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Effect of roughness on hydromagnetic squeeze films between porous rectangular plates

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ABSTRACT

The theoretical investigations made in this paper are to study the combined effects of unidirectional surface roughness and magnetic effect on the performance characteristics of a porous squeeze film lubrication between two rectangular plates. The stochastic Reynolds equation accounting for the magnetic effect and randomized surface roughness structure is mathematically derived. The expressions for dimensionless pressure, load carrying capacity and squeeze film time are obtained. Results are computed numerically and it is observed that a roughness effect enhances pressure, load carrying capacity and squeeze film time.

1. Introduction

Early lubrication theories using the Reynolds equation neglected roughness and assumed perfectly smooth surfaces but as the clearance between the bearing surfaces decreases, the effect of surface roughness becomes significant. In general, the roughness asperity height is of the same order as the mean separation between the lubricated contacts. There are two types of averaged value methods have been proposed to model the large number of roughness asperities on the bearing surfaces.

1) Christensen [1] postulated a stochastic model for directional roughness. Christensen and Tonder [2] presented two types of one-dimensional roughness, the longitudinal and transverse ones, with striations parallel or perpendicular to the sliding directions. Two averaged equations were obtained that were widely used by many researchers [3–8].
2) Patir and Cheng [9] postulated an averaged flow model for directional or isotropic roughness. They introduced flow factors into a traditional Reynolds equation to derive a modified Reynolds equation. Although the theory derived from the average flow model gave a good explanation of the average pressure in the journal bearing, it failed to predict the local pressure oscillations around surface irregularities with the lubricated conjunction.

Christensen's stochastic theory was successfully used by Prakash and Tiwari [10,11] to study the effect of surface roughness on the lubrication of porous bearings. The study of surface roughness on the lubrication of porous bearings is of greater importance mainly because the roughness is inherent in the process used for their manufacture. Naduvinamni et al. [12,13] used stochastic theory to study surface roughness effects on the characteristics of couplestress squeeze films between isotropic and anisotropic porous rectangular plates. When two porous surfaces approach each other only part of the fluid between them is squeezed out, remaining flows out through media and thus the bearing capacity decreases and the film thickness attained in a specific time also decreases. Wu [14] and Prakash and Vij [15] analyzed and discussed the behavior of the squeeze film when one surface was porous and backed by an impermeable solid wall. Further, the reason for choosing rectangular plate geometry is that, this is the simplest geometry which can show the important effects of one-dimensional roughness on a two-dimensional bearing surface. It is also possible to obtain semi-analytical solutions, unlike other two-dimensional geometry. In addition the side leakage effects can be studied and the distinction between one-dimensional roughness and isotropic roughness can be easily made.

The aim of this paper is to study the combined effect of surface roughness and magnetic effect on the squeeze film lubrication of porous rectangular plates. The study of squeeze film lubrication between two rough surfaces is quiet important to clarify the contact situation between two mating surfaces during squeezing effect in conjunction with the surface topography. It is shown that the applied roughness and magnetic field enhances the pressure,

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Nomenclature

a	length of the plate
b	width of the plate
B_0	applied magnetic field in z-direction
d	a/b aspect ratio
$\overline{h}$	Non-dimensional film thickness
h_0	initial film thickness
$\overline{c}=\frac{c}{h_0}$	non-dimensional roughness parameter
$\overline{\delta}=\frac{\delta}{a}$	Thickness of the porous facing
k	permeability of porous facing
m'	porosity
M_0	Hartmann number, $\frac{B_0 h_0}{\sqrt{\sigma/\mu}}$
$E(p)$, P	pressure in the film and porous region, respectively
$\overline{p}$	dimensionless pressure $=-\frac{E(p)h^3}{\mu a^2 dh/dt}$
t	time
u,v,w	velocity components in film region
$\overline{u},\overline{v},\overline{w}$	velocity components in porous region
$\overline{W}$	$-\frac{E(w)h^3}{\mu a^3 b dh/dt}$, Dimensionless load
x,y,z	rectangular co-ordinates
α_m	$\frac{m\pi}{a}$
β_n	$\frac{n\pi}{b}$
γ_{mn}	$\frac{\pi}{a}(m^2+d^2n^2)^{1/2}$
$\overline{\gamma}_{mn}$	$a\gamma_{mn}$
μ	viscosity of fluid
σ	conductivity of fluid
ψ_0	$\frac{k\delta}{h_0^3}$, permeability parameter
ΔT	$-\frac{h_0^2 E(w)}{\mu a^3 b}\Delta t$ dimensionless squeeze film time

load carrying capacity and time of approach and the results are compared with corresponding non-magnetic and non-roughness case [14,16].

2. Mathematical formulation and solution of the problem

A schematic diagram of the squeeze film geometry is shown in Fig. 1. Consider a squeezing flow between two rectangular plates when the upper plate has a porous facing is assumed to move while the lower plate remains fixed. A uniform magnetic field B_0 is applied perpendicular to the two plates with the account of velocity slip at the porous facing [17]. The flow in the porous media follow the modified Darcy's law due to Horia [18], while in the film region the usual assumptions of hydromagnetic lubrication theory [19] hold good.

Following the assumptions of Wu [14] and the usual assumptions of magneto hydrodynamic lubrication [19], the basic equations governing the hydromagnetic law of the lubricant in different regions are:

For the film region:

$$\frac{\partial^2 u}{\partial z^2}-\frac{M_0^2}{h_0^2}u=\frac{1}{\mu}\frac{\partial p}{\partial x} \tag{1}$$

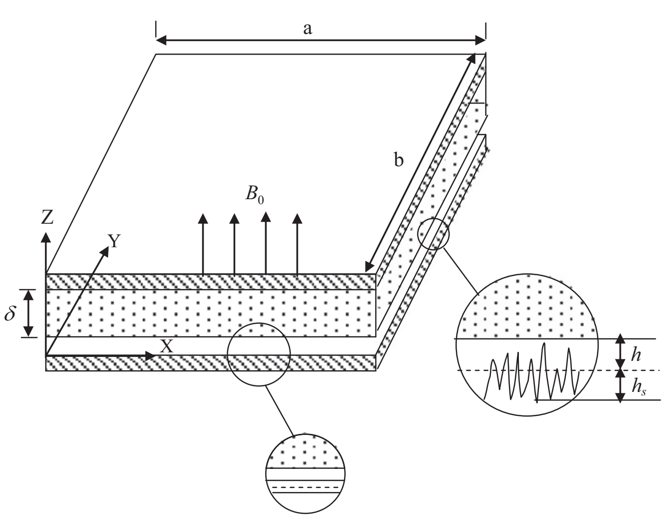

Fig. 1. Squeeze film geometry: enlarged pictures in circles indicate the unidirectional roughness pattern in y-direction (longitudinal roughness).

$$\frac{\partial^2 v}{\partial z^2}-\frac{M_0^2}{h_0^2}v=\frac{1}{\mu}\frac{\partial p}{\partial y} \tag{2}$$

$$\frac{\partial p}{\partial z}=0 \tag{3}$$

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \tag{4}$$

For the porous region:

$$\overline{u}=-\frac{k}{\mu}\frac{\partial P}{\partial x}\frac{1}{\left(1+\frac{k}{m'}\frac{M_0^2}{h_0^2}\right)} \tag{5}$$

$$\overline{v}=-\frac{k}{\mu}\frac{\partial P}{\partial y}\frac{1}{\left(1+\frac{k}{m'}\frac{M_0^2}{h_0^2}\right)} \tag{6}$$

$$\overline{w}=-\frac{k}{\mu}\frac{\partial P}{\partial z} \tag{7}$$

$$\frac{\partial \overline{u}}{\partial x}+\frac{\partial \overline{v}}{\partial y}+\frac{\partial \overline{w}}{\partial z}=0 \tag{8}$$

The relevant boundary conditions for the velocity components are

$$u=v=0 \quad \text{at} \quad z=0 \tag{9}$$

$$u=v=0 \quad \text{at} \quad z=H \tag{10}$$

The solution of Eqs. (1) and (2) subject to Eqs. (9) and (10) are

$$u=\frac{h_0^2}{\mu M_0^2}\frac{\partial p}{\partial x}\left\{\left[\cosh\left(\frac{M_0 z}{h_0}\right)-1\right]-\frac{\left[\cosh\left(\frac{M_0 H}{h_0}\right)-1\right]}{\sinh\left(\frac{M_0 H}{h_0}\right)}\sinh\left(\frac{M_0 z}{h_0}\right)\right\} \tag{11}$$

$$v=\frac{h_0^2}{\mu M_0^2}\frac{\partial p}{\partial y}\left\{\left[\cosh\left(\frac{M_0 z}{h_0}\right)-1\right]-\frac{\left[\cosh\left(\frac{M_0 H}{h_0}\right)-1\right]}{\sinh\left(\frac{M_0 H}{h_0}\right)}\sinh\left(\frac{M_0 z}{h_0}\right)\right\} \tag{12}$$

Substituting Eqs. (11) and (12) into (4) and integrating across the film thickness H, we obtain

$$\frac{\partial}{\partial x}\left\{\frac{h_0^2}{\mu M_0^2}\frac{\partial p}{\partial x}\left(\frac{h_0}{M_0}f_1(H,M_0)\right)\right\}+\frac{\partial}{\partial y}\left\{\frac{h_0^2}{\mu M_0^2}\frac{\partial p}{\partial y}\left(\frac{h_0}{M_0}f_1(H,M_0)\right)\right\}=-[w_H-w_0] \tag{13}$$

Since the lower plate is non-porous and fixed $w_0=0$. The velocity component in z-direction is continuous at the plate interface, so