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Hydrodynamic lubrication with deterministic micro textures considering fluid inertia effect

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ABSTRACT

Although, Reynolds equation is widely used in thin film lubrication, its use in textured surfaces is not fully convincing, especially while operating in moderate to high Reynolds numbers. Fluid inertia which is generally neglected in Reynolds equation becomes significant. Therefore, an attempt has been made to study the lubricating performance of textured parallel sliding contacts considering fluid inertia effect. The modified Reynolds equation is derived from Navier–Stokes equation assuming suitable velocity profiles and retaining the inertia terms, and solved iteratively using finite difference method. The result shows that fluid inertia effect is influential in altering the performance parameters.

1. Introduction

The basic assumption in thin film lubrication includes negligible fluid inertia forces in comparison to viscous forces. In recent developments, lubricants with low or high viscosity, e.g. synthetic lubricants, specifically even with high velocities are also used in industries. Because of high velocity it is possible to attain such a situation where flow is laminar but fluid inertia forces are significant. Hence, this assumption may not hold good for such situations with increasing Reynolds number or for abrupt change in film thickness as in the case of textured surfaces, where the inertia forces could be the same order of viscous forces. Therefore, the fluid inertia effect should be considered in hydrodynamic lubrication of textured surfaces. Performance characteristics of plain journal bearing and thrust bearing considering fluid inertia effect have been explored by various researchers. Constantinescu et al. [1] theoretically studied the effect of fluid inertia on velocity profiles of fluid film lubrication. They noticed that fluid inertia has a negligible effect on the velocity profiles when longitudinal flow is considered. Effect of fluid inertia on externally pressurised rectangular gas bearings are analysed by Salem and Shawky [2]. They observed that for viscous inertial flow, sliding velocity and film thickness has considerable effect on pressure distribution and consequently on load support. Abdel-Latif and Abdel-Monem [3] noticed that in thermo-hydrodynamic condition of thrust bearing with michell pads, inertia forces play a significant role on the bearing performance characteristics. Another approach with CFD analysis by Gandjalikhan Nassab [4], showed that in thermo-hydrodynamic analysis of journal bearing, fluid inertia has significant effect on load support as compared to temperature field. Furthermore, in MHD porous thrust bearings, Zaheeruddin [5] observed that fluid inertia plays a vital role on the load support and flow flux. The combined effect of turbulence and fluid inertia in different applications are explained by Frene et al. [6]. The effect of inertia in squeeze film air contact is analysed by Stolarski and Chai [7] and they noticed that fluid inertia shows negligible effect on load support. Kakoty and Majumdar [8] investigated the effect of fluid inertia on the stability of oil journal bearings under unidirectional constant load. They found that fluid inertia is not affecting much the steady-state characteristics but it shows considerable effect on the stability of oil bearing.

Surface texturing is a feasible method to improve hydrodynamic lubrication performance in parallel sliding contacts. A considerable work has been carried out on the effect of surface textures in hydrodynamic lubrication performance of parallel thrust pad bearings [9–16]. However, most of the available work deals with classical Reynolds equation where fluid inertia has been neglected. Due to surface texturing, a sudden change in geometry occurs at the edges of textures, where effect of fluid inertia may become predominant. Limited literatures are available on textured parallel sliding contacts considering fluid inertia effect. Sahlin et al. [17] carried out 2-D CFD analysis on parallel sliding contacts with circular and splined grooves. Their results indicated that load support increases with increase in Reynolds number and groove width.

Feldman et al. [18] numerically analysed the applicability of Reynolds equation in hydrostatic gas lubricated textured parallel surfaces. They have observed that if film thickness is less than 3% of dimple diameter, then the results of Reynolds equation is valid. On the other hand, in case of oil lubricated contacts, Dobrica and Fillon [19] computationally studied the use of Reynolds equation

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Nomenclature

$\bar{a}$	aspect ratio (area of textured surface/area of unit cell)
C	maximum clearance between the surfaces
F, $\bar{F}$	friction force, ($\bar{F} = FC/\eta U L_X L_Z$)
h, $\bar{h}$	film thickness of the lubricant ($\bar{h} = h/C$)
h_g, $\bar{H}$	height of the texture ($\bar{H} = h_g/C$)
k	ratio of the unit cell lengths (L_X/L_Z)
l	length of the square protrusion
L_X	length of the unit cell in x-direction
L_Z	length of the unit cell in y-direction
N_x, N_z	mesh size in x, and z directions respectively
p, $\bar{p}$	pressure of the lubricant film ($\bar{p} = pC^2/\eta U L_X$)
Q, $\bar{Q}$	end flow in z-direction ($\bar{Q} = Q/UCL_X$)
Re, $\overline{\text{Re}}$	Reynolds number ($\overline{\text{Re}} = \text{Re}(C/L_X)$)
u, $\bar{u}$	velocity component in x direction ($\bar{u} = u/U$)
v, $\bar{v}$	velocity component in y direction ($\bar{v} = vL_X/UC$)
w, $\bar{w}$	velocity component in z direction ($\bar{w} = w/U$)
W, $\bar{W}$	load support ($WC^2/\eta U L^2{}_X L_Z$)
$\bar{x}$, $\bar{y}$, $\bar{z}$	dimensionless coordinates (x/L_X), (y/C), (z/L_Z)
$\mu(L_X/C)$	friction parameter
η	dynamic viscosity of the lubricant
ρ	density of the lubricant

in textured sliders considering infinite width. Their result depicts that use of Reynolds equation not only depends on Reynolds number but also depends on dimple length to depth ratio. Moreover, they have also noticed that Reynolds equation is applicable when difference in local pressure is less than 10% with respect to Navier–Stokes model. Cupillard et al. [20] numerically analysed inertia effect on textured parallel sliders using Navier–Stokes equation and Stokes equation. Two types of models were solved using finite volume method with software package CFX 11.0. They observed that inertia effect may show positive or negative results depending on texture depth. More so, recirculation of fluid in dimples is a crucial factor for pressure building. Traore and Wang Li [21] studied the textured wall surfaces, for the prediction of wear and drag in 2D micro-asperities using flow simulation of Solidworks 2010. They observed that sliding wear and drag are influenced by speed and texture height. Moreover, texture height should be as small as possible or a combination of flow speed and texture height values that will give optimum result.

In the present work, a theoretical model is developed to study the influence of texture shapes on hydrodynamic lubrication performance of parallel sliding contacts including fluid inertia effect. Furthermore, effect of multi-texture in transverse direction, and orientations of elliptical and triangular textures are also studied.

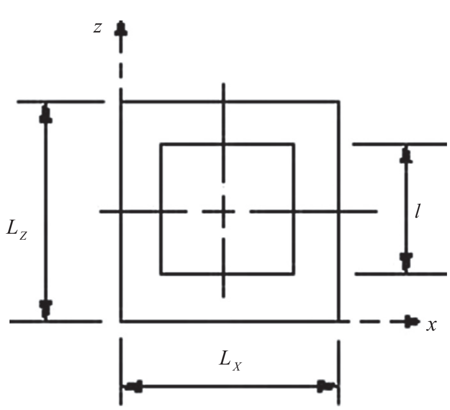

Fig. 1. Single unit cell.

2. Theory

2.1. Numerical model of surface texture

In this present analysis, it has been assumed that textures are uniformly distributed on stationary surface of parallel sliding contacts. A single unit cell is considered for the analysis by keeping appropriate boundary conditions along the edges of unit cell. The lengths of a unit cell is L_X and L_Z and the unit cell is assumed to be square shape as shown in the Fig. 1. The cross-sectional view of unit cell along the texture is shown in the Fig. 2, where, texture height/depth 'h_g' and clearance 'C' between the two parallel surfaces are specified. The available gap or film thickness between the slider and stationary textured surface is given as

for positive texture,

$$h = \begin{cases} C - h_g & \text{above the protrusion} \\ C & \text{elsewhere} \end{cases} \tag{1}$$

and for negative texture,

$$h = \begin{cases} C + h_g & \text{above the recess} \\ C & \text{elsewhere} \end{cases} \tag{2}$$

Texture height h_g is constant over x and z direction for all texture shapes except ellipsoidal texture as shown in the Fig. 3 and it is

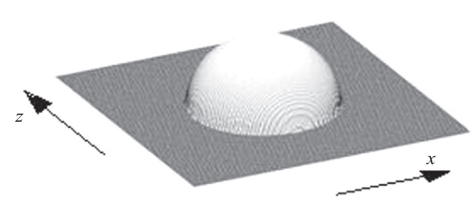

Fig. 3. Ellipsoidal texture on a unit cell.

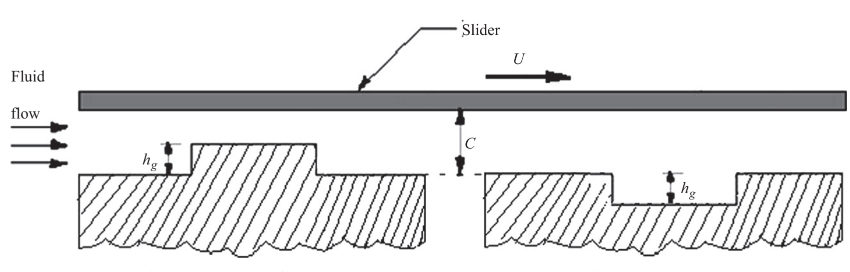

Fig. 2. Cross-sectional view of single model cell.