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Interaction of inertia and cavitation in textured hydrodynamically lubricated bearing in very low sliding velocity considering slip

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Abstract. Surface texturing is becoming an effective way for increasing the performance of hydrodynamic bearings. However, introducing the texture on the lubricated sliding contact may lead to the presence of the inertia effect as well as the cavitation effect. In this study, the correlation between the inertia and the cavitation in textured bearing is investigated in terms of hydrodynamic pressure and load support. The Navier-Stokes equation based on CFD and modified Reynolds equation are applied. In addition, the use of slip condition and its effect on the performance of bearing is of particular interest. The simulations are conducted in very low sliding velocity to address the low inertia effect. The result shows that increasing inertia effect can increase the load support, but the cavitation effects is not found in the bearing pattern in which the inertia is not significant. The other interesting result concludes that slip reduces the load support, but on the other hand slip also increases the load support depending on the texture length.

1. Introduction

Textured surface have become an effective technique to improve the tribological performance of lubricated mechanical components. It is known that by introducing textured surfaces significantly can affect the load support of sliding bearings. In recent years, a great deal of effort has been addressed to consider the effect of the texture's geometric parameters on the lubrication performance. However, as is well known, when the texture is applied on the bearing, the inertia as well as the cavitation may exist and affect the lubrication performance.

Many researchers expressed that the inertia has a strong impact on the bearing performance either numerically [1,2,4,5,7] or theoretically [3,6,8]. Based on the numerical simulations, Dobrica and Fillon [1] analysed the validity of Reynolds equation and proposed on how to take into account the inertia effect in modelling textured infinitely wide parallel sliders. These results showed that inertia has negative effects, reducing the load capacity of the slider.

However, texture on bearings may create significant issues such as the emergence of cavitation zone. Therefore, cavitation is strongly recommended to be considered in solving the hydrodynamic problem.

Fowell et al. [9] observed the entrainment and inlet suction of two mechanisms of hydrodynamic lubrication in textured bearings. Their observation claimed that to get a great load support of pocketed bearings, the cavitation pressure should be as low as possible. On the other study, Shi and Ni [10] using the numerical method studied the effects of groove textures on fully lubricated sliding with cavitation. The simulation results showed that with the increase of cavitation pressure, the hydrodynamic pressure effect becomes more pronounced, while the friction force does not change very much.

Along with the development of technology, in order to get the best performance, the bearing surface can be modified by applying an artificial slip using a hydrophobic coating. The studies of the beneficial of slip have been investigated by Rao et al. [11], Zhang et al. [12], Tauviqirrahman et al. [13], Cheng and Ji [14]. Their results leads to the similarity of conclusions. All of them agree that the slip in certain pattern enables improvement of the tribological performance. In contrast, Zhang et al. [15] studied concluded that slip causes the pressure drop. Based on literature survey, one can find that most of studies have not considered the cavitation model in detail, and they do not consider the inertia term in their model.

Based on literature survey, one can find that the correlation between the inertia and the cavitation in lubricated sliding contact is still not clear, especially when the slip situation is applied. Thus, in this study, the interaction between inertia effect and cavitation condition considering slip is explored. In hydrodynamic problem of textured bearing is solved using modified Reynold equations (with slip) and compared to the CFD approach based on Navier-Stokes equation. In addition, the cavitation model is taken into account both for Reynolds equation and Navier-Stokes equation.

2. Methods

Figure 1 represents the illustration of a two-dimensional slider bearing model of single textured sider bearing. Slider bearing applied consists of two parallel walls with one as a stator (stationary wall) and another wall as the moving wall. The texture is on the stationary wall.

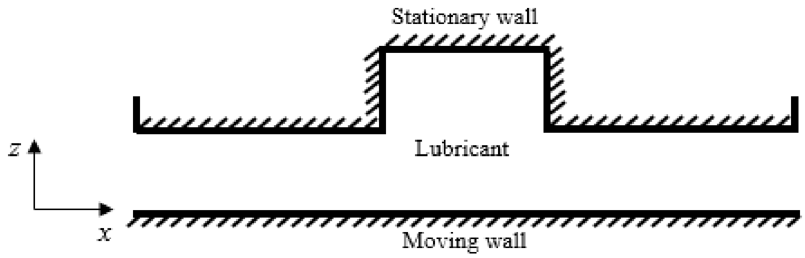


Figure 1. Model of two-dimensional slider bearing.

The main parameters of two-dimensional geometry model of slider bearing are follows: B_0=2x10^{-3} m (the length of bearing), h_0 = 4 x 10^{-6} m (the minimum film thickness), h_d = 4 x 10^{-6} m (the texture depth), a = 0.75 x 10^{-3} m (the inlet length), the value of b (the texture length) is varied i.e. 0.25 x 10^{-3}, 0.50 x 10^{-3} and 0.75 x 10^{-3} m, c as the outlet length is also varied depending on the value of the texture length. The parameters are detailed on Fig. 2. Assuming the fluid material applied had a value of density (ρ) and dynamic viscosity (μ) of 962 kg/m^3 and 0.013468 Pa.s. The velocity of moving wall U is 0.1 m/s is assumed as corresponding the Reynolds number Re is 0.028. In the following study, the coefficient of slip is 0.02 based on study of Muchammad et al. [16].

In the present study, to explore the correlation between the inertia, the cavitation, and the slip, three textured bearings are of main particular interest. First, the bearing with low texture length (b = 0.25 mm). Second, the bearing with medium texture length (b = 0.50 mm) and third the bearing with high texture length (b = 0.75 mm). The variation of b is aimed to alter the inertia effect. In the analysis, when slip is particular interest, the slip is implemented to all stationary surface including the texture cell as mentioned before. It should be noted that in this analysis, the inlet length a is set to constant, i.e 0.75

mm. As a consequently, when b value is varied, the outlet length c will change. For all following computation, the texture depth h_d is set to 4 μm, which means that $h_d = h_0$.

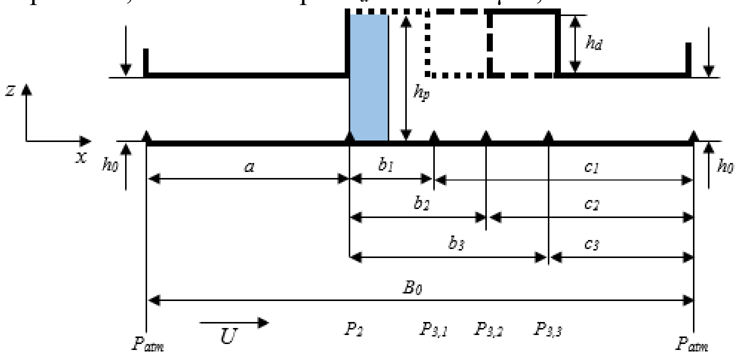


Figure 2. Geometry of two-dimensional slider bearing.

To investigate the effect of inertia on hydrodynamic lubrication with boundary wall slip and considering cavitation, modifying Reynolds equation and numerical simulation by the computational fluid dynamics method are set.

2.1. Reynold Equation

An analytical equation based on first-order derivation of Reynolds approach is used in this present study. In this approach, the Reynolds equation is modified by including slip and cavitation. For detail, derivation of equation (1) the reader can refers to the published work of Muchammad et al. [16]. To resolve the problem using the governing equations employing an analytical solution for the slip case is:

$$P_2\left[\left(h_p^3+3h_p^3K_p\right)\frac{ab+bc}{ab^2}+\left(\frac{h_0^3+3h_0^3K_0}{a}\right)\right]=P_{atm}\left[\left(h_p^3+3h_p^3K_p\right)\frac{ab+bc}{ab^2}+\left(\frac{h_0^3+3h_0^3K_0}{a}\right)\right]$$
$$-6\mu U\left[\left(h_p+h_pK_p\right)-(h_0+h_0K_0)\right] \quad (1)$$

In this study, the load support W is also particular interest.

2.2. Navier – Stokes Equation

In the current study, the hydrodynamic lubrication is investigated by the Navier-Stokes equations using the commercial CFD software package FLUENT® which are determined over the domain applying a finite-volume method. The Navier–Stokes and the continuity equations can be represented, respectively, as [17]:

$$\rho\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}\right)-\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right)+\frac{\partial p}{\partial x}=0 \quad (2a)$$

$$\rho\left(u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}\right)-\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right)+\frac{\partial p}{\partial y}=0 \quad (2b)$$

$$\rho\left(u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}\right)-\mu\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right)+\frac{\partial p}{\partial z}=0 \quad (2c)$$

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \quad (3)$$

2.3. CFD Model

The flow is assumed to be turbulent, incompressible, steady and using the Newtonian fluid. In the current study, the moving wall is varied by applying the full slip (boundary slip is applied on the entire surface of stationary wall including the surface of texture) and no slip boundary condition. The slippage boundary condition is shown in the Figure 3. At the inlet and outlet of the domain, the pressure was set to atmospheric and a zero velocity gradient in the direction normal to sliding was assumed. This can also be thought of as a fully developed flow approximation. The various parameter about cavity phenomenon (i.e. cavitation and no cavitation) is applied in the present work.

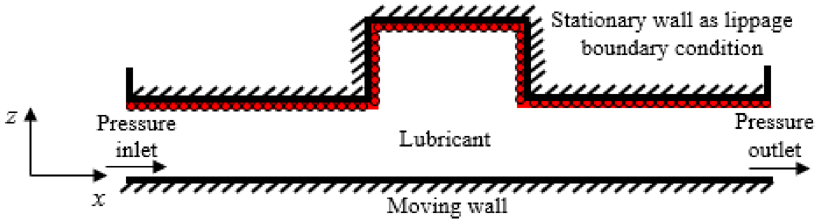
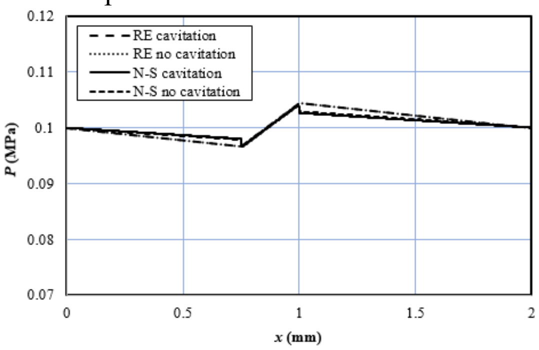


Figure 3. Slippage boundary condition of two-dimensional slider bearing.

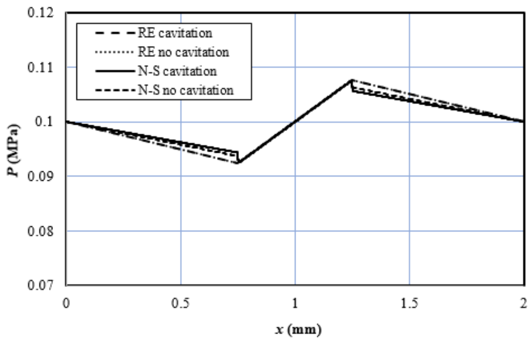
3. Results and discussions

In this research, all of simulations were performed in the low inertia condition referring to the work of Dobrica and Fillon [1]. In this present study, the Reynolds number was set to 0.028, which means that the Navier-Stokes prediction and Reynolds equation have very close prediction [1]. This research is aimed to explore the inertia effect on the load support considering cavitation for slip and no slip situation.

Figure 4 shows the comparison between the Reynolds equation and the Navier-Stokes equation in terms of hydrodynamic pressure distribution varying texture length for the slip situation. It can be seen from Figure 4. that the deviation between the Reynolds equation and Navier-Stokes equation is not significant for all value of b with and without cavitation model. However, when it is solved by NSE, there is a pressure jump in the edge of the texture cell. This prevails, for the case of cavitation and no cavitation. For the case of the bearing with low texture length (i.e b = 0.25 mm), the pressure profile predicted by both Reynolds equation and Navier-Stokes equation with/without cavitation model is quite lower than that with higher b. However, for low b 0.25 mm, in this case, the cavitation region is also lowest. Based on the physical point of view it means the lowest b can achieve the highest load support. In general speaking, for the bearing with low inertia, the Reynolds number is quite effective to solve the lubrication problem.



(a)



(b)

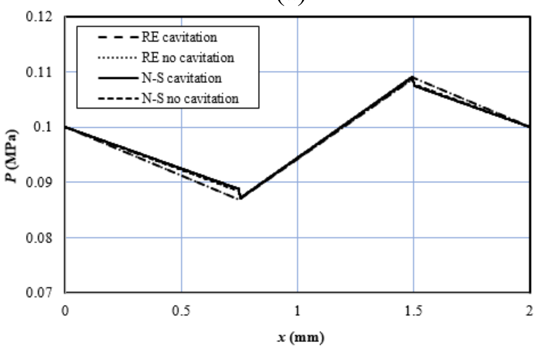
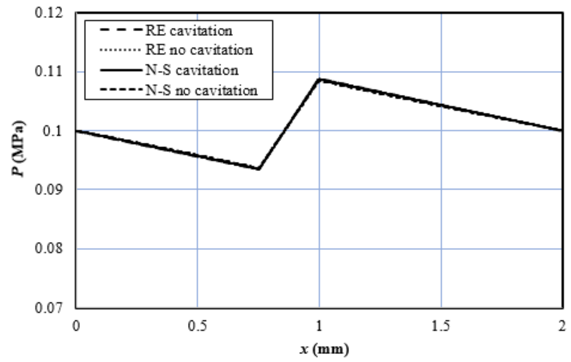


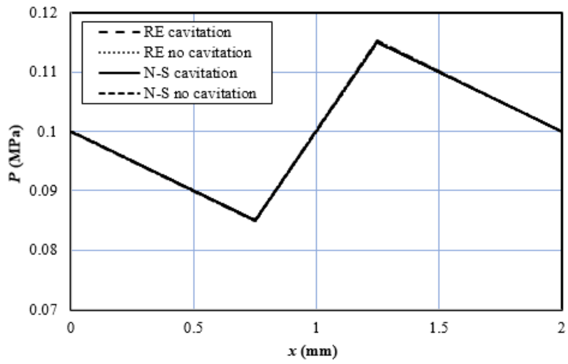
Figure 4. Pressure distribution in slip condition on texture length (a) b = 0.25 mm, (b) b = 0.50 mm and (c) b = 0.75 mm.

(c)

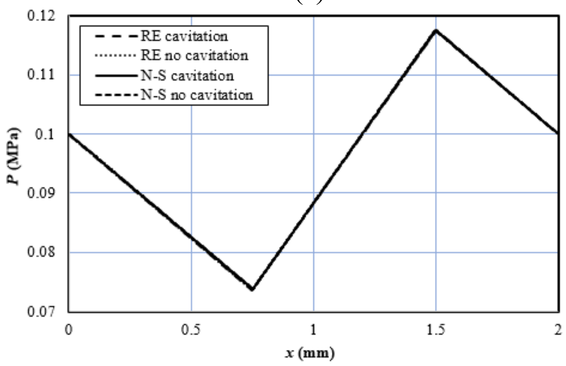
From Figure 5 it can be observed that prediction of RE and NSE in terms of hydrodynamic pressure are similar, it indicates that the inertia has no significant role in this pattern. Based on Figure 5 it can be seen that the increasing the texture length does not affect the cavitation effect. Based on the physical point of view it can be concluded that when the bearing is designed to have a low inertia effect, the cavitation effect does not change very much.



(a)



(b)



(c)

Figure 5. Pressure distribution in no-slip condition on texture length (a) b = 0.25 mm, (b) b = 0.50 mm and (c) b = 0.75 mm.

The inertia effect can be obtained by comparing the NSE and RE. Figure 4 shows that for the case of slip situation, the deviation between the Navier-Stokes and Reynolds equation is observed. Based on the pressure distribution between NSE and RE in slip conditions, there are differences at the peaks and valleys of the graph. But the difference is very small. It means that the slip condition can increase the inertia effect even though it is very small. Different results are shown in Figure 5 where no slip are applied. The pressure distribution looks the same between NSE and RE in all variations b (texture length).

The most significant founding of this research is the fact that the slip has two influences on the load support: Slip can reduce the load support W but at the sametime, slip can increase the load support. It can be observe from Table 1 that for low texture length b, the load support can be reduced by the slip up to ±1%. But for the case with high b, the load support can be improved by the slip ±3%. It seems that there is an "optimal value of texture length b". However, the investigation regarding to the optimal value of b is out of the scope.

Table 1. Load support of slider bearing.

Parameters	Load Support (Pa.m^2)					
	Reynolds Equation (RE)			Navier-Stokes Equation (NSE)		
	b = 0.25 mm	b = 0.50 mm	b = 0.75 mm	b = 0.25 mm	b = 0.50 mm	b = 0.75 mm
Slip and cavitation	201.107	200.000	195.598	200.655	199.996	196.256
No-slip and cavitation	202.215	200.030	191.180	202.167	199.999	191.282
Slip and no cavitation	201.107	200.000	195.598	200.738	199.995	196.127
No-slip and no cavitation	202.215	200.030	191.180	202.083	199.999	191.262

Note: Load support is defined as the integration of pressure over the surface area.

4. Conclusions

The hydrodynamic pressure in single textured bearing with slip and no slip condition, considering and not considering cavitation has solved by the modified Reynold equation (RE) and Navier-Stokes (N-S) solution. The effect of texture length variation is of particular interest. Based on the results and discussion, the following conclusion can be drawn as follows:

1. Increasing the inertia effect (i.e lowering texture length *b*) can increase the load support for all situation (slip or no slip, cavitation or no cavitation),
2. Slip can reduce the load support, but on the other hand slip also can increase the load support depending on the texture length,
3. The cavitation effects is not found in the bearing pattern in which the inertia is not significant.

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