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MATHEMATICAL MODEL OF SHLIOMIS MODEL BASED FERROFLUID LUBRICATED ROUGH POROUS CONVEX PAD SLIDER BEARING WITH EFFECT OF SLIP VELOCITY

Nitin D Patel[1], Jimit R Patel[2] & G. M. Deheri[3]

[1]Assistant Professor, Department of Basic Sciences and Humanities, BACA, AAU, Anand - 388 110, Gujarat, India

[2]Assistant Professor, Department of Mathematical sciences, PDPIAS, CHARUSAT, Changa-388421, Gujarat, India

[3]Former Professor, Department of Mathematics, S. P. University, V.V. Nagar, Gujarat-388120, India

ABSTRACT

An attempt has been made to analyse the performance characteristics of a Shliomis model based ferrofluid lubrication of a rough porous convex pad slider bearing with effect of slip velocity. Regarding roughness, the stochastic method adopted by Christensen and Tonder to finds the application here in statistical averaging of the associated Reynolds equation. The graphical representation suggests that the adverse effect of surface roughness can be reduced to certain extent by the positive effect of Shliomis model based ferrofluid lubrication. Further, for this type of bearing system, this model remains more effective as compared to Neuringer-Rosensweig model.

KEYWORDS: *Convex Pad Slider Bearing, Roughness, Porosity, Shliomis Model, Pressure, Slip Velocity*

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INTRODUCTION

The variety of bearing are adopted by agro-industrial sector (hydrodynamic bearings, hydrostatic bearings, rolling element bearings etc.) having great influence on reliability, life and power consumption of agricultural machines, tools or equipment's dealing friction, wear, heat generation and its dissipation presented[1]. It altogether requires a thoughtful apprehension towards modelling of tribological losses, with a right kind of physical and mathematical understandings and suitable deliberations in terms of solutions, which could be properly utilized at the ends of engineers, designers and researchers who so ever is engaged in such industrial interventions. Bearing Lubrication is notable in modern applications and their primary preferences compared with rolling and friction bearings are their part in decrease in friction and turning in high exactness. Different applications and the analyses of the reheological properties of magnetic fluids increased detectable significance amid the most recent couple of years. These days, the flow and the application potential outcomes of suspensions of magnetic nano particles are the great enthusiastic research field. In fact, investigations of the properties, the flow and the application possibilities of suspensions of magnetic nano particles are an extremely lively research field nowadays. Recent experimental as well as theoretical investigations have established that the formation of structure of magnetic nano particles has significant influence on the magneto viscous behaviour of ferrofluids.

As many researchers have suggested, studying the surface roughness will help to improve the performance of a bearing system. Due to this reason, many researchers [2-4] studied the performance of various bearing systems using the stochastic concept of [5-7]. Surface roughness assessment is fundamental problem for some classical problems, for example, load carrying capacity, contact deformation, heat and electric current conditions, tightness of contact joints and positional accuracy. Evolution of effect of slip velocity in bearing systems is very classical problem. [8] and later on [5-7] proposed new technique for evaluating the impact of both, transverse and longitudinal, roughness patterns.

The performance characteristics of a Shliomis model based ferrofluid lubrication of a rough porous convex pad slider bearing examined [9]. It was manifest that adverse effect of surface roughness can be reduced to certain extent by the positive effect of Shliomis model based ferrofluid lubrication and for this type of bearing system, this model remains more effective as compared to Neuringer-Rosensweig model. The effect of slip velocity on the performance of a short bearing lubricated with a ferrofluid analysed [10]. For any type of improvement the slip was required to be kept at minimum level.

The effect of slip velocity on the performance of a magnetic fluid based transversely rough porous narrow journal bearing discussed [11]. It was found that the combined effect of slip velocity and surface roughness is to decrease the load carrying capacity significantly, in general. In augmenting the performance of the bearing system, the eccentricity ratio plays a central role even if the slip parameter is at minimum. It is established that the bearing can support a load even in the absence of flow, unlike the case of a conventional lubricant. The effect of sinusoidal magnetic field on a rough porous hyperbolic slider bearing system investigated [12]. It was studied that the striking result reported in the present study is that the sinusoidal magnetic field enhances the load-bearing capacity by a factor $\frac{\mu_0}{\pi}$ which amounts to 38.3 % of increase in the load-carrying capacity. The magnetisation of the ferrofluid lubricant and slip parameter augments the load-bearing capacity within certain range. The Shliomis ferrofluid flow model and continuity equation for the film as well as porous region on circular squeeze film bearings considering the effects of oblique radially variable magnetic field (VMF), slip velocity at the film– porous interface and rotations of both the discs has been discussed [13]. It was observed that the Shliomis ferrofluid flow model is important because it includes the effects of rotations of the carrier liquid as well as magnetic particles.

A study on the performance of a ferrofluid based double layer porous rough slider bearing presented and concluded that the positive effect of double layered gets enhanced by the magnetic fluid lubrication [14]. A comparison of all the three magnetic fluid flow models (Neuringer–Rosensweig model, Shliomis model, Jenkins model) concerning the performance of a ferrofluid squeeze film in curved rough porous circular plates considering the slip velocity has been studied [15]. They established that Shliomis model remains more favourable for designing the bearing system. It is also appealing to note that for lower to moderate values of slip, Neuringer–Rosensweig model may be adopted. Besides, Jenkins model may be used when the roughness is at lower level and the slip is at minimum. In the existing literature on Neuringer-Rosensweig model based ferrofluid lubrication of a porous convex pad slider bearing with slip velocity has been discussed.

Also, it is well known that the roughness affects the bearing system significantly. One gets the information from the literature regarding ferrofluid flow that, Shliomis model registers an improved performance as compared to Neuringer-Rosensweig model. Thus, it was thought proper to analyse the performance characteristics of a Shliomis model based ferrofluid lubrication of a rough porous convex pad slider bearing with slip velocity.

ANALYSIS

The configuration of plate slider bearing with squeeze velocity $\dot{h} = dh/dt$ is displayed in Figure 1. The lower surface is a slider of length A and moving with uniform velocity U in the x direction. Also, the slider is having width B in the y direction with $A << B$. Moreover, h_2 and h_1 are maximum and minimum film thicknesses respectively.

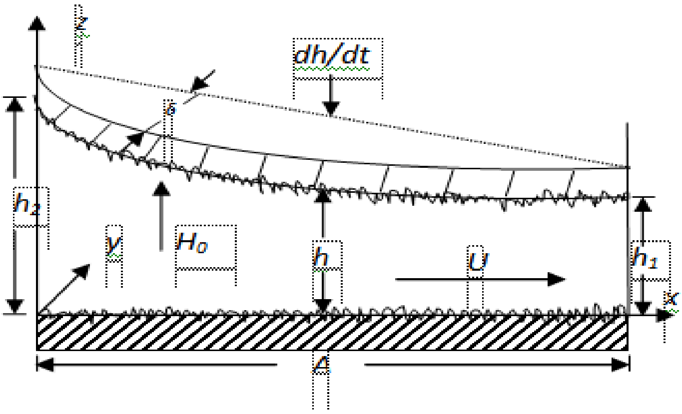

Figure 1: Configuration of the Bearing System.

The bearing surfaces are considered to be transversely rough. In line with the discussions of [5-7], the thickness $\mathrm{h(x)}$ of the lubricant film is taken in the form of

$$\mathrm{h}(\mathrm{x}) = \bar{\mathrm{h}}(x) + h_s \tag{1}$$

Where $\bar{\mathrm{h}}(x)$ denotes the mean film thickness and h_s is the deviation from the mean film thickness characterizing the random roughness of the bearing surfaces. h_s is considered to be stochastic in nature and governed by the probability density function

$$f(h_s) = \begin{cases} \dfrac{35}{32c}\left(1 - \dfrac{h_2^2}{c^2}\right)^3, -c \le h_s \le c \\ 0, elsewhere \end{cases}$$

Where in c is the maximum deviation from the mean film thickness. The mean α, the standard deviation σ and the parameter ε which is the measure of symmetry of the random variable h_s are defined and discussed in detail in [5-7].

The basic equations governing Shliomis model based ferrofluid lubrication are discussed [16-17] by

$$-\nabla p + \eta \nabla^2 \bar{q} + \mu_0 (\bar{M} \nabla) \bar{H} + \frac{1}{2} \mu_0 \nabla \times (\bar{M} \times \bar{H}) = 0 \tag{2}$$

and

$$\bar{M} = M_0 \frac{\bar{H}}{H} + \tau_B \bar{\Omega} \times \bar{M} - \frac{\mu_0 \tau_B \tau_s}{I} \bar{M} (\bar{M} \times \bar{H}) \tag{3}$$

Where p represents the pressure, η is the viscosity of the suspension, μ_0 denotes the permeability of free space, $\overline{H}$ is the applied magnetic field, $\overline{M}$ is the magnetization vector, $\overline{q}$ denotes the fluid velocity, $\overline{S}$ represents internal angular momentum, I is the sum of moments of inertia of the particle per unit volume, τ_B is the Brownian relaxation time, τ_s is the magnetic moments relaxation time and M_0 denotes the equilibrium magnetization.

For the strong magnetic field Langevin's parameter $\xi > 1$, the above equation takes the form

$$\overline{M} = \frac{M_0}{H}\left[\overline{H} + \bar{\tau}\left(\overline{\Omega} \times \overline{H}\right)\right] \tag{4}$$

with

$$\bar{\tau} = \frac{6\eta\phi}{nk_B T\left(1 + \xi \coth \xi\right)} \tag{5}$$

where

$$M_0 = n\mu\left(\coth \xi - \frac{1}{\xi}\right), H = \frac{k_B T \xi}{\mu_0 \mu}, \tag{6}$$

for a suspension of spherical particles

$$\frac{I}{\tau_s} = 6\eta\phi \quad \text{and} \quad \tau_B = \frac{3\eta V}{k_B T}, \tag{7}$$

$\phi = nV$ is the volume concentration of the particles, k_B is the Boltzmann constant, n denotes the number of particles per unit volume, V is the volume of the particle, T represents the temperature and μ is the magnetic moment of a particle.

Under the uniform magnetic field $\overline{H} = \left(0, 0, H_0\right)$, equations yield

$$\frac{\partial^2 u}{\partial z^2} = \frac{1}{\eta\left(1 + \tau\right)} \frac{dp}{dx} \tag{8}$$

where

$$\tau = \frac{3}{2}\phi \frac{\xi - \tanh \xi}{\xi + \tanh \xi} \tag{9}$$

Solving equation (8) under the no slip boundary conditions

$u = 0$ at $z = h$ and $u = U$ at $z = 0$,

one can find

$$u=\frac{1}{\eta(1+\tau)}\left(\frac{z^2}{2}-\frac{h}{2}z\right)\frac{\partial p}{\partial x}+U\left(1-\frac{z}{h}\right) \tag{10}$$

Substituting u in the integral form of the continuity equation for the film region

$$\frac{\partial}{\partial x}\int_0^h udz+w_h-w_0=0 \tag{11}$$

yields

$$\frac{d}{dx}\left[-\frac{h^3}{12\eta(1+\tau)}\frac{dp}{dx}+\frac{Uh}{2}\right]=\dot{h} \tag{12}$$

Considering $w_h=-\dot{h}$ and $w_0=0$ as the lower plate is impermeable.

If η_0 represents the viscosity of the main liquid, the viscosity of the suspension is given by the Einstein formula [16]

$$\eta=\eta_0\left(1+\frac{5}{2}\phi\right) \tag{13}$$

Equations (12) and (13) lead to

$$\frac{d}{dx}\left[-\frac{h^3}{12\eta_0\left(1+\frac{5}{2}\phi\right)(1+\tau)}\frac{dp}{dx}+\frac{Uh}{2}\right]=\dot{h} \tag{14}$$

The usual assumptions of hydro magnetic lubrication [18-20] are made. Now, the often used well-known stochastic averaging method of [5-7] transforms equation (14) to the modified Reynolds equation governing the pressure distribution,

$$\frac{d}{dx}\left[-\frac{g(h)}{12\eta_0\left(1+\frac{5}{2}\phi\right)(1+\tau)}\frac{dp}{dx}+\frac{Ug(h)^{\frac{1}{3}}}{2}\right]=\dot{h} \tag{15}$$

Where

$$g(h)=\left(h^3+3h^2\alpha+3(\alpha^2+\sigma^2)h+3\sigma^2\alpha+\alpha^3+\varepsilon+12\varphi H\right)\frac{(4+sh)}{(1+sh)}$$

Introducing the non-dimensional quantities,

$$X=\frac{x}{A},\bar{h}=\frac{h}{h_1}=4\bar{\delta}X^2-\left(a-1+4\bar{\delta}\right)X+a,\bar{\delta}=\frac{\delta}{h_1},P=\frac{h_1^2 p}{U\eta_0 A},D=\frac{A\dot{h}}{Uh_1},\bar{\sigma}=\frac{\sigma}{h_1},$$

$$\bar{\alpha}=\frac{\alpha}{h_1},\bar{\varepsilon}=\frac{\varepsilon}{h_1^3},\psi=\frac{\varphi H}{h_1^3},S=\frac{s}{h_1} \tag{16}$$

and solving above equation subject to the boundary conditions

$$P(0)=P(1)=0 \tag{17}$$

One arrives at the dimensionless pressure as

$$P=\int_0^X \frac{F}{G}dX-D\int_0^X \frac{X}{G}dX-Q\int_0^X \frac{1}{G}dX \tag{18}$$

where

$$G=\frac{g(\bar{h})}{E},E=12\left(1+\frac{5}{2}\phi\right)(1+\tau),F=\frac{g(\bar{h})^{\frac{1}{3}}}{2},Q=\frac{\int_0^1 \frac{F}{G}dX-D\int_0^1 \frac{X}{G}dX}{\int_0^1 \frac{1}{G}dX}$$

and

$$g(\bar{h})=\left(\bar{h}^3+3\bar{h}^2\bar{\alpha}+3\left(\bar{\alpha}^2+\bar{\sigma}^2\right)\bar{h}+3\bar{\sigma}^2\bar{\alpha}+\bar{\alpha}^3+\bar{\varepsilon}+12\psi\right)\frac{\left(4+S\bar{h}\right)}{\left(1+S\bar{h}\right)}$$

The non-dimensional load carrying capacity then can be obtained as

$$W=\frac{h_1^2 w}{BUA^2\eta_0}=\int_0^1 \frac{F}{G}(1-X)dX-D\int_0^1 \frac{X}{G}(1-X)dX-Q\int_0^1 \frac{1}{G}(1-X)dX \tag{19}$$

RESULTS AND DISCUSSIONS

Equation (18) and (19) represents the pressure distribution and load carrying capacity with magnetic fluid effect which is different from conventional fluid based bearing system. Also, it is observed that equation (19) is linear with respect to magnetization parameter. Therefore, it is enough to notice that load carrying capacity would gain with enhancing magnetization parameter.

In the absence of slip velocity, this study reduces to the study of [9]. Figures (2) - (7) lead the problem to the results and discussion. The effect of magnetization parameter with respect to slip velocity is displayed in figures (2).

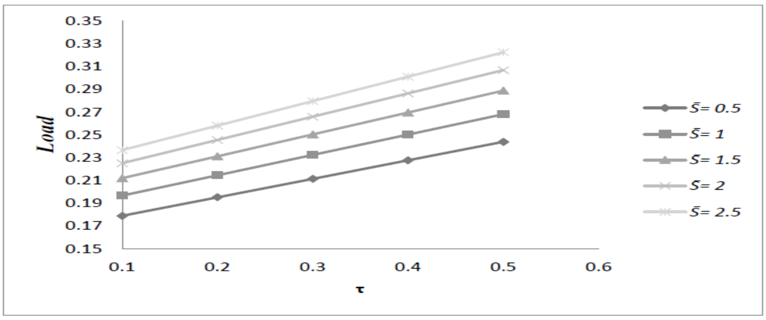

Figure 2: Variation of Load Carrying Capacity With Respect To τ and S.

The Influence of Slip Velocity can be observed From Figures (3)-(7).

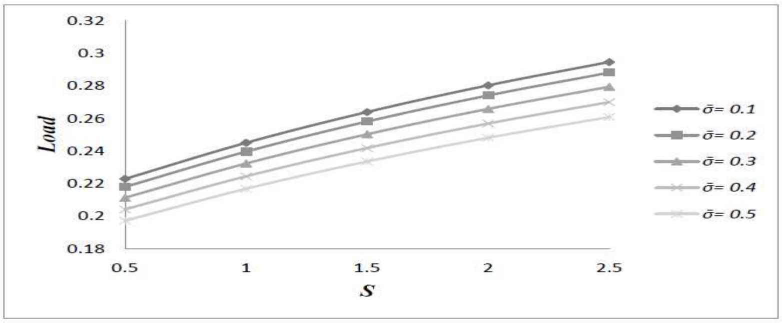

Figure 3: Variation of Load Carrying Capacity With Respect To S and $\overline{\sigma}$.

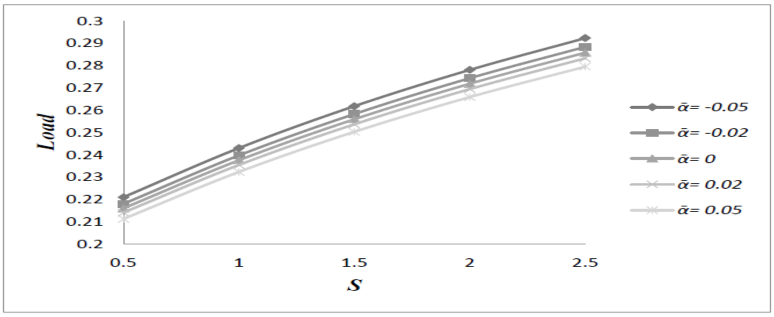

Figure 4: Variation of Load Carrying Capacity With Respect To S and $\overline{\alpha}$.

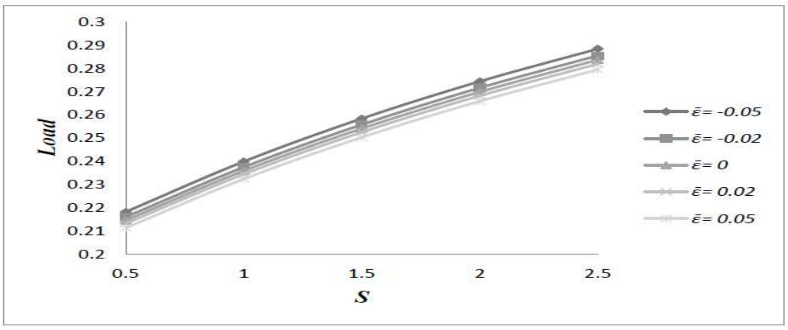

Figure 5: Variation of Load Carrying Capacity With Respect To S and $\overline{\varepsilon}$.

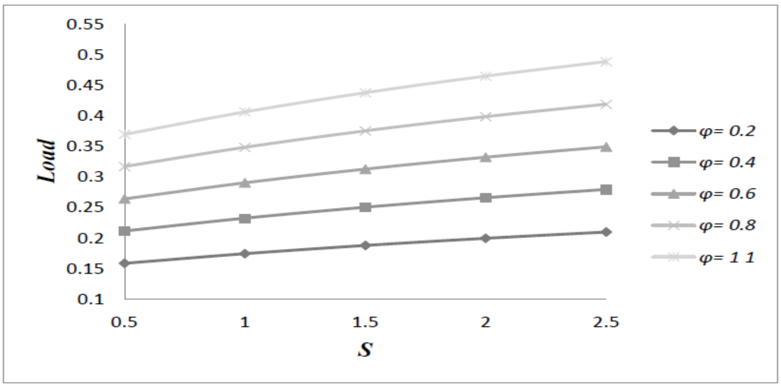

Figure 6: Variation of Load Carrying Capacity with Respect To S and ϕ .

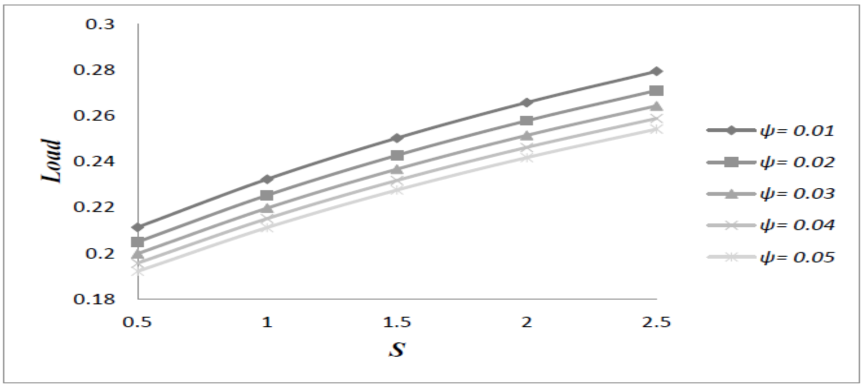

Figure 7: Variation of Load Carrying Capacity With Respect To S and ψ .

From Graphical Formation of the Problem, One Can Conclude,

- Shliomis model may prefer as compared to Neuringer-Rosensweig's model.
- The combined effect of slip velocity and ϕ parameters enhance the load carrying capacity.
- The positive effect of negatively skewed roughness and variance (-ve) be likely to enlarge the bearing performance.
- A little unfavourable effect of porosity and roughness can be overcome by combined effect of slip velocity and Shliomis model based magnetization parameter.

CONCLUSIONS

It can be conclude that the Shliomis model may be adopted to overcome the effect of roughness and porosity when slip is at reduced level. The bearing can support some amount of load even absence of flow which cannot seen in traditional lubricant. Lastly, the roughness evidences helpfulness while designing the bearing system even if Shliomis model is in force.

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