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INFLUENCE OF TRANSVERSE SURFACE ROUGHNESS THROUGH A SERIES OF FLOW FACTORS ON THE PERFORMANCE OF A ROUGH FINITE PLANE SLIDER BEARING

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ABSTRACT

An analysis of the influence of roughness parameters on the pressure and load carrying capacity for a rough finite inclined plane slider bearing with transversely rough surfaces has been conducted through a series of empirical pressure and shear flow factors. The associated stochastically averaged Reynolds' type equation is solved with suitable boundary conditions. Expressions are obtained for pressure and load carrying capacity. The numerical results are presented graphically. It can be seen that the load carrying capacity increases with the decrease in the surface roughness pattern parameter.

Keywords: Reynolds' equation, Finite inclined plane slider bearing, Pressure flow factor, Shear flow factor, Transverse Roughness, Load carrying capacity.

INTRODUCTION

It is assumed in many theoretical studies on lubricating films that the bearing surfaces are smooth. In reality this assumption is valid until the ratio of the nominal film thickness to the standard deviation of the roughness becomes large enough. The study of roughness effect is very important from the bearing's life period point of view. It is well known that the bearing surfaces after having some run-in and wear develop roughness. Sometimes even the contamination of lubricants and chemical degradation of the surfaces contribute to the roughness.

Due to an enormous use of slider bearings in various fields, like clutch plates, automobile transmission etc., there are many studies dealing with the investigations of slider bearings. The effect of surface roughness was dealt with many investigations viz. Tonder [1], Liao-Liang Ke et al. [2] and Thomas et al. [3]. The stochastic concept and Stochastic Reynolds' equation governing the mean pressure in bearings having transverse and longitudinal roughness were introduced by Christensen and Tonder [4-7]. This stochastic approach formed the basis of the analysis to study the effect of surface roughness in a number of investigations [8-10]. The thermal and roughness effects on different characteristics of finite rough tilted pad slider bearings were analyzed by Deresse and Sinha [11]. It was observed that for nonparallel slider bearing the load carrying capacity due to the combined effect is less than the load capacity due to the roughness effect for both longitudinal and transverse roughness models. Panchal et al. [12-13] analyzed the influence of roughness parameters on the pressure and load carrying capacity in a rough finite plane slider bearing for longitudinally rough surfaces by taking account of the influence of surface roughness through a series of flow factors, in which it was seen that the load carrying capacity decreases with the increase in the surface roughness pattern parameter.

The surface roughness effects on the dynamic characteristics of slider bearings with finite width were theoretically studied by Chiang, Hsiu-Lu et al. [9] and observed that the steady load-carrying capacity, dynamic stiffness and damping coefficient were increased as the effects of transverse roughness increased while the influences of the isotropic and longitudinal roughness had a reverse tendency. The effect of surface roughness on hydrodynamic lubrication of slider bearings of various film shapes such as plane, exponential, secant and hyperbolic slider was analyzed by Andharia et al. [10]. Patir and Cheng [14-15] modified the averaged Reynolds' equation for rough surfaces. They defined pressure and shear flow factors which were obtained independently by numerical flow simulation using randomly generated roughness profiles. Etsion and Izhak [16] analyzed that theoretical modelling of surface texturing in hydrodynamic lubrication is a necessary first step to obtain favorable effect of the texturing. The effects of surface roughness characteristics on the load carrying capacity of tilt pad thrust bearings with water lubrication were studied though the average flow model by Wang, Yuechang et al. [18].

In this paper, an analysis has been conducted to evaluate the influence of surface roughness parameters and flow factors which are strongly dependent on the surface pattern parameter on a transversely rough plane inclined slider bearing.

ANALYSIS

Patir and Cheng [14-15] developed "Averaged Reynolds' equation" which took an account of the surface topography [17] (Fig. 1).

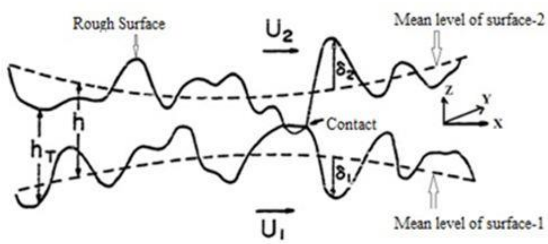

Fig. 1 Surface roughness and film geometry

The mean pressure in a rough slider bearing is governed by the averaged Reynolds' equation:

$$\frac{\partial}{\partial x}\left[\varphi_x \frac{h^3}{12\mu}\frac{\partial \bar{p}}{\partial x}\right]+\frac{\partial}{\partial y}\left[\varphi_y \frac{h^3}{12\mu}\frac{\partial \bar{p}}{\partial y}\right] = \frac{U}{2}\frac{\partial \bar{h}_T}{\partial x}+\frac{U\sigma}{2}\frac{\partial \varphi_s}{\partial x} \quad (1)$$

where φ_x and φ_y are pressure flow factors, φ_s is shear flow factor, $h_T=h+\delta$ is local film thickness, h is nominal film thickness (compliance), $\bar{h}_T$ is expected value of mean gap between two surfaces (separation), U is velocity of slider, μ is viscosity of lubricant, $\sigma=\sqrt{\sigma_1^2+\sigma_2^2}$ is composite r.m.s. roughness and $\bar{p}$ is mean pressure level.

The investigation assumes that the flow of lubricant is steady and in X-direction only. Moreover, for transversely rough surface *($\gamma < 1$)*, the variations in roughness heights in *X*-direction are significant [17] (Fig. 2) so far as the performance is concerned. Hence, the effect of shear flow factor-φ_s is significant, which of course is negligible in the case of longitudinal rough surface *($\gamma > 1$)*. Here γ is ratio of x and y correlation lengths of roughness.

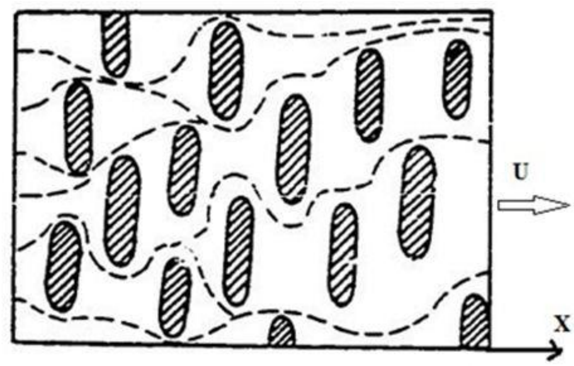

Fig. 2 Transverse rough surface (γ<1)

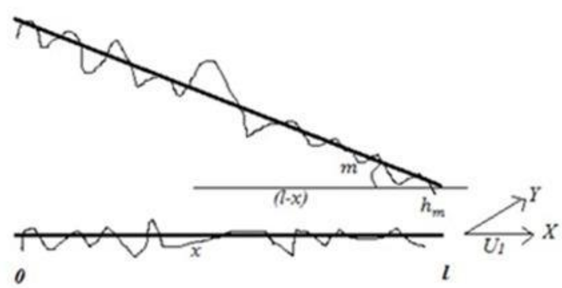

Fig. 3 Inclined plane slider bearing geometry

In view of above assumptions, Eq. (1) results in,

$$\frac{\partial}{\partial x}\left[\varphi_x \frac{h^3}{12\mu}\frac{\partial \bar{p}}{\partial x}\right]=\frac{U}{2}\frac{\partial \bar{h}_T}{\partial x}+\frac{U\sigma}{2}\frac{\partial \varphi_s}{\partial x} \quad (2)$$

For a rough plane slider bearing having the configuration as shown in Fig. 3, one considers

$$h = h_m + m(l - x) \tag{3}$$

where, h_m is minimum film thickness at the trailing edge of the slider bearing, l is the length of the slider bearing, m is the inclination of the slider bearing(Fig. 3).

Since δ is assumed to be stochastic in nature and is governed by the probability density function $f(\delta)$, $-c < \delta < c$, the mean α, the standard deviation σ and the skewness parameter ε are described as in Christensen – Tonder [4-7] and Deheri et al. [8] as:

$$E(R) = \int_{-c}^{c} R\, f(\delta)\, d\delta \tag{4}$$

$$E(\delta) = \alpha \tag{5}$$

$$E\left[(\delta - \alpha)^2\right] = \sigma^2 \tag{6}$$

And

$$E\left[(\delta - \alpha)^3\right] = \varepsilon \tag{7}$$

Where, c is maximum deviation from the mean film thickness. It is noteworthy that while α and ε can assume both positive and negative values, σ is always positive.

Following the discussion of in Christensen - Tonder [4-7], an approximation to $f(\delta)$ is,

$$f(\delta) = \begin{cases} \dfrac{32}{35c}\left(1 - \dfrac{\delta^2}{c^2}\right) & -c \le \delta \le c \\ 0 & elsewhere \end{cases} \tag{8}$$

Thus $\bar{h}_T$ can be approximated as,

$$\bar{h}_T = \frac{13h}{8} \approx h \tag{9}$$

Now as per the averaging process discussed by Deheri et al. [8], Eq. (2) reduces to,

$$\frac{d}{dx}\left[\varphi_x \frac{g(h)}{12\mu}\frac{d(\bar{p})}{dx}\right] = \frac{U}{2}\frac{dh}{dx} + \frac{U\sigma}{2}\frac{d\varphi_s}{dx} \tag{10}$$

Where $(\bar{p})$ is expected value of the mean pressure level $\bar{p}$ and

$$g(h) = h^3 + 3h^2\alpha + 3h(\sigma^2 + \alpha^2) + (\varepsilon + 3\sigma^2\alpha + \alpha^3) \tag{11}$$

The empirical relations for φ_x and φ_s provided by Patir [17] are as under:

$$\varphi_x = 1 - C\,e^{-rH} \quad (\gamma \;\pi\; 1) \tag{12}$$

And

$$\varphi_s = A_1 H^{\alpha_1} e^{-\alpha_2 H + \alpha_3 H^2} \quad (\gamma \;\pi\; 1) \tag{13}$$

The dimensionless forms of these flow factors are

$$\varphi_x = 1 - C\,e^{-rh^* H_m} \quad (\gamma \;\pi\; 1) \tag{14}$$

And

$$\varphi_S = A_1 (h^* H_m)^{\alpha_1} e^{-\alpha_2 (h^* H_m) + \alpha_3 (h^* H_m)^2} \quad (\gamma \;\pi\; 1) \tag{15}$$

Where

$$H = \frac{h}{\sigma},\; h^* = \frac{h}{h_m},\; H_m = \frac{h_m}{\sigma} \tag{16}$$

While the constants C, r, A_1, α_1, α_2 and α_3 are given as functions of γ in the Table 1 and Table 2 (Patir [17]).

Making use of the following dimensionless quantities

$$h^* = \frac{h}{h_m},\; X = \frac{x}{l},\; m^* = \frac{ml}{h_m},\; \bar{P} = \frac{h_m^{\;2}(\bar{p})}{\mu U l},$$

$$\alpha^* = \frac{\alpha}{h_m},\; \sigma^* = \frac{\sigma}{h_m},\; \varepsilon^* = \frac{\varepsilon}{h_m^{\;3}} \tag{17}$$

And

$$G(h^*) = h^{*3} + 3h^{*2}\alpha^* + 3h^*(\sigma^{*2} + \alpha^{*2}) + (\varepsilon^* + 3\sigma^{*2}\alpha^* + \alpha^{*3}) \tag{18}$$

Eq. (10) turns to the dimensionless form

$$\frac{d}{dx}\left[\varphi_X\, G(h^*)\frac{d\bar{P}}{dX}\right] = 6\frac{d}{dX}\left[h^* + \sigma^*\varphi_S\right] \tag{19}$$

With the aid of the following boundary conditions:

$$\bar{P} = 0, \text{ at } X = 0 \text{ and } 1 \tag{20}$$

$$\frac{d\overline{P}}{dX} = 0, \text{at which the mean gap is maximum}$$

Eq. (19) leads to,

$$\overline{P}(X) = \int_0^X \frac{6\left(h^* + \sigma^* \varphi_X\right) - Q^*}{\varphi_X \, G(h^*)} dX \qquad (21)$$

Where,

$$Q^* = \frac{\int_0^1 \frac{6\left(h^* + \sigma^* \varphi_X\right)}{\varphi_X \, G(h^*)} dX}{\int_0^1 \frac{1}{\varphi_X \, G(h^*)} dX} \qquad (22)$$

The dimensionless load carrying capacity per unit width is given by,

$$W^* = \frac{w h_m^{\;2}}{\mu U l} = \int_0^1 \overline{P} \, dX$$

$$\therefore W^* = \int_0^1 \left[\int_0^X \frac{6\left(h^* + \sigma^* \varphi_X\right) - Q^*}{\varphi_X \, G(h^*)} dX \right] dX \qquad (23)$$

RESULTS AND DISCUSSION

In Fig. 4-6, we have the variations in load carrying capacity of the bearing with respect to α, which establish that the load carrying capacity increases with the increasing values of α (-ve) while α (+ve) causes decrease in the load carrying capacity, a property similar to the case of longitudinal roughness pattern [12,13]. We can observe that the increasing values of standard deviation σ, skewness ε (+ve) and roughness pattern parameter γ decrease the load carrying capacity.

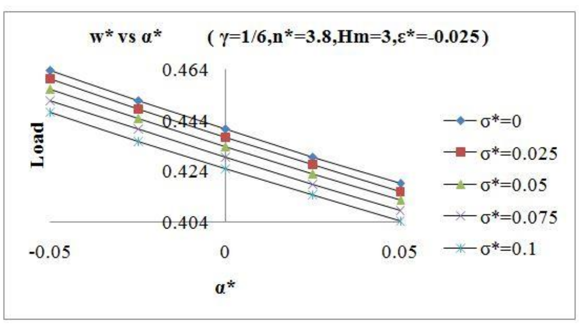

Fig. 4 Variation of load carrying capacity with respect to **α***

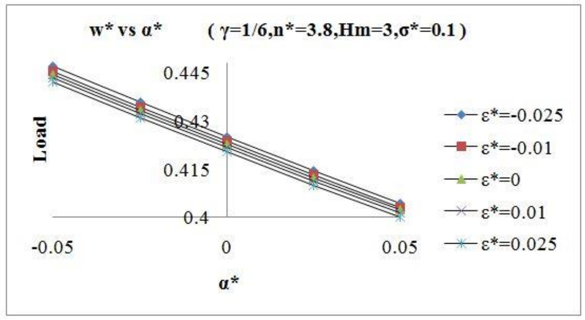

Fig. 5 Variation of load carrying capacity with respect to **α***

The variations in load carrying capacity of the bearing with respect to the standard deviation *σ* can be seen from Fig. 7-9, for various values of *ε, α* and *γ*. These reveal that the load carrying capacity enhances due to the decreasing values of standard deviation, increasing values of negatively skewed roughness, increasing values of variance (-ve) and decreasing values of roughness pattern parameter *γ* of the surfaces.

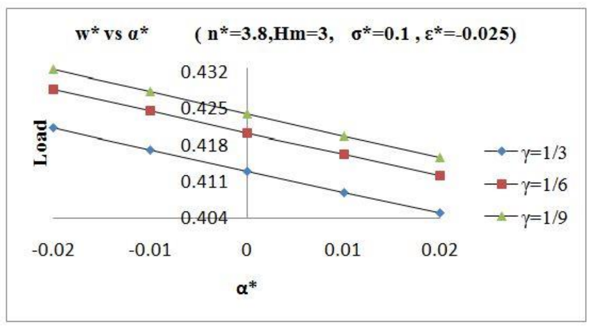

Fig. 6 Variation of load carrying capacity with respect to **α***

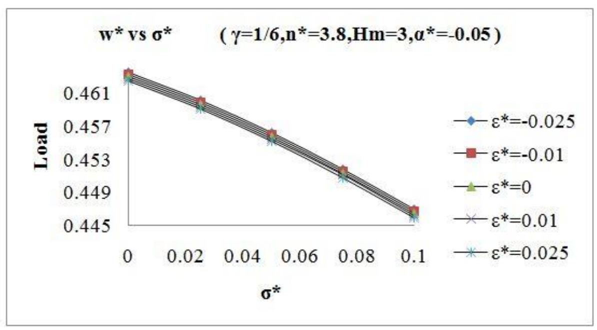

Fig. 7 Variation of load carrying capacity with respect to **σ***

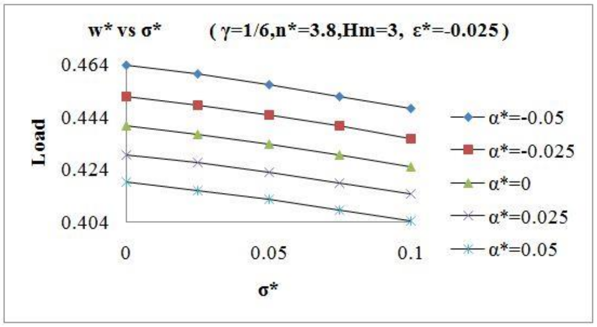

Fig. 8 Variation of load carrying capacity with respect to **σ***

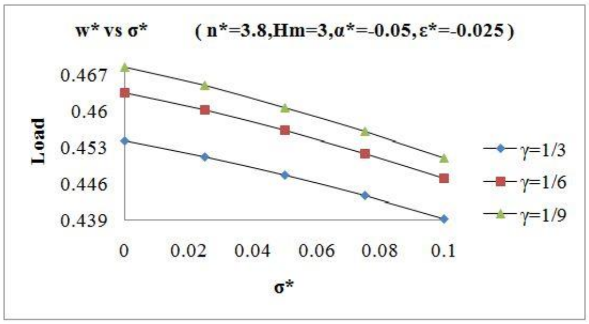

Fig. 9 Variation of load carrying capacity with respect to **σ***

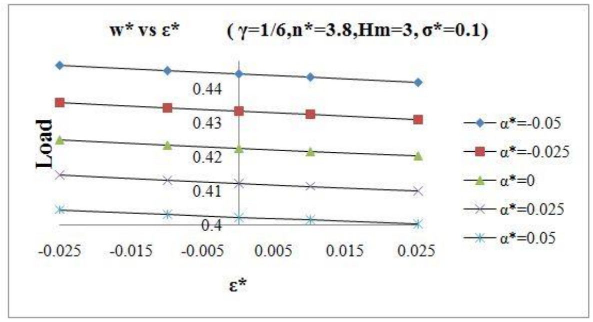

Fig. 11 Variation of load carrying capacity with respect to ε*

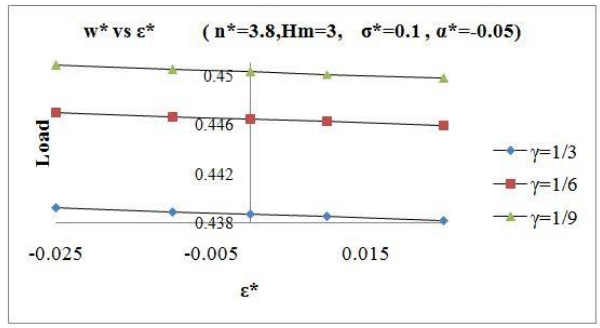

Fig. 12 Variation of load carrying capacity with respect to ε*

Fig. 10-12 dealing with the effect of skewness on the load carrying capacity establishes that the load carrying capacity increases with the negatively skewed roughness, similar to the case of longitudinal roughness pattern [12-13] but the rate at which it goes up is very small.

The trend of load carrying capacity with respect to the roughness pattern parameter γ amplifies as the surface is more transverse while in the case of longitudinal roughness [12] the load carrying capacity reduces as the surface roughness is more longitudinal.

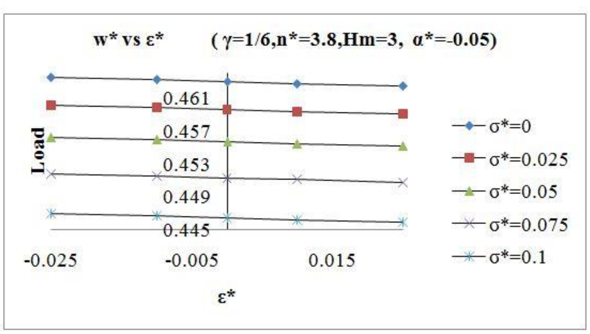

Fig. 10 Variation of load carrying capacity with respect to ε*

CONCLUSION

In this paper, the effect of roughness parameters on the pressure and load carrying capacity for a rough finite inclined plane slider bearing with transversely rough surface has been analyzed. The results obtained here are compared with those of [8, 12-13]. It is observed that the load carrying capacity can be increased by decreasing the value of the roughness pattern parameter. This investigation suggests that the adverse effect of transverse surface roughness can be overcome to a great extent in the case of negatively skewed roughness under the presence of variance (-ve). However, from longevity point of view, the roughness aspect needs to be evaluated while designing the bearing system.

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Table-1: Relation between γ, C, r and H

γ	**C**	**r**	H
1/3	1.16	0.42	H >0.75> 0.5
1/6	1.38	0.42	H > 1>0.5
1/9	1.48	0.42	H >1>0.5

Table-2: Relation between γ, A_1, α_1, α_2, α_3 and H

γ	A_1	α_1	α_2	α_3	H=h/σ
1/3	1.858	1.01	0.76	0.03	H > 0.5
1/6	1.962	1.08	0.77	0.03	H > 0.5
1/9	2.046	1.12	0.78	0.03	H > 0.5