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Influence of roughness on porous finite journal bearing with heterogeneous slip/no-slip surface

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ABSTRACT

A numerical study of effect of surface roughness on finite porous journal bearing with heterogeneous slip/no-slip surface is presented. Generalized Reynolds type equations are derived for both types of unidimensional roughness structure. The well established Christensen stochastic theory is used to study the roughness effect. The governing differential equation can be solved by finite difference method. The effect of surface roughness parameter, slip parameter, permeability parameter and eccentricity ratio on pressure and hydrodynamic load is investigated. It has been shown that pressure and load carrying capacity increases with surface roughness for the bearing with slip/no-slip surface.

1. Introduction

Aim of this work is to study the effect of roughness on journal bearing with heterogeneous surface theoretically because, in general, no surfaces are smooth, even a highly polished surface when examined in microscope has an irregularities nature. There is a possibility of asperity contact when the bearings are not smooth and pressure developed due to an asperity will carry some amount of applied load. In the view of this nature, many researchers proposed to study the surface roughness effects on bearing surface. The effects of surface roughness on porous short and long journal bearing with Newtonian fluid are studied by Gururajan and Prakash [1–4]. They examined that there exist a strong interaction between roughness effect and slip effect. The effect of surface roughness on porous journal bearing with couple stress fluid is studied by Naduvinamani et al. [5,6]. They found that couple stress fluid as lubricant in narrow porous journal bearing and rotor bearing show significant increase in load capacity and decrease in coefficient of friction. The combined effect of surface roughness and MHD is studied by some of the authors like Naduvinamani et al. [7] and Ramesh et al. [8]. They identified that performance of bearing characteristics increases with increase in roughness parameter and Hartmann number. In the earlier engineering, no-slip boundary condition is assumed for many solid surfaces, but recent development shown that surfaces produce an apparent slip with aqueous solution and Newtonian fluid and is demonstrated by Watanabe et al. [9,10]. Fortier and Salant exploited theoretically the slip phenomenon to improve the fluid film bearing performance by considering judicious choice of both slip and no-slip bearing surface called heterogeneous pattern. Authors made bearing surface as such slip occurs in one region and absent in other, also, in the liquid lubrication fluid flow pattern is altered. Numerical analysis of slider bearing and journal bearing by considering heterogeneous pattern are given in [11,12], the analysis states that heterogeneous slip/no-slip surface improves bearing performance and load support is substantially larger than convention bearing with or without recess. Here authors assumed smooth bearing surface, but practically it is not true. The effect of surface roughness on porous journal bearing with heterogeneous surface is examined in paper [13]. They have derived the generalized Reynolds equation by considering roughness nature and porosity by adopting Christensen stochastic process. They identified that heterogeneous pattern of slip/no-slip surface of porous narrow journal bearing increases load carrying capacity and reduce coefficient of friction. Balarinia et al. [14] have investigated the effect of initial roughness and circular axial run-out on friction and wear behavior of Si_3N_4–Al_2O_3 sliding in water. Authors found that circular axial run-out and initial roughness structure increases the running duration, wear rates of Si_3N_4 balls are higher than the Al_2O_3 disks and also friction coefficient decreases. Ryszard Buczkowski and Michal Kleiber [15] have investigated the methodology to improve the design of elasto-plastic shrink fitted joint by taking surface roughness and micro slip into account. It was found that static behavior of the assembly

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Nomenclature

A	dimensionless slip coefficient, $\alpha\mu/\Delta r$
C	dimensionless roughness parameter $(=c/\Delta r)$
c	maximal asperity deviation from the nominal film height
$E()$	expected value of
e	bearing eccentricity
h	film thickness $(=h_m+h_s)$
h^*	nominal fluid film
H_0	thickness of porous bearing height $(=H/\Delta r)$
h_m	nominal film height $(=(\Delta r)(1+\epsilon\cos\theta))$
h_s	deviation of film height from the nominal level
k	permeability
L	bearing length
$\bar{p}$	pressure in the film thickness
$\bar{p}^*$	non-dimensional mean pressure
R	journal radius
u_s	shaft surface speed
W	load capacity
$W_o, W_{\pi/2}$	load components
W^*	mean load capacity
x, y, z	Cartesian co-ordinates
α	slip coefficient
σ	standard deviation
$\varnothing$	attitude angle
ψ	non-dimensional permeability parameter
ε	eccentricity ratio $(=e/\Delta r)$
μ	viscosity of the lubricant
θ	circumferential co-ordinate $(x=R\theta)$
Δr	radial clearance
ξ	random variable
Σ	$\frac{A}{h+A}$

Superscripts

-	nondimensional parameter
*	nondimensional parameter

depends on surface finish of the mating components and also, plasticity reduces the strength of the assembly.

The objective of the current paper is the numerical study of surface roughness effects and porosity on finite journal bearing by considering slip/no-slip bearing surface. Here, conventional lubrication theory assumptions are adopted. Slip is assumed to be occurred due to Navier relation [16]. Also, Zhu and Granick suggestion that before slip onset the critical value of shear stress may be considered is adopted [17]. The assumption of porous region such as flow is due to Darcy's law, porous matrix is isotropic and homogeneous are considered. Christensen theory is adopted to study the effect of roughness. Both the effects of roughness and the permeability parameter are analyzed. It is believed that as roughness increases the choice of slip/no-slip pattern of bearing surface will improve the bearing characteristics such as pressure and load carrying capacity. The two types of roughness patterns such as longitudinal and transverse roughness cases are studied.

The bearings with heterogeneous slip/no-slip surface are practically used to improve the quality of mechanical sealing [18] and to reduce the friction loses in pipe flow [9,10] and fluid film bearings [19,20].

2. Analysis

The physical configuration of the porous journal bearing is shown in Fig. 1. The lubricant film thickness is given by

$$h_m=\Delta r(1+\epsilon\cos\theta). \tag{1}$$

The governing equation of fluid flow between the surfaces of a journal bearing in which one surface contains a region where the fluid slip occurs is investigated by considering Navier–Stokes equations.

$$\frac{\partial^2 u}{\partial y^2}=\frac{1}{\mu}\frac{\partial p}{\partial x}, \tag{2}$$

$$0=\frac{\partial p}{\partial y}, \tag{3}$$

$$\frac{\partial^2 w}{\partial y^2}=\frac{1}{\mu}\frac{\partial p}{\partial z}. \tag{4}$$

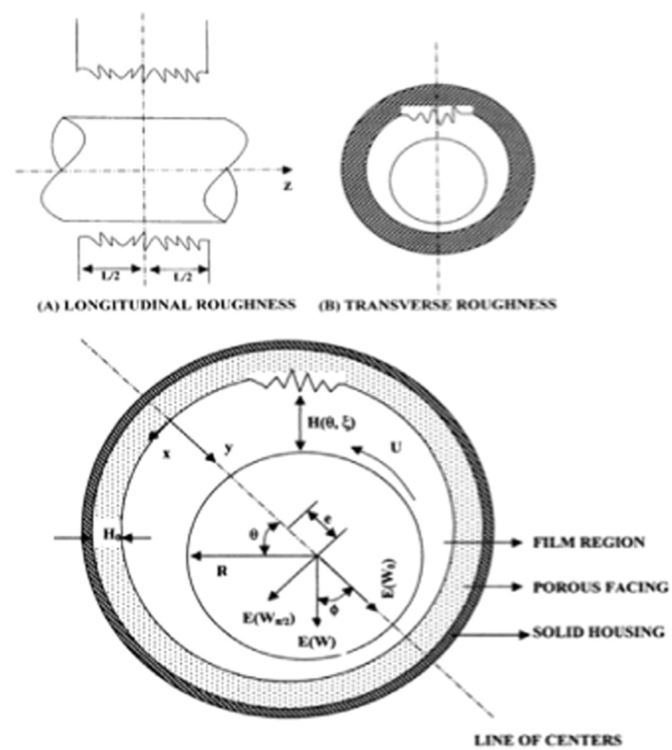

Fig. 1. Bearing geometry and journal bearing configuration.

The continuity equation is given by

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0. \tag{5}$$

The heterogeneous slip/no-slip nature of journal bearing surface is shown in Fig. 2. Slip/no-slip pattern is applied to surface 2 which is stationary surface and surface 1 is surface of shaft moving with the speed $u_s=\omega R$ in x- direction and is shown in Fig. 2(a). Surface 1 is made of conventional material, so that no-slip condition applies everywhere. In surface 2 some areas are treated to allow slip and others are not. Fig. 2(b) shows pattern of surface 2 in which fluid enters with slip region (Region I) and exit with no-slip region (Region II). In the bearing, occurrence of slip is determined by two ways. First, on surface 2 slip may occur in those