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Cite as: AIP Conference Proceedings **2097**, 030068 (2019); https://doi.org/10.1063/1.5098243
Published Online: 23 April 2019

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Effect of Eccentricity Ratio on the Hydrodynamic Performance of Journal Bearing Considering Cavitation

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Abstract. Hydrodynamically lubricated journal bearings are traditionally designed using Reynolds boundary condition which is questionable. This theory provides acceptable results for modelling cavitation in bearing, but a better understanding of the characteristics including cavitation can be achieved by modeling multi-phase flow. For this reason, the main aim of this study is to investigate the effect of the eccentricity ratio on the performance of the journal bearing including multi-phase cavitation based on computational fluid dynamic (CFD) method. The Navier-Stokes and the continuity equation, as well as the cavitation models, have been solved by the finite volume method. The simulation results show that increasing the eccentricity ratio will enhance the hydrodynamic pressure as well as the load support. However, a contrary result is found in terms of friction force. The large eccentricity ratio does not much affect the friction force.

INTRODUCTION

Along with the development of the industrial sector, bearing becomes a very important component. Bearing serves to limit the relative motion between two or more engine components to always move in the desired direction. Bearing keeps the shaft always rotating against the axis of the shaft, or also maintains a linear moving component to always be in its path. Journal bearing is one type of bearing that is often used in industry. The fluid has a major role in the process of bearing journal work.

The 4th International Conference on Industrial, Mechanical, Electrical, and Chemical Engineering
AIP Conf. Proc. 2097, 030068-1–030068-6; https://doi.org/10.1063/1.5098243
Published by AIP Publishing. 978-0-7354-1827-1/$30.00

In the journal bearing, there are two regions, that is, convergent and divergent area. In the divergent area, the cavitation exists. Several workers have paid much attention to the cavitation phenomena as well as its modelling. Council [1] presented a parametric analysis to investigate the influence of the rotational speed and the relative eccentricity on the attitude angle, the reaction forces, the pressure distribution and the power losses of a small journal bearing by considering the multi-phase cavitation. Mao et al. [2] proposed an analytical model which is feasible to predict the cavitation performance of various textures. In a recent publication, when the slip condition induced by hydrophobic coating becomes popular, the lubrication of hydrophobic bearing is attracting to researchers, for example, Wang and Lu [3], and Muchammad et al. [4]. They used the mass conserving cavitation model to represent more accurate phenomena of cavitation in terms of hydrodynamic pressure. However, along with the complexity of the lubrication problem, it is necessary to define the phase change in lubrication zone of a journal bearing in several eccentricity ratios in which in previously published works, this change has been neglected.

Therefore, in the present work, an attempt has been made to explore the influence of the eccentricity ratio on the lubrication characteristics of finite length journal bearings by considering the cavitation characterized by the multi-phase flow. The effect of the eccentricity ratio on the lubrication performance in terms of the hydrodynamic pressure and the load support, as well as the friction, is also discussed.

METHODOLOGY

Governing equations

In the present study, the lubrication problem is solved by the Navier-Stokes and continuity equations. The Navier–Stokes (N-S) equations are solved over the domain using a finite-volume method with the commercial CFD software package FLUENT®. The Navier–Stokes and the continuity equations can be expressed, respectively,

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

$$\nabla \bullet \mathrm{u} = 0 \tag{2}$$

Not like the previously published works in which the cavitation model is ignored, in the present study, the cavitation effect is taken into account. In FLUENT®, there are three available cavitation models: Schneer and Sauer model, Zwart-Gelber-Belamri model and Sighal et al. model [5]. In this study, the Zwart-Gelber-Belamri is employed due to their capability (less sensitive to mesh density, robust and converge quickly [5].

In cavitation, the liquid-vapor mass transfer (evaporation and condensation) is governed by the vapor transport equation [5]:

$$\frac{\partial}{\partial t}\left(\alpha_v \rho_v\right) + \nabla .\left(\alpha_v \rho_v \mathrm{v}\right) = R_g - R_c \tag{3}$$

where α_v is vapour volume fraction and ρ_v is vapour density. Rg and R_c account for the mass transfer between the liquid and vapour phases in cavitation. For Zwart-Gelber-Belamri model, the final form of the cavitation is as follows:

$$\text{if } p \le p_v,\ R_g = F_{evap} \frac{3\alpha_{\mathrm{nuc}}\left(1-\alpha_\upsilon\right)\rho_\upsilon}{R_\mathrm{B}} \sqrt{\frac{2}{3}\frac{\mathrm{P}_\upsilon - \mathrm{P}}{\rho_\mathrm{l}}} \tag{4}$$

$$\text{if } p \ge p_v,\ R_c = F_{cond} \frac{3\alpha_\upsilon\rho_\upsilon}{R_\mathrm{B}} \sqrt{\frac{2}{3}\frac{\mathrm{P} - \mathrm{P}_\upsilon}{\rho_\mathrm{l}}} \tag{5}$$

where F_{evap} = evaporation coefficient = 50, F_{cond} = condensation coefficient = 0.01, R_B = bubble radius = 10^{-6} m, α_{nuc}= nucleation site volume fraction= 5x10-4, ρ_l = liquid density and p_v = vapour pressure.

CFD model and boundary condition

Figure 1 gives the schematic illustration of a journal bearing. The assumption of the no-slip is adopted. In the present study, for all following computations, the eccentricity ratio ε is varied. Three different values of ε are assumed, that is, 0.41, 0.61 and 0.81. The main characteristics of the bearing and the lubricant properties studied are presented in Table 1.

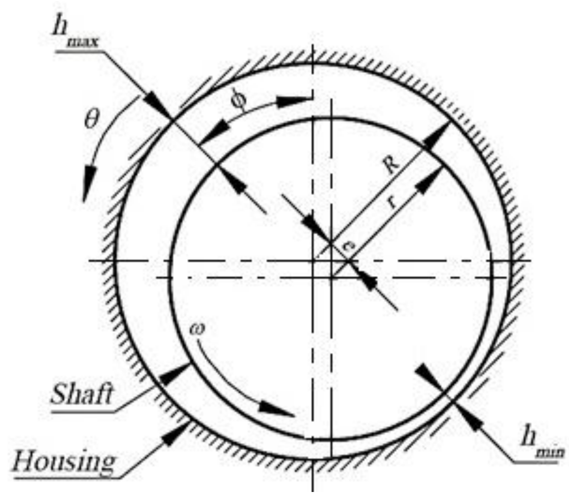


FIGURE 1. Schematic of the journal bearing.

Table 1. Parameter calculation

Parameter	Symbol	Value
Housing radius	R	50.145 mm
Shaft radius	r	50 mm
Bearing length	L	100 mm
Bearing clearance	c	0.145 mm
Eccentricity ratio	ε	0.14; 0.61; and 0.81
Density of lubricant vapour	ρ_{sat}	2 x 10^5 Pa-s
Viscosity of lubricant vapour	η_{sat}	1.2 kg/m^3
Saturation pressure of a vapour	P_{sat}	20.000 Pa
Lubricant density	ρ	840 kg/m^3
Lubricant viscosity	η	0.0127 Pa-s

Solution method

The solution method is a setup process where parameters such as momentum, volume fraction, turbulent kinetic energy are determined by discretion. In this study, pressure-velocity coupling uses a SIMPLE scheme. Whereas first order upwind is used to discretize momentum, volume fraction and turbulent kinetic energy, this type is used because this discretization has produced quite accurate results. After defining the solution method then the calculation is done. If the results do not reach convergence and divergence occurs, it is necessary to determine the solution control. The smaller the parameter value at each solution control, the easier it will be to achieve convergence, but the results are not more accurate than the solution control which has a solution control parameter that has a high accuracy.

Before conducting a case of study, first, determine the independent mesh in the modelling process. This aims to prove that the results obtained by this modelling are not affected by the meshing. The results of the mesh independent can be seen in the load support value of the calculation in Figure 2. The independent mesh graph in Figure 2 starts linear when the mesh size approaches element size 0.5 mm. This indicates that the mesh used is independent and can be used for modelling.

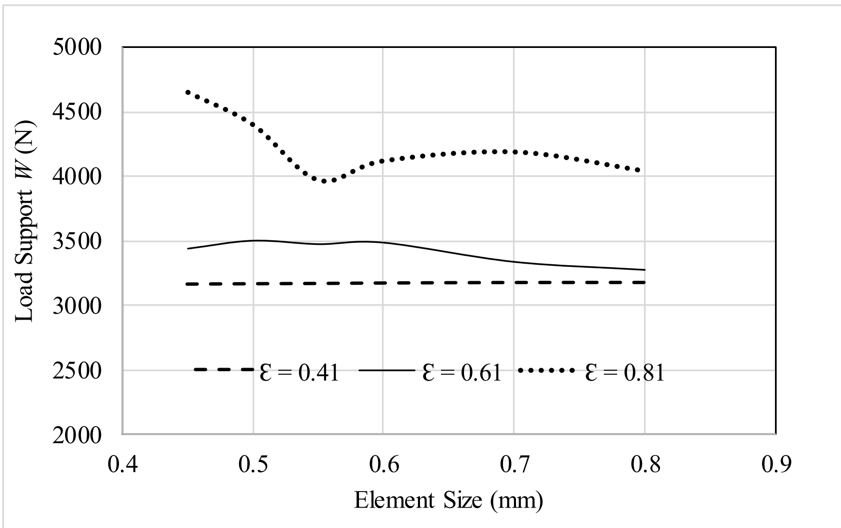


FIGURE 2. Effect of element size on the predicted load support W for different eccentricity ratios ε.

RESULTS AND DISCUSSION

Figure 3 shows the effect of the eccentricity ratio on the hydrodynamic pressure profile over the lubricated contact. Two specific features can be drawn from Figure 3. Firstly, the larger the eccentricity ratio, the smaller the hydrodynamic pressure resulted. This is as expected because increasing the eccentricity ratio will increase the supply of the lubricant and thus the minimum film thickness. Secondly, when the large eccentricity ratio is used, the cavitation region seems to be bigger compared to other eccentricity ratios. Based on Figure 3, for the case of ε = 0.81, the cavitation region predicted occurs at $\theta = 180^{\circ}$ to $\theta = 270^{\circ}$ o, while for smallest ε (ε = 0.41 in this case), the cavitation region occurs at $\theta = 200^{\circ}$ to $\theta = 285^{\circ}$. From the physical point of view, it indicates that the cavitation phenomena becomes larger at the bigger ε. This is as expected because, for larger ε, the lubricant must be supplied much more, and as a consequence, the area in which the phase changes will become bigger. This result can be compared with the case of slider bearing as discussed by Muchammad et al. [4].

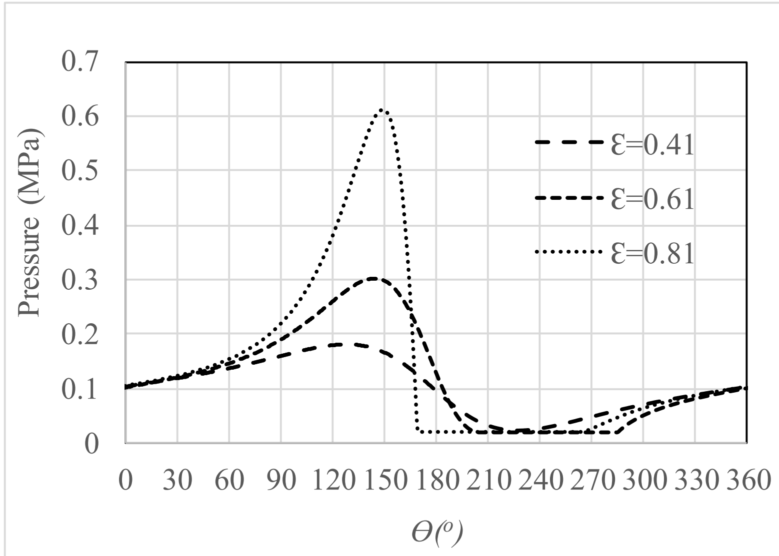
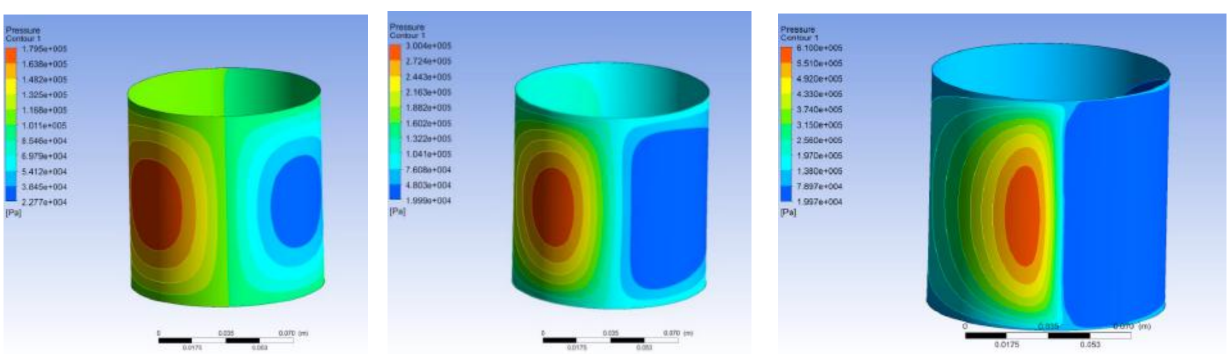


FIGURE 3. Hydrodynamic pressure profile over the lubricated contact varying the eccentricity ratios.

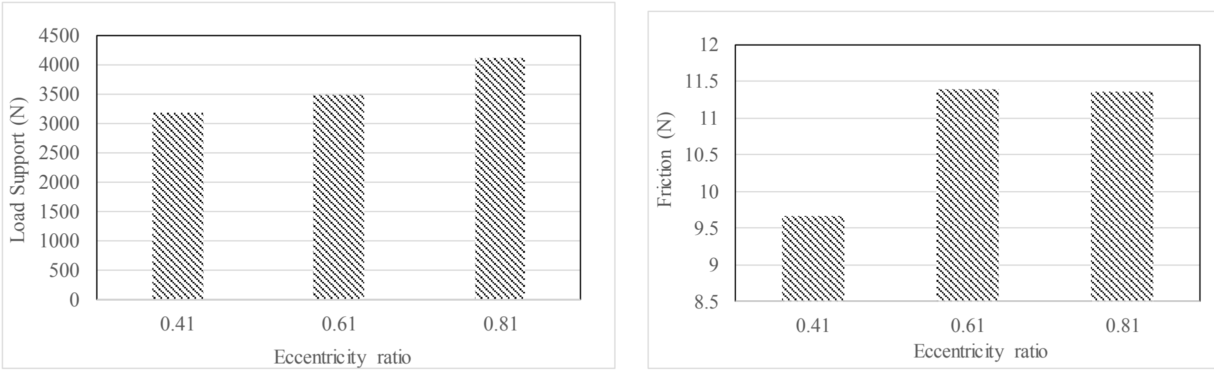
Figure 4 shows the contour of hydrodynamic pressure over the lubricated contact containing divergent and convergent areas for different eccentricity ratios. It can be observed that for high eccentricity ratio (ε = 81 in this case), the highest hydrodynamic pressure locally occurs at $\theta = 120^{o}$-170^{o} and the minimum hydrodynamic pressure is found at θ 170^{o}-300^{o}. Based on Figure 4, it can also found that increasing the eccentricity ratio will reduce the area of high hydrodynamic pressure. This is the reason why the bearing with low ε generates lower load support compared with higher ε.



(a) (b) (c)

FIGURE 4. Hydrodynamic pressure contour over the lubricated contact varying the eccentricity ratios: (a) ε = 0.41, (b) ε = 0.61, and (c) ε = 0.81

Figure 5 reflects the predicted load support as well as the friction force for different eccentricity ratios. It can be observed that in terms of load support, increasing the eccentricity ratio generates higher load support (up to 22% for ε = 0.81). With respect to the friction force, there is an interesting result. Bearing with low ε generates lower friction, but for ε = 0.61 and ε = 0.81, the friction force is slightly the same. It indicates that there is an optimal value of friction force for the eccentricity ratio, which means that increasing the eccentricity ratio does not affect the friction force very much.



(a) (b)

FIGURE 5. Prediction of (a) load support and (b) friction force varying the eccentricity ratios.

CONCLUSION

The present study explored the effect of eccentricity ratio on the hydrodynamic performance of the journal bearing taking into account the multi-phase cavitation model. The CFD approach is adopted to predict the hydrodynamic pressure, the load support and the friction force. Based on the discussion mentioned earlier, it was concluded that the larger the eccentricity ratio, the biggest the maximum hydrodynamic pressure, and as a consequence, the largest load support is achieved. In addition, there is an optimal value of the eccentricity ratio for predicting the friction force. This finding can be used as a guideline to design the journal bearing varying the eccentricity ratios.

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