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Cavitation modelling effect on pressure distribution of inclined lubricated contacts and textured surfaces using CFD

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KEYWORDS

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Cavitation
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ABSTRACT

In liquid lubricated contact, cavitation is often found and directly influences the hydrodynamic pressure profile. However, a large number of reseachers working on textured bearing still often neglected the cavitation phemonena. In this paper, the effect of cavitation on the lubrication performance is discussed, based on a CFD model. The comparison between the case of "no-cavitation" and the "with cavitation" for the lubrication analysis is performed for the case of inclined lubricated contact and of textured surfaces with no slip condition. Based on the simulation results, it is found that in the case of conventional (incined) slider bearing including of the cavitation modelling in the analysis gives the same prediction with the case of "no-cavitation" with respect to the pressure distribution. However, in the case of simple textured parallel slider bearing, it is highlighted that the inclusion of cavitation modeling affects the prediction of load support significantly compared to that neglecting the cavitation model.

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1.0 INTRODUCTION

A bearing is a machine element that constrains relative motion to only the desired motion, and reduces friction between moving parts. The insertion of a lubricant into the region around the interacting devices could avoid direct contact between the surfaces, so the wear can be minimized. Numerically, the cavitation analysis of hydrodynamically lubricated bearings falls into several classes, using the Sommerfeld theory, using Half-Sommerfeld theory, using Reynolds approach, or using mass-conservative approach. The first three theories are often considered as a rough approximation, because it is not based on real physical phenomenon (Braun and Hannon, 2010). For this reason, it is common practice to use the so-called mass–conservative approach in analyzing the lubrication problems. Recently, some numerical works adopt this approach were presented by Fillon's group (Dobrica et al., 2010; Bendaoud et al., 2012) and Tauviqirrahman's group (Tauviqirrahman et al., 2016; Muchammad et al., 2016).

Recent technological advances have presented some new methods such as grafting, coating, laser surface texturing, and micro machining to improve the tribological characteristic (higher low support but lower friction) of the bearing. Within the broad area of tribology, the researches relating to the lubrication have paid much attention to surface texturing, as is reflected in many recent paper. Buscaglia et al. (2007) studied the effect of one-dimensional and two-dimensional textures on the load support of a bearing with a "homogenized" effect and a homogenization error. Scaraggi et al. (2014) investigated the friction properties of the lubricated laser textured surface by tuning micro hole depth. With the aim of minimizing the friction, different surfaces characterized by different micro hole depths, but same void ratio have been explored.

Therefore, more work is required in the research area of cavitation effect to provide the needful information for the design process. The contribution of this paper is to study numerically the effect of cavitation model on the prediction of the hydrodynamic pressure based on CFD (computational fluid dynamic) approach. In particular, conventional inclined lubricated contact (i.e. bearing with slope incline ration of 2.2) and on bearings with textured surfaces in no slip condition are investigated. In the present study, the cavitation model, which governs the mass exchange between the phases, is adopted. Another contribution of this paper is to numerically study the texturing geometry (i.e. pocket texture profile) based on a general parametric model.

2.0 METHODOLOGY

2.1 Governing Equation

In this paper, in order to investigate the significance of the inclusion of the cavitation model, two configurations of bearing are presented: conventional (inclined) slider bearing and simple textured parallel slider bearing, as shown in Figure 1 and 2, respectively. The computational fluid dynamic (CFD) method is employed to analysis the lubrication problem. Navier–Stokes equations as well as the continuity equation (Equations 1) are solved over the domain using a finite-volume method with the commercial CFD software package FLUENT 16.0 ®.

$$\rho(\mathbf{u} \bullet \nabla)\mathbf{u} = -\nabla p + \eta \nabla^2 \mathbf{u} \tag{1a}$$

$$\nabla \bullet \mathbf{u} = 0 \tag{1b}$$

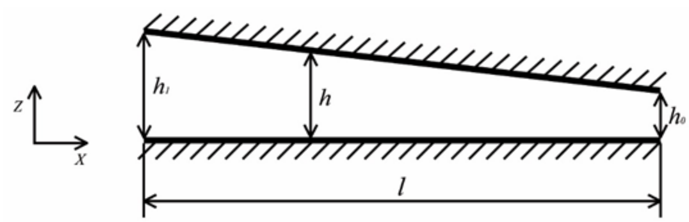

Figure 1**:** Schematic of a lubricated traditional sliding contact. (Note: h_d = dimple depth, h_i = inlet film thickness, h_o = outlet film thickness, *l* = length of textured zone, *u* = sliding velocity).

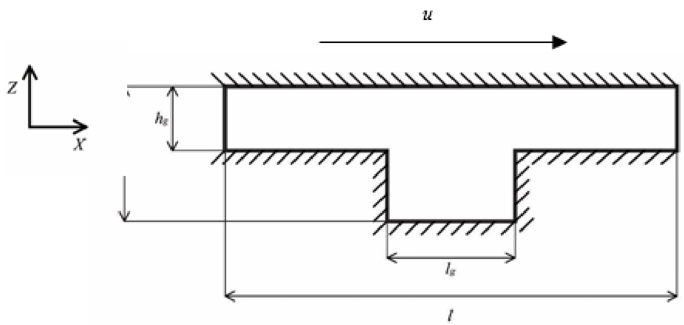

Figure 2: Schematic of the textured surfaces step slider bearing with no slip condition. (Note: h = Maximum high, hg = Minimum high, lg = length of texture zone, l = length of bearing, u = sliding velocity).

As is known, the cavitation may occur in the bearing. In FLUENT®, there are three available cavitation models: Schneer and Sauer model, Zwart-Gelber-Belamri model and Sighal. model. In this study, the Zwart-Gelber-Belamri is employed due to their capability (less sensitive to mesh density, robust and converge quickly). In cavitation, the liquid-vapor mass transfer (evaporation and condensation) is governed by the vapor transport equation (Mitidieri, 2005):

$$\frac{\partial}{\partial t}(\alpha_v \rho_v) + \nabla.(\alpha_v \rho_v v) = R_g - R_c \tag{2}$$

Where αv is vapor volume fraction and ρ_v is vapor density. R_g and R_c account for the mass transfer between the liquid and vapor phases in cavitation.

If

$$p \leq p_v, R_g = F_{evap} \frac{3a_{nuc}(1-a_v)\rho_v}{R_B} \sqrt{\frac{2}{3}\frac{P_v - P}{\rho_l}} \tag{3}$$

If

$$p \geq p_v, R_c = F_{cond} \frac{3a_v \rho_v}{R_B} \sqrt{\frac{2}{3}\frac{P - P_v}{\rho_l}} \tag{3}$$

Where F_{evap} = evaporation coefficient = 50, F_{cond} = condensation coefficient = 0.001, R_B = bubble radius = 10^{-6} m, α_{nuc}= nucleation site volume fraction= $5x10^{-4}$, ρ_l = liquid density and p_v = vapor pressure.

2.2. Discretization

In this paper, the pressure velocity coupling used is SIMPLE. The spatial discretization of the pressure is PRESTO due to convergence reason. The laminar flow in lubricant fluid is assumed since the Reynolds number is really small.

The mesh used in the inclined lubricated contact bearing consists of a block with uniform grid as shown in Figure 3. The number of grid points in the longitudinal (Nx) and transversal (Nz) directions is 100 x 50, and the total load will be observed. Table 4 shows the numerical simulation results as a comparison between Fluent software modelling and analytical modelling, which the analytical solutions that use Reynolds equation and numerical solutions have been completed by Mitidieri (2005) using FOAM computing software.

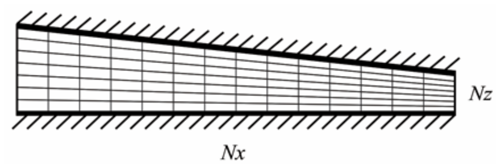

Figure 3: The mesh structure of the computational domain on lubricated traditional sliding contact (model 1).

The mesh used in the pocket texture profile step-bearing model consists of three uniform grid blocks as shown in Figure 4. The number of grid points in the longitudinal (Nx) and transversal (Nz) directions is 100 x 50.

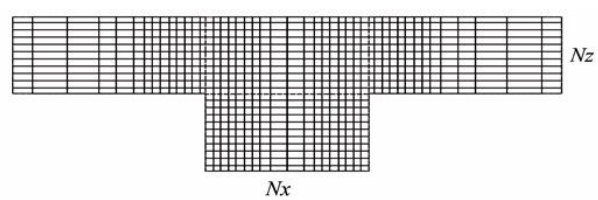

Figure 4: The mesh structure of the textured surfaces step slider bearing with no slip condition (model 2).

2.3. Operating Condition

Table 1 and 2, respectively shows the boundary condition used for pattern 1 and 2. While Table 3 depicts the geometry of the bearing used in the paper.

Table 1: Boundary condition for model 1.

Density	ρ	1000 kg/m^3
Sliding velocity	U	1 m/s
Viscosity	η	0.01 Pa s
Inlet pressure	P_{inlet}	1 Atm
Oulet pressure	P_{outlet}	1 Atm
Slope incline ratio	H ($H = h_i/h_o$)	2.2

Table 2: Boundary condition for model 2.

Sliding velocity	U	1 m/s
Density of lubricant (liquid)	ρ_l	962 kg/m^3
Density of lubricant (vapor)	ρ_v	0.02556 kg/m^3
Dynamic viscosity of lubricant (liquid)	η_l	0.013468kg/m.s
Dynamic viscosity of lubricant (vapor)	η_v	1.256 x 10-5kg/m.s
Inlet pressure	P_{inlet}	1 Atm
Oulet pressure	P_{outlet}	1 Atm

The assumption of the pressure value at the entry and exit side of slider bearing model 1 and 2 is set to zero and the velocity gradient is zero in the normal direction of the sliding. On a moving surface, a no-slip boundary condition is assumed for the flow equation. Then the velocity is considered constant, while the pressure has a zero gradient boundary condition.

Table 3: Geometry used in this analysis.

Model 1	
Length of bearing	20 mm
Maximum height	2 μm
Minimum height	1 μm
Model 2	
Length of bearing	2 mm
Length of texture	0.5 mm
Maximum height	20 μm
Minimum height	10 μm

3.0 RESULTS AND DISCUSSION

In the present study, for optimization process, the comparison between the analysis considering cavitation modelling and the analysis without cavitation is conducted and the influence of texture dimension as well as texture position should be exempted. Optimization predictions for this study are initiated by pre-setting the parameters. It is found that for the case of inclined lubricated contact with slope incline ratio of 2.2 (i.e., optimal traditional lubricated sliding contact), the prediction gives the same trend. It means that the cavitation which may occurs in the lubricant does not exists. In order to ensure that the lubricated interface was under hydrodynamic lubrication regime, the film thickness parameter (ho = 10 m) is kept constant throughout the computation processes.

Figure 5 shows the hydrodynamic pressure predicted by two methods, i.e. method considering cavitation versus method without cavitation.

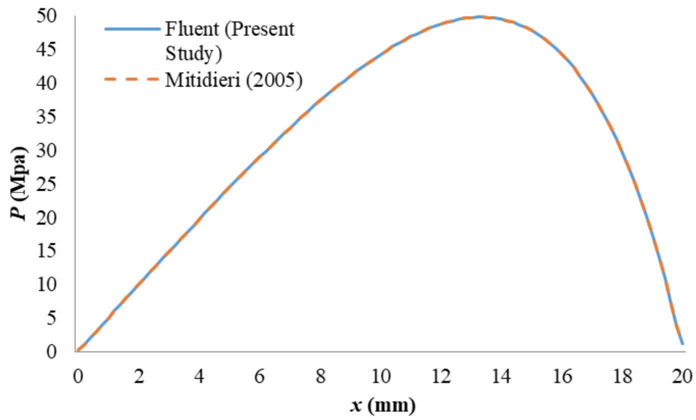

Figure 5: Pressure distributions along lubricated traditional sliding contact (model 1).

Showing the difference between the hydrodinamic pressure of the initial configuration by Mitidieri and the optimized pattern in present study, then both of them have a same trend as shown in Figure 5. It means that no cavitation takes place in first model.

This is as expected because the wedge effect of the inclined slider bearing prevents the occurrence of the cavitation. For this reason, in order to reduce the computational time, for design analysis of the lubricated contact, in particular for the cases of the inclined bearing, the cavitation modelling may not be used. For detail, Table 4 depicts the deviation of the prediction by two methods regarding to the shear stress and profile distribution.

Table 4: Load support, friction, and maximum pressure on inclined slider bearings.

	W (N)	**F (N)**	**P_{max} (MPa)**
Fluent (Present study)	632.821	0.154	49.760
Mitidieri (2005)	632.822	0.153	49.770
Δ (%)	1.583	-0.006	0.0002

Figure 6 and Figure 7 shows the comparison between the hydrodynamic pressure of the initial configuration by Olver et al. (2006) and that of the optimized pattern in present study. It can be observed that based on the optimization process, the hydrodynamic pressure profile increases significantly along the contact area. In the textured area, it can also be highlighted that the pressure peak in the case of optimized pattern increases up two times compared to the initial pattern.

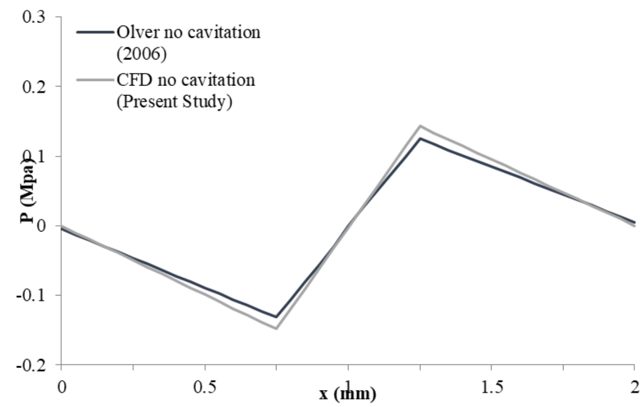

Figure 6: Pressure distribution along the lower wall of the textured surfaces step slider bearing without cavitation.

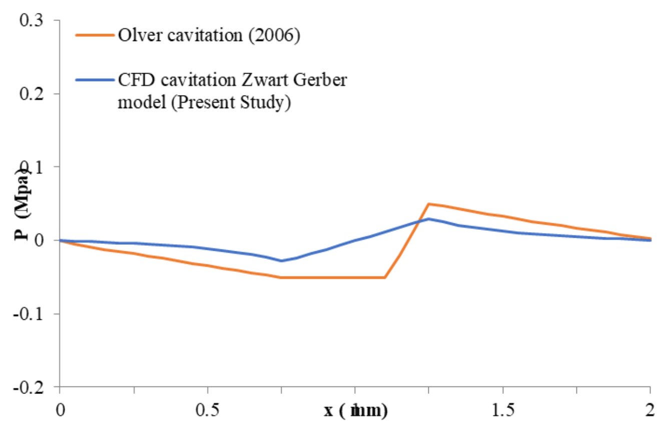

Figure 7: Pressure distribution along the lower wall of the textured surfaces step slider bearing with cavitation.

Based on Figure 7, it can also be reflected that there is a shift of the starting point of the texture profile. For this reason, cavitation modelling is very important to be considered because there is a difference results between no-cavitation modelling and with cavitation modelling, so that the pressure distribution comparison between the hydrodynamic pressures of the initial configuration by Olver can be obtained as shown in Figure 8.

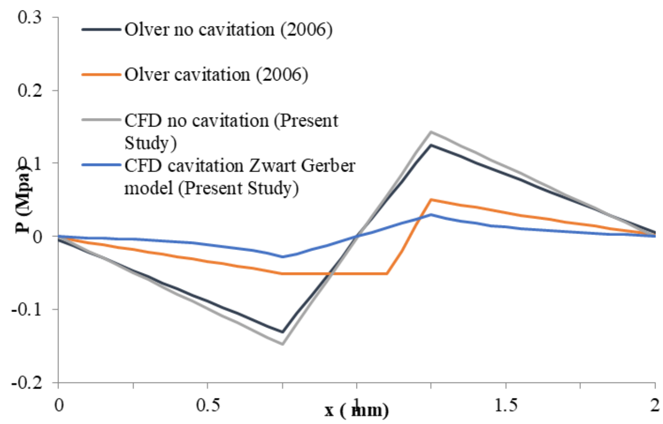

Figure 8: Comparison of pressure distribution along the lower wall of the textured surfaces step slider bearing with no slip condition.

This figure shows that on the step slider bearing texture occurs cavitation which affects the load support. From the physical point of view, the slip boundary decreases the gradient along the slip area (i.e. inlet length), and this generates the increased hydrodynamic pressure. Other interesting result is the origin of the pattern. Again, it strengthens the previous statement that the slip has more dominant effect in the case of texture length in this case. This result is in a good agreement with recent publication.

4. CONCLUSIONS

The aim of the investigation was to examine the effect of the cavitation model on the inclined lubricated sliding contact by using CFD software. It can be concluded that taking into account of the cavitation model in the analysis gives the same prediction with respect to pressure compared with the case of “no cavitation”. Numerical analysis also shows that texturing can be a trigger to lead of the cavitation phenomena. Thus, in order to obtain more accurate results, one cannot neglect the cavitation modelling for the bearing with texturing.

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