3D simulation of the lubrication film in journal bearing using Fluid-Structure Interaction (FSI)

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Submission date: 08-May-2020 11:48AM (UTC+0700)

Submission ID: 1319157724

File name: Ramdhani_2018_J._Phys.__Conf._Ser._1090_012025.pdf (1.2M)

Word count: 1566

Character count: 8507

Journal of Physics: Conference Series

PAPER • OPEN ACCESS

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To cite this article: S Ramdhani *et al* 2018 *J. Phys.: Conf. Ser.* **1090** 012025

IOP Conf. Series: Journal of Physics: Conf. Series **1090** (2018) 012025 doi:10.1088/1742-6596/1090/1/012025

3D simulation of the lubrication film in journal bearing using Fluid-Structure Interaction (FSI)

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Abstract. Most of the studies of journal bearing performance are based on a two-dimensional calculation approach which lead to the questionable conclusions. In addition, the deformation of the surface is often ignored in the analysis. In the present study, modern technique for analyzing the lubrication performance is developed based on fluid-structure interaction (FSI) method to get more realistic result. In this way, the deformation which may affect the lubricant thickness will be recalculated based on the film thickness profile in each step. The validation of the developed FSI technique is also carried. The simulation results show that FSI method can be used to analyze the performance of current journal bearing calculation in more accurate compared to conventional method.

1. Introduction

Today the design of journal bearings is performed by solving the Reynolds differential equation.This equation is based on the assumption that the film thickness profile is negligible compared to the other lubrication film dimensions both in axial and circumferential directions. Based on literature survey, numerous workers have paid much attention to calculation programs using Reynolds equation.

Gertzos et al. [1] examined the performance characteristics and the core formation in a hydrodynamic journal bearing lubricated with a Bingham fluid. Their main conclusion was that the load carrying capacity, the film pressure, and the frictional force of a Bingham solid are larger than those of a Newtonian fluid. Rao [2] based on Reynolds equation studied the journal bearing based on the extent of the slip region on the bearing surface. An extended Reynolds equation was proposed based on the slip length model.It was found that an increase in the stability threshold can be achieved with a higher value of the slip length and a smaller extent of the slip region on the bearing surface. Zhang et al [3] presented a mathematical model and a computational methodology to simulate the complicated flow behaviors of the journal microbearing in the slip regime. They concluded that the slip-flow boundary condition enhances the stability of the gas-lubricated journal bearing-rotor system.Wang et al. [4] based on Reynolds approach investigated the two dimensional spiral oil wedge sleeve bearing based on the critical shear stress model. They highlighted that the special structure of spiral oil wedge and the increase of eccentricity ratio make slip more difficult to occur.Solghar et al [5] explored thermohydrodynamic characteristics of journal bearings with two axial grooves by means of computational fluid dynamics technique. Kalavathi et al. [6] numerically investigated the effect of surface roughness on finite porous journal bearing with heterogeneous slip/no-slip surface based on generalized Reynolds approach. It was shown that pressure and load support increases with surface

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roughness for the bearing with slip/no-slip surface.In recent publication, Tauviqirrahman et al. [7] explored effect of cavitation on the lubrication performance of the journal bearing operating with non-Newtonian lubricant. In their study, however, two-dimensional analysis of bearing was adopted.

Based on literature survey, one can find that journal bearing calculationswere mostly based on a two-dimensional analysis and the analyses was conducted by ignoring the deformation of the journal bearing. Thus, in the present paper, the main contribution is to investigate the performance of journal bearing based on three dimensional approach considering the deformation of the journal bearing. The CFD (computational fluid dynamic) technique based on Navier-Stokes equations coupled with solid dynamic equation also called FSI method (fluid-structure interaction) is applied using commercial software ABAQUS.

2. Methodology

In the present work, the lubrication problem is solved by the Navier-Stokes equation and continuity equations. The Navier–Stokes (N-S) equations are solved over the domain using the commercial software package ABAQUS. The Navier–Stokes and the continuity equations can be expressed, respectively,

$$\rho \frac{Du_i}{Dt} = -\frac{\partial p}{\partial x_i} + \rho G_i + \frac{\partial}{\partial x_j}\left[2\eta e_{ij} - \frac{2}{3}\eta\left(\nabla . u_i\right)\delta ij\right] \qquad (1)$$

$\nabla \bullet u = 0$ (2)

The boundary condition used here is the inlet as well as the outlet adopts the pressure boundary. The inlet as well as the outlet pressure is set to zero. The no-slip condition is assumed, while the angular velocity is 48.1 rad/s.

For the solid analysis, a finite element method is applied, and ABAQUS is used to calculate the deformation of the bearing. By concept, the fluid and structure affect each other, the hydrodynamic pressure exerts a force onto the solid structure (i.e. bearing surfaces) and makes it move or deform.In the present work, the number of nodes used is 131,596, while the number of elements is 65,404. The type of mesh used is linear hexahedral elements.

3. Results and Discussion

3.1. Fluid analysis

Figure 1 shows the hydrodynamic pressure of journal bearing predicted by the fluid analysis based on the Navier-Stokes equations coupled with continuity equation. It can be observed that the maximum hydrodynamic pressure occurs at the range of angle 60-110^{o}.

It can also be observed from Figure 1 that the cavitation phenomena exist at the divergent area (blue colour). This is as expected that the rupture of the film occurs due to the lack of lubricant supply at the divergent area.

For detail, the hydrodynamic pressure is shown in Figure 2. It is found that the transition region from convergent to divergent occurs at the angle of 180^{o}. Based on Figure 2, the symmetric profile is highlighted. This condition is valid when the cavitation model is not considered as conducted in the present study.

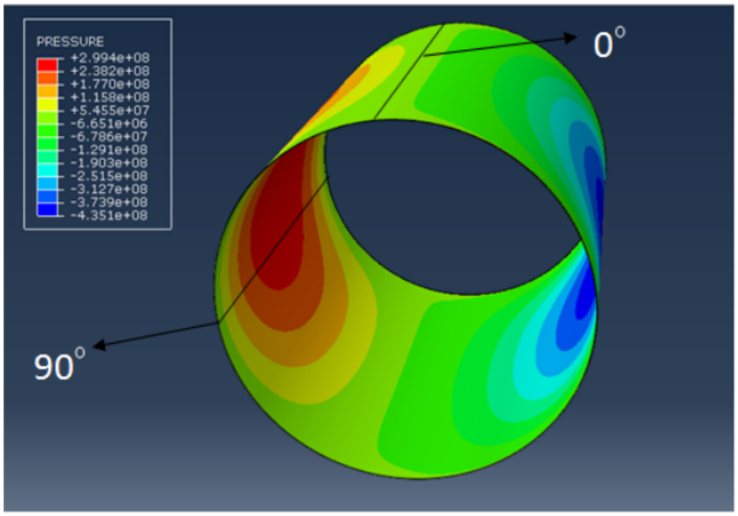

Figure 1. Contour of hydrodynamic pressure of journal bearing

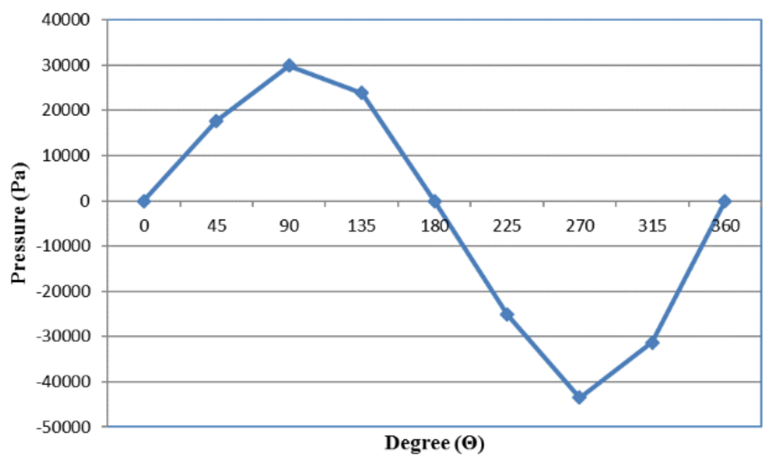

Figure 2. Distribution of hydrodynamic pressure of journal bearing

3.2. Solid analysis

Figure 3 shows the deformation contour of the sleeve as well as the journal. It seems that the deformation occurs on certain area of the bearing. The most possible explanation is that the pressure received by solid structure is local, which indicates that some area of solid is able to handle the possible deformation. This result mean that the deformation of the journal bearing is big enoghr compared to the dimension of the journal. Thus, for analysis of the journal bearing, the deformation which may occur cannot be ignored for obtaining more realistic and accurate result.

Figure 4 depicts the von Mises stress contour of journal bearing. It can be found that the maximum value of the stress is much lower than the yield strength of the material used. As a note, the for all following computation, the material of bearing as well as the journal has the yield strength of 2.5 x 10^8 Pa. It means that the operating condition is safe to used, and thus the design of the bearing can be chosen.

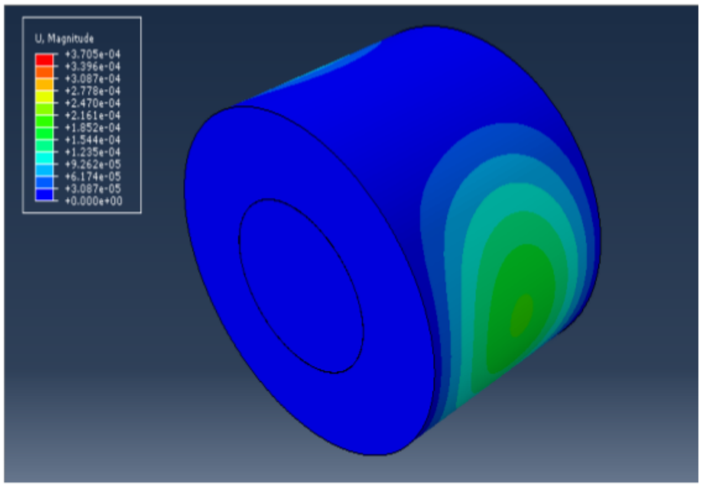

Figure 3. Contour of deformation of journal bearing

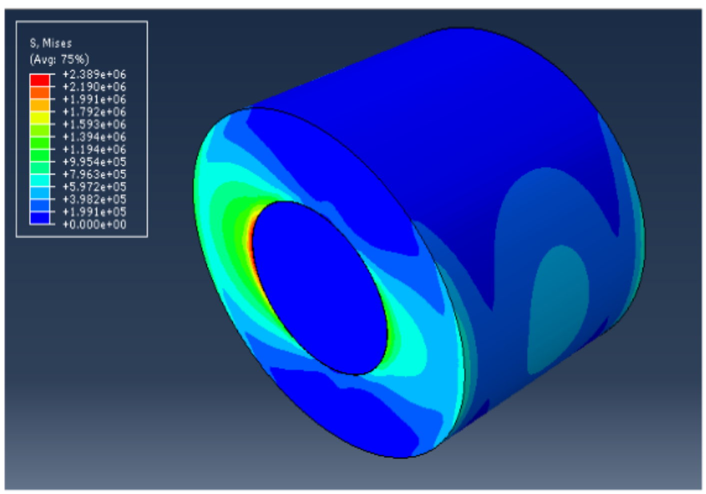

Figure 4. Contour of von Mises stress of journal bearing

4. Conclusions

In the present work, three-dimensional work analysis of journal bearing was conducted based on Navier-Stokes equation. The commercial software ABAQUS was used to investigate its capability in handling the fluid-structure analysis. Based on the explanation above, the conclusions can be drawn that the fluid-structure interaction method developed here is successful to apply in case of journal bearing analysis. In getting more realistic and accurate results, the deformation that occurs can not be ignored.

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