\vec{g}$ and $\vec{F}$ are the gravitational body force and external body body forces respectively. The three dimensional energy equation for steady-state and incompressible flow is given as [5].

$$\frac{\partial}{\partial t}(\rho C_P T) + \nabla(\rho\vec{v}C_P T) = \nabla(K.\nabla T) + Q_V \tag{3}$$

where, Q_V represents volumetric heat source; C_P and K represents the Specific heat and thermal conductivity of the lubricant respectively.

The properties of the lubricating oil changes with the variation of the pressure and the temperature. In iso-thermal analysis, the effect of variation of pressure and temperature is not being considered on the viscosity of the lubricant. Therefore, viscosity is assumed constant during iso-thermal analysis. In thermo-hydrodynamic analysis, the effect of pressure and temperature on the viscosity of the lubricant is considered. The effect of variation of pressure and temperature on the viscosity of lubricant is given as [7].

$$\mu = \mu_0\, e^{\alpha\,(P-P_0)}\, e^{-\beta(T-T_0)} \tag{4}$$

Geometrical Model

In the present work, the surface of the bearing is modeled by taking journal diameter = 100 mm; Bearing Length = 100 mm; Radial clearance = 100 μm. The eccentricity ratio is considered at 0.6 and the attitude angle is taken as 55°. The lubricant properties are taken as density = 850 kg/mm^3; lubricant viscosity = 0.4986 Pa-Sec; specific heat = 2000 J/Kg °C and Thermal Conductivity = 0.13 w/m °C.

Computational Procedure

The Navier-Stokes equations and mass and momentum energy conservation equations are solved in steady state taking gravity forces into account. The operating pressure is set up 101325 Pa. In the current work, results are obtained by assuming flow to be laminar. The bearing shell is modeled as a stationary wall. The journal is modeled as a moving wall with an absolute rotational speed of 2500 rpm. Rotational axis origin is set to the value of eccentricity. The lubricant inlets are modeled as pressure inlets and the two sides of the clearance are modeled as pressure outlets. A user defined function is used for incorporating the effect of pressure and temperature on the viscosity for thermo-hydrodynamic analysis. The segregated solver is chosen for the present numerical analysis. The velocity pressure coupling is treated using the SIMPLE Algorithm and the first order upwind scheme is used for momentum and energy. For greater accuracy, a convergence criterion of the order of 10^{-6} is used for all residual terms.

Results and Discussions

The isothermal pressure and thermal pressure for the modelled circular journal bearing has been shown in Figs. 2 and 3. The maximum pressure in iso-thermal analysis reaches to 8.17 M Pa while the maximum pressure in thermo-hydrodynamic analysis is 6.84 M Pa.

Fig. 3 and Fig. 4 represent three dimensional temperature distribution of circular journal bearing by considering constant viscosity and by considering the effect of pressure and temperature on the viscosity of the lubricant respectively. It has been observed that the rise in temperature in iso-thermal analysis was obtained 31.1 K while 22.8 K rise was obtained in thermo-hydrodynamic analysis.

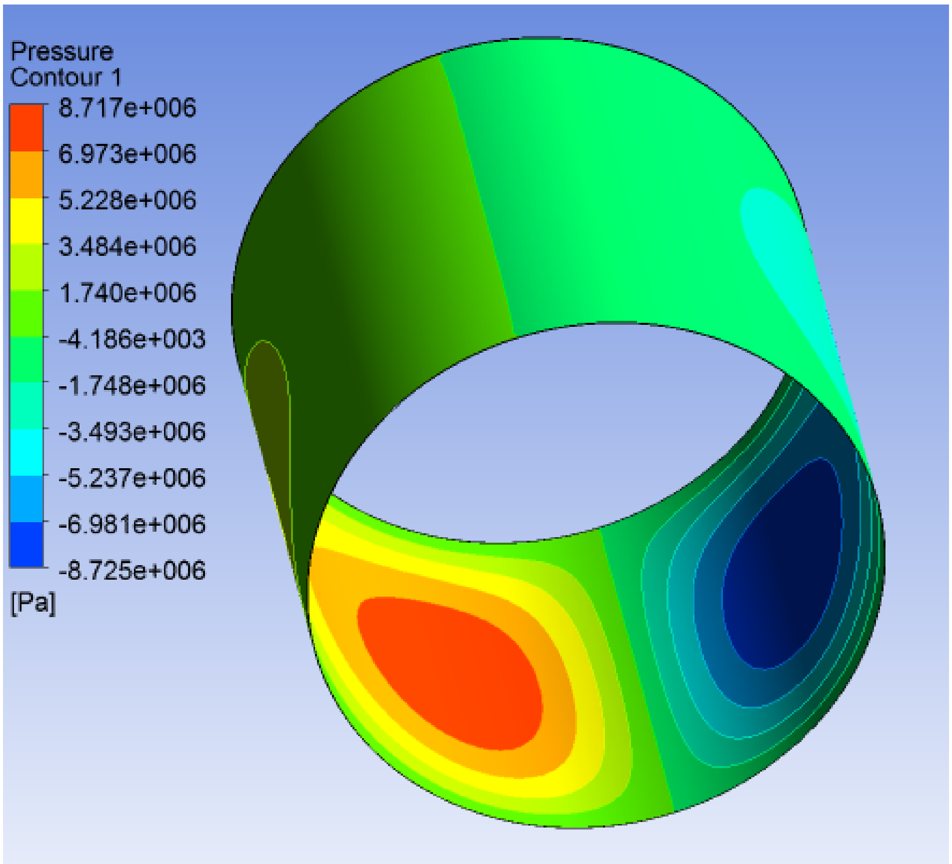

Fig. 2: Iso thermal pressure

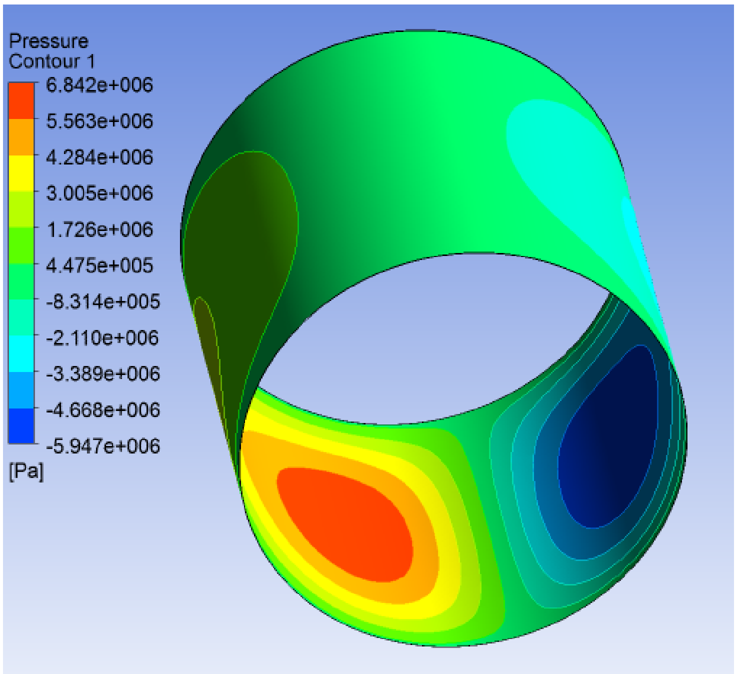

Fig. 3: Thermo-hydrodynamic pressure

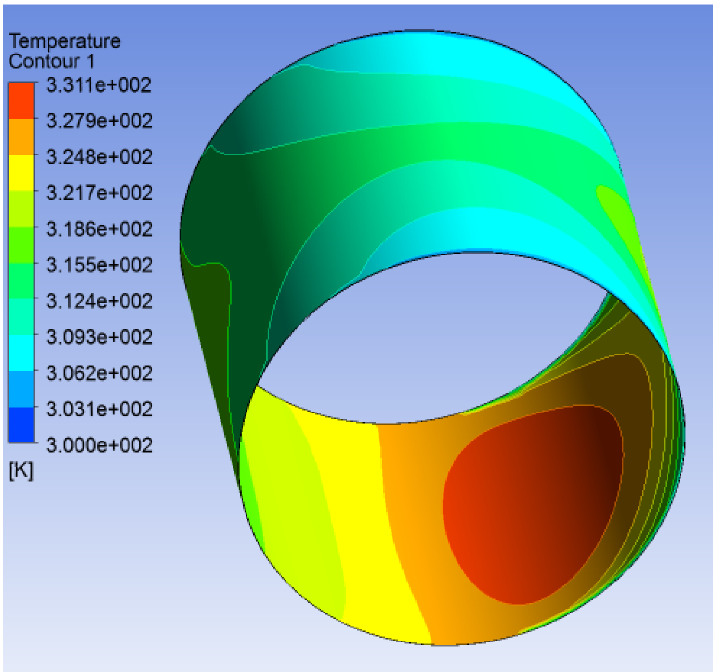

Fig. 3: Temperature distribution keeping constant viscosity

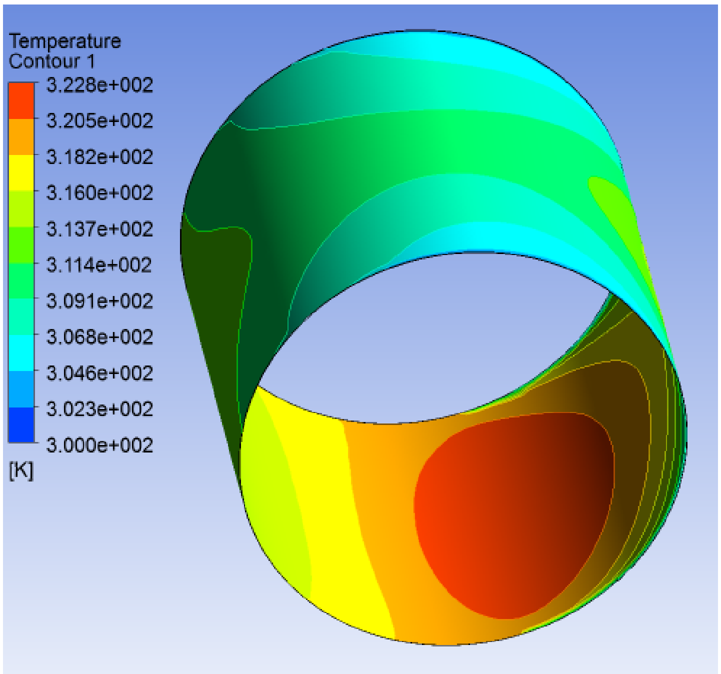

Fig. 4: Temperature distribution by considering the effect of pressure and temperature on viscosity of lubricant

Conclusions

Thermo-hydrodynamic analysis for circular journal bearing has been carried out using the application of Computational Fluid Dynamics. It has been found that when viscosity is kept constant the temperature rise is more in the lubricant and the maximum pressure obtained is also high. But it does not represent real life time scenario as when temperature increases, viscosity of lubricant decreases which affects the load carrying capacity of bearing. Therefore obtaining the bearing performance characteristics by keeping constant viscosity may gives wrong prediction about the bearing. So the present analysis may be helpful in prediction of bearing performance parameters in actual working conditions and may help in increased life of the bearing.

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