International Journal of Manufacturing and Materials Processing
Vol. 4: Issue 2
www.journalspub.com

CFD Analysis of Hydrodynamic Journal Bearing

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ABSTRACT

Journal bearings have the longest history on scientific study of any class of fluid-film bearings. These journal bearings are widely used in most of the rotating machineries due to its high load-carrying capacity and formation of fluid-film thickness during the operation. This research paper represents performance evaluation of hydrodynamic journal bearing using Computational Fluid Dynamics (CFD) approach. For this study, two different geometrical bearings are considered (circular and non-circular) operating with commercially used lubricant. Comparative analysis of both the bearings is carried out at the same operating conditions. Analytical results are obtained for pressure distribution for both the bearings and these results are compared with CFD simulated results. A good agreement is found between the comparative results that propose a validation of the analytical results. The CFD method can be a very useful tool for study on the bearing lubrication problem and can accurately predict the performance characteristics of hydrodynamic journal bearing.

Keywords: CFD, hydrodynamic journal bearing, pressure distribution, temperature rise

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INTRODUCTION

The hydrodynamic journal bearing is an established mechanical element in internal combustion engines. It stands out by the fact of bearing high loads, nearly wearless and low-noise operating conditions. The simple design and the low-priced manufacturing are further advantages. Like in other hydrodynamic applications, cavitation is still a problem in journal bearings. Caused by the cavitation, erosion of the surface can occur and that can result in the breakdown of the bearing. To prevent the damage of the journal bearing, it is necessary to have knowledge about the cause of cavitation. Only if vapour appears in the flow, cavitation can occur. During the operation of the bearing, due to high journal speed, the variation in temperature along the lubricant film significantly affects the properties of the lubricating oil. Hence it affects the performance of the bearing as the lubricating oil inside the bearing depends upon the pressure and the temperature. The increase in the temperature of the oil film causes the breakage in the layers of the lubricating film which consequently leads to metal contact between the bearing and journal surface. Here, the lubricant film between the journal and the bearing is responsible for low friction and high load-carrying capacity of such bearings. The variation in temperature and pressure of lubricant in journal bearings affects the performance of the bearing. Most of the researchers do the total harmonic distortion (THD) analysis by solving the Reynolds and Energy equation only in the two dimensions by neglecting the variation of pressure and temperature across the film thickness. Computational Fluid Dynamics (CFD) software solves these equations in three dimensions by considering its variation along film thickness also. First, a remarkable work on thermo-hydrodynamic study of journal bearing was done by Hughes and Osterle [1]. The authors have 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. Gertzos et al. [2] have investigated journal bearing performance with a non-Newtonian fluid, i.e. Bingham fluid, considering the thermal effect. Chauhan et al. [3] have presented a comparative study on the thermal characteristics of elliptical and offset-half journal bearings. It has been reported by the authors that the offset-half bearing run cooler when compared with elliptical bearing with minimum power loss and good load capacity. Ouadoud et al. [4] have considered two numerical methods, the finite volume is used to determine the pressure, temperature and velocity distributions in the fluid film and the displacement field radial is obtained by the finite element method, respectively, by using numerical simulation: CFD and fluid–structure interaction (FSI). The authors have analysed the influence of the operating conditions on the pressure, temperature and displacement. Cupillard et al. [5] presented an analysis of a lubricated conformal contact to study the effect of surface texture on bearing friction and load-carrying capacity using CFD. The work mainly concentrates on a journal bearing with several dimples. The authors have reported that the coefficient of friction can be reduced if a texture of suitable geometry is introduced and the same can be achieved either in the region of maximum hydrodynamic pressure for a bearing with high eccentricity ratio or just downstream of the maximum film for a bearing with low eccentricity ratio. Sahu et al. [6] have carried out THD analysis of a journal bearing as a tool. The authors have presented two-dimensional (2D) distribution and three-dimensional (3D) pressure of the lubricating film. Basri and Gethin [7] have investigated the thermal aspects of various non-circular journal bearings using adiabatic model. Hussain et al. [8] presented a work on the prediction of temperature distribution in non-circular journal bearings: two-lobe, elliptical and orthogonally displaced bearings. The authors have presented results for these geometries including the conventional circular bearing. Liu et al. [9] have used CFD and FSI methods to study rotor-bearing system. The authors have investigated the dynamic response of the system with both the rigid and flexible bodies and made an assumption of isothermal behaviour for all the models. Further, the authors 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. 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 the method presented by them can effectively predict the transient flow field of the system under consideration. Pandey 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 and wall shear stress at different eccentricities ratios. Suryawanshi and Pattiwar [12] recently conducted the study based on the tribological behaviour of fluid-film journal bearing operating with different lubricants. The authors have also considered nano-lubricant in this paper for performance evaluation of journal bearing. The plain and elliptical journal bearings were considered to investigate the performance characteristics of journal bearing. The pressure contour obtained in this paper using CFD simulation study is compared with the analytical pressure values reported in the above-mentioned literature [12]. The results proposed in this paper would be very useful to the bearing designers, academicians and research scholars concerned with the relevant study.

ANALYSIS

When the analysis of a bearing was done using Reynolds equation, it governs the pressure distribution around the circumference of journal in the clearance space of fluid-film bearing. It is used to plot the pressure profile in the hydrodynamic fluid-film theory. The coordinate system and the geometry of fluid-film journal bearing is shown in Figure 1.

An equilibrium position under the external load is attended due to the hydrodynamic pressure generated by the lubricant film through journal rotating with an angular velocity ω.

Reynolds's equation in 2D form is

$$\frac{U}{2}\frac{\partial h}{\partial x}-\frac{1}{12\mu}\frac{\partial}{\partial x}\left(h^{3}\frac{\partial p}{\partial x}\right)-\frac{1}{12\mu}\frac{\partial}{\partial z}\left(h^{3}\frac{\partial p}{\partial z}\right)=0$$

The assumption of the non-circular hydrodynamic journal bearing is that it is a rigid aligned bearing with steady-state condition. The flow is Newtonian, isothermal, iso-viscous, incompressible, and has no inertia effect. Both journal and bearing surfaces are smooth, and only a constant vertical load is to be applied at the journal centre. Lubricant pressure distribution as a function of journal speed, bearing geometry, clearance and lubricant viscosity is described by Reynolds equation.

COMPUTATIONAL PROCEDURE

The Navier–Stokes equations and mass and momentum energy conservation equations are solved in steady state taking gravity forces into account. In order to analyse pressure distribution in the bearings using ANSYS Fluent software, meshing was done using Solid-edge. Solid-edge is a pre-processor software used for engineering analysis. Edge meshing was carried out with interval count as 30° along the length and elliptical and circular profile. Face meshing and volume meshing were carried out consequently. The mesh file was imported into ANSYS Fluent to obtain the pressure contour plots. The bearing wall was considered as stationary and the journal was modelled as a moving wall. The sides of the lubricant volume had been assigned with a zero-pressure condition for lubricant to flow freely. The sides of the bearing were assigned pressure inlet and pressure outlet (Figure 2(a, b)).

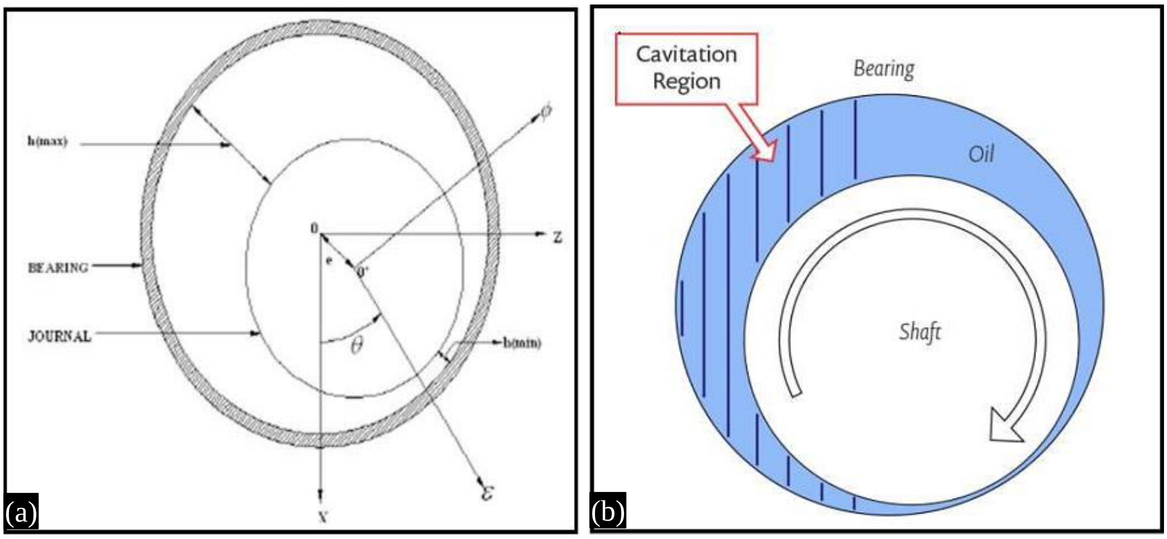

Fig. 1. *Schematic diagram of circular journal bearing, which shows the cavitation region.*

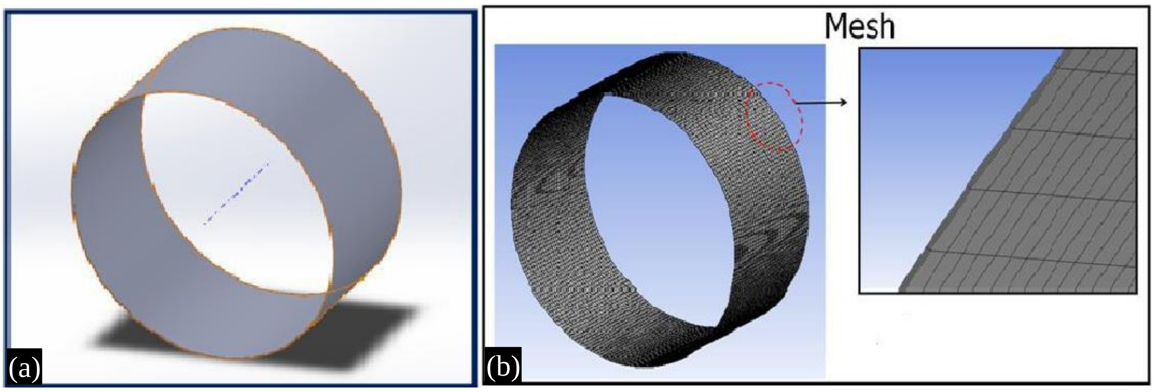

Fig. 2. *(a) Model generation; (b) mesh generation.*

Table 1. *Geometrical and operating parameters for bearing.*

Parameter	Value
Journal diameter, *D*	50 mm
Bearing length, *L*	50 mm
L/*D* ratio	1
Clearance, *C*	0.05 mm
Type of lubricant	MOBIL DTE 25
Viscosity, MPa-s	39.89×10^{-9}
Journal speed, *N*	500–1000 rpm
Load, *W*	1000 N
Clearance ratio, *C*/*R*	0.002
Preload ratio for elliptical bearing, *m*	0.5
Major diameter of elliptical bearing	50.3 mm
Minor diameter of elliptical bearing	50.2 mm
Elliptical ratio, E_m	0.5

The temperatures of each of the entities, i.e. bearing, journal, pressure inlet and outlet, were taken as 27°C. The journal was given a rotational speed in rpm. At the pressure outlet, the pressure distribution was assumed to be radial. The solution scheme was taken as SIMPLE. The spatial discretization of pressure was taken as PRESTO. Standard initialization was used and was computed from the inner most layer, i.e. the journal. The geometrical and operating parameters considered during the study are shown in Table 1.

RESULTS AND DISCUSSION

The steady-state condition has been assumed. The fluid flow is considered as laminar. The equations have been solved without assuming the body forces. A constant load has been assumed to be applied on the journal surface. For meshing, a hexahedral structural mesh is used. Name selection for various boundaries like fixed wall for bearing surface and moving wall for journal surface is done in ANSYS meshing. Following are the comparative results for circular bearing using three speeds (500, 750, 1000 rpm) operating with oil (Mobil DTE 25) and constant load of 1 kN using theoretical relations and CFD results. The performance parameters using CFD approach are evaluated using ANSYS FLUENT by importing the meshed model that has been prepared in SOLID EDGE software. Figure 3 illustrates the pressure contour in the plain circular bearing operating with Mobil DTE 25 at different speeds and 1 kN load. The pressure profile obtained in the oil film is then computed with pressure values and found very close to each other. The pressure contours obtained at speeds 500, 750 and 1000 rpm are represented as shown in Figure 3(a–c). The comparison between theoretical pressure and pressure values using CFD is also shown in Figure 4(a–c). The theoretical pressure distribution values are considered from the study carried out by Suryawanshi and Pattiwar [12] in the literature. The cavitation phenomenon is considered during the analysis; hence pressure distribution in the divergent region is neglected. The percentage variation during the analysis of pressure distribution is between 0.82% and 3.18%

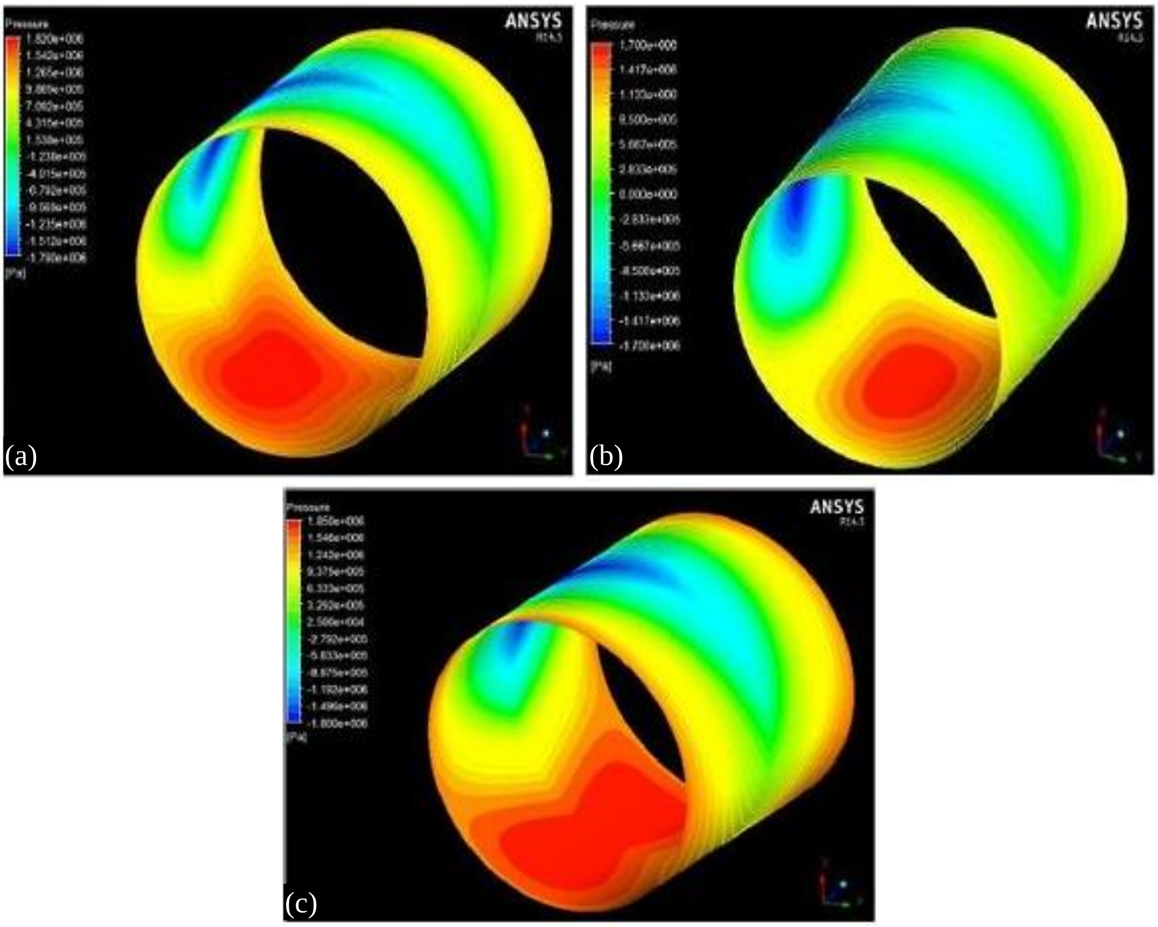

Fig. 3. *Pressure contour for circular bearing with Mobil DTE 25: (a) 500 rpm; (b) 750 rpm; (c) 1000 rpm.*

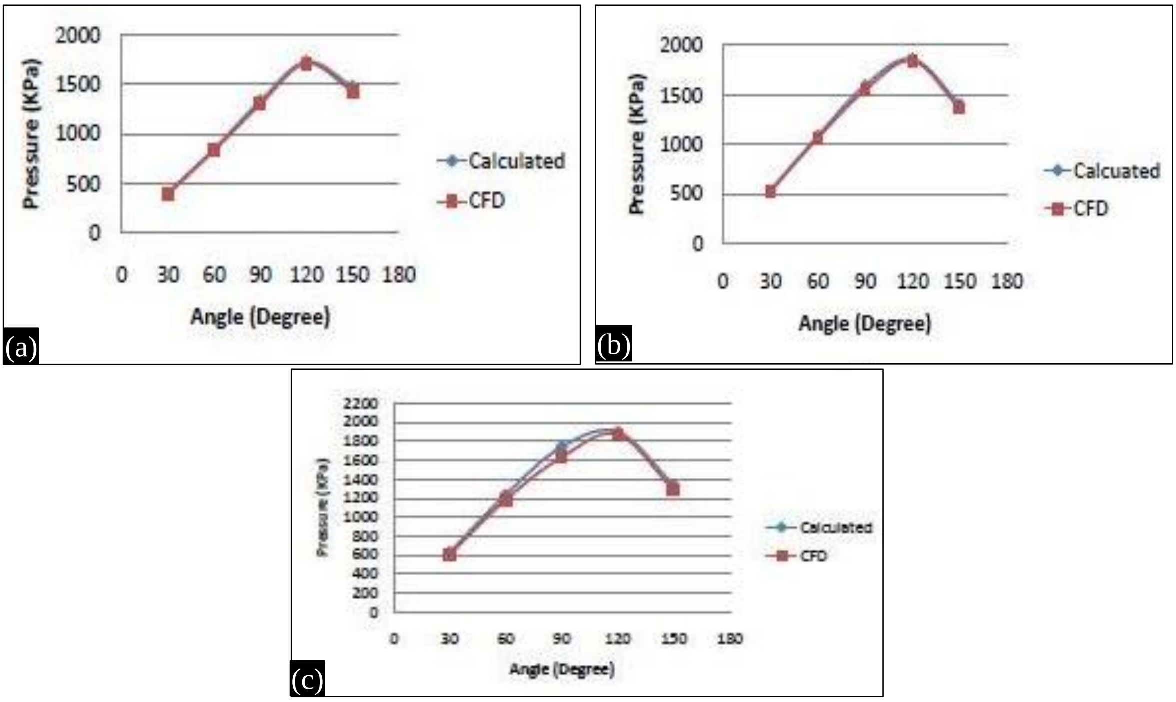

Fig. 4. *Comparison of pressure distribution in oil film of Mobil DTE 25: (a) 500 rpm; (b) 750 rpm; (c) 1000 rpm.*

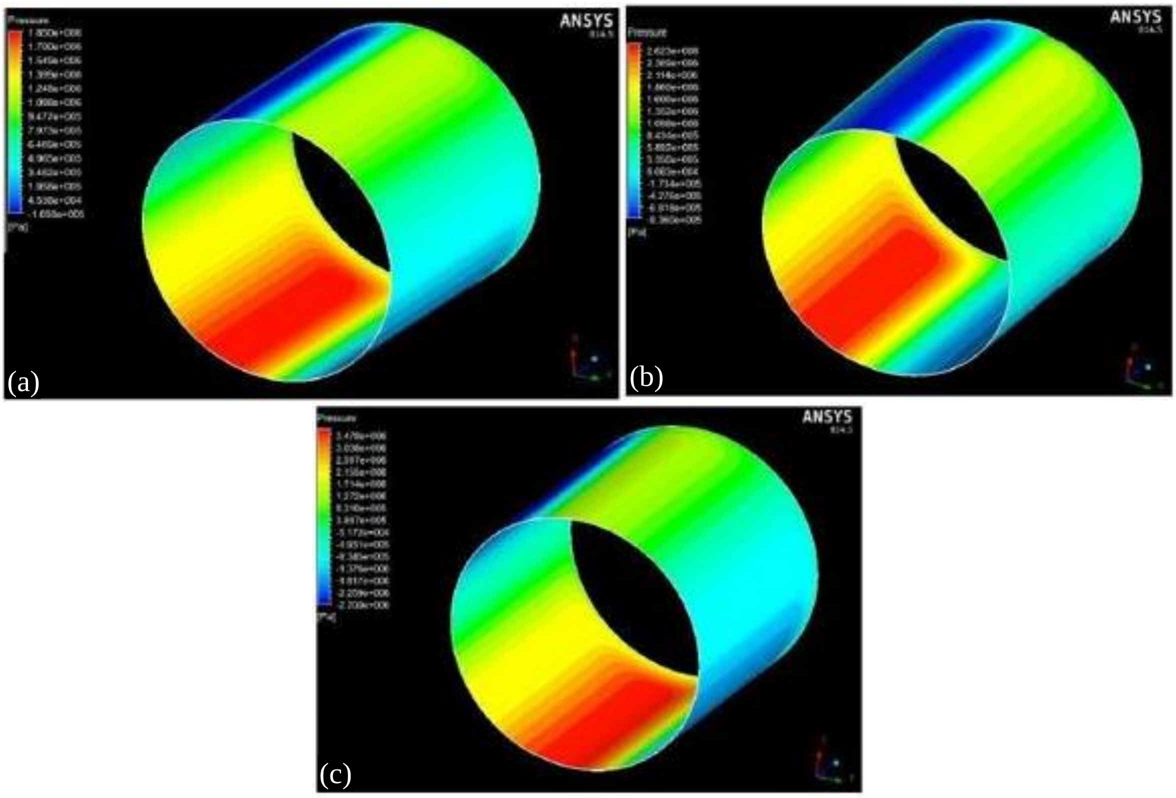

Fig. 5. *Pressure contour for elliptical bearing with Mobil DTE 25: (a) 500 rpm; (b) 750 rpm; (c) 1000 rpm.*

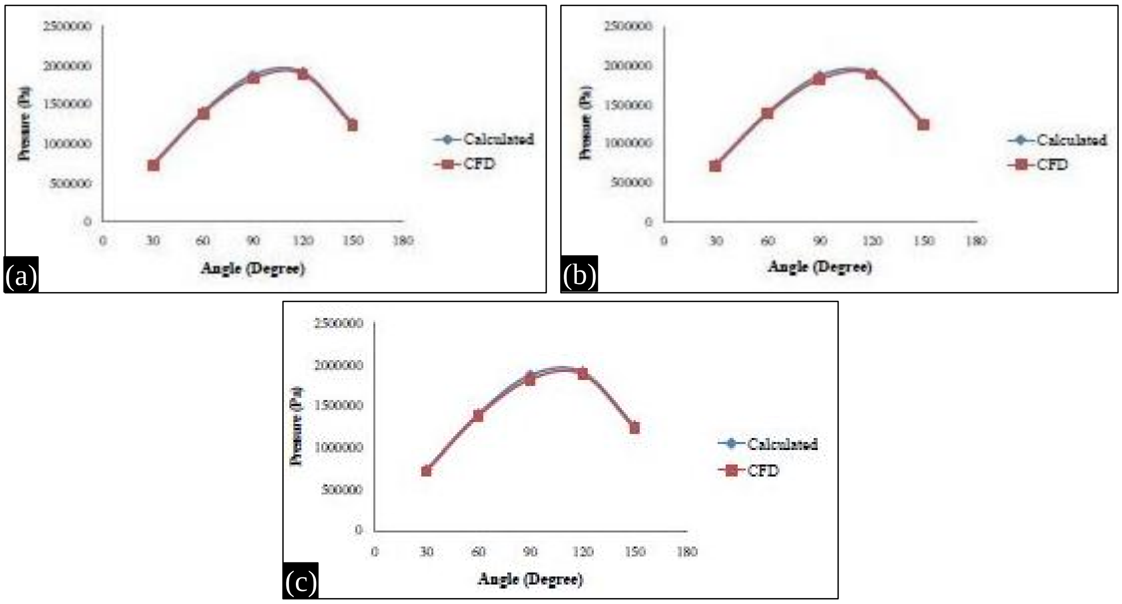

Fig. 6. *Comparison of pressure distribution in oil film of Mobil DTE 25: (a) 500 rpm; (b) 750 rpm; (c) 1000 rpm.*

at 500 rpm; 1.15% and 3.14% at 750 rpm; and 1.34% and 6.17% at 1000 rpm. The loaded lobe (lower lobe) is considered during the analysis as this is the crucial section of bearing geometry during the running condition. Figure 5 depicts the pressure distribution in oil film of lubricant Mobil DTE 25 in elliptical journal bearing. The operating conditions are kept the same as of plain journal bearing. Figure 5(a–c) represents pressure contours in the oil film at speeds 500–1000 rpm obtained through CFD simulation. The comparison between these CFD simulated values with analytical data is represented in Figure 6(a–c). The analytical values of the pressure distribution in the upper lobe (cavitation zone) of the elliptical bearing are varying than that of the plain journal bearing due to different eccentricity ratios in the upper lobe. The percentage variation during the analysis of pressure distribution in Mobil DTE 25 is between 0.82% and 3.18% at 500 rpm, 0.50% and 4.36% at 750 rpm; and 1.34% and 6.17% at 1000 rpm.

CONCLUSION

In this paper, validation of theoretical obtained results is carried out by CFD simulation. CFD simulation is carried out for both the bearings (plain and elliptical) to investigate the performance characteristics of journal bearing operating with different lubricants and different speeds. The pressure distribution in the oil film using CFD approach is in a very good agreement with theoretical values. The maximum percentage error is found as 6.17% in case of plain as well as elliptical bearings**.** The pressure distribution in the loaded lobe is increased in the elliptical journal bearing than plain circular journal bearing operating with the same operating conditions. As the speed increases, the pressure distribution also increases in both the bearings.

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