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Ferrofluid based squeeze film for a rough conical bearing with deformation effect

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Abstract

This paper aims to discuss the combined effect of longitudinal surface roughness and deformation on the behavior of a ferrofluid based squeeze film in conical plates. The Neuringer and Rosenweig model for ferrofluid flow has been considered resorting to an unusual form of the magnitude of the magnetic field. For the evaluation of surface roughness the stochastic model of Christensen and Tonder has been adopted. The concerned stochastically averaged Reynolds type equation is solved to obtain the pressure distribution which results in the calculation of load carrying capacity. The results establish that the positive effect of magnetization adds to the positive effect of longitudinal surface roughness under restricted circumstances. However, for an overall improved performance the bearing deformation must be addressed carefully as it has a significant effect on the squeeze film behavior. Besides, this article offers an additional degree of freedom through the magnitude of the magnetic field for designing the bearing system.

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1 Introduction

These magnetic fluids are a kind of multi functional materials which are manufactured by dispersing the magnetic particles into a carrying liquid. (Jacod et al, 2004) dealt with the effect of longitudinal roughness on the friction in EHL contacts by means of numerical simulations. It was shown that for the effect on friction such a combined pattern could be represented by a single equivalent wave. The performance of a squeeze film formed by a magnetic fluid between longitudinally rough conical plates analyzed in (Andharia and Deheri, 2010). By choosing a suitable combination of the magnetization parameter and the semi-vertical angle of the cone, the performance of the longitudinally rough bearing system could be enhance. (Vadher et al, 2011) deliberated on the behavior of a hydromagnetic squeeze film between conducting porous transversely rough truncated conical plates. It was examined that the negative effect induced by porosity and standard deviation could be overcome completely by the positive effect of the magnetization parameter and conductivities by choosing suitable aspect ratio and the semi-vertical angle in the case of negatively skewed roughness. The behaviour of a magnetic fluid based squeeze film between rough porous truncated conical plates by taking into consideration the effects of bearing deformation and slip velocity discussed in (Shimpi and Deheri, 2014). It was found that the combined effect of bearing deformation and slip velocity was relatively adverse. The magnetic fluid lubricant saved the situation to a limited extent, at least in the case of the negatively skewed roughness. (Shah and Parikh, 2014) studied the effects of ferrofluid lubricant on slider bearings considering rotation of the magnetic particles and their magnetic moments under a constant transverse magnetic field. It was noted that a constant magnetic field did not enhance load carrying capacity in Rosensweig's ferrofluid flow model whereas it did in the case of the Shliomis model. (Lin, 2016) analyzed the performance characteristics of a magnetic fluid lubricated short journal bearing with rough surfaces using the magnetic fluid model incorporating the stochastic model. It was obtained that the effects of longitudinal roughness patterns result in an increased load capacity as well as a reduced friction parameter and attitude angle. (Patel and Deheri, 2016) presented a comparison of all the three magnetic fluid flow models so far as the performance of a magnetic fluid based parallel plate rough slider bearing. It was found that for a bearing's long life period the Shliomis model might be employed for higher loads.

2 Analysis

The geometry of the bearing system, which is infinite in the Y- direction is displayed in Figure 1. Here, $\dot{h} = \frac{dh}{dt}$ is the squeeze film velocity in the z-direction. The magnetic field M is oblique to the lower plate.

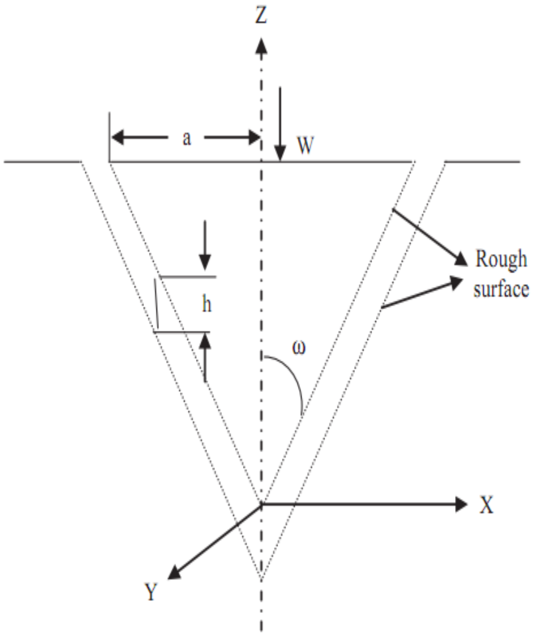

Figure 1: Configuration of the bearing system.

In view of usual assumptions of the hydromagnetic lubrication, the related Reynold's equation ((Andharia and Deheri, 2010), (Shimpi and Deheri, 2014), Patel and Deheri, 2016)) governing the in the present study is obtained as,

$$\frac{1}{x}\frac{d}{dx}\left[xh^{3}\frac{d}{dx}\left(p-\frac{1}{2}\mu_{0}\bar{\mu}M^{2}\right)\right]=\frac{12\mu\dot{h}_{0}}{\sin^{2}\omega} \tag{1}$$

Where

$$M^{2}=\frac{x^{2}}{a^{2}}\sin^{2}\omega\sin\left(1-\frac{x^{2}}{a^{2}}\sin^{2}\omega\right)$$

Here longitudinally rough bearing surfaces are considered. Therefore, the stochastic film thickness of the lubricant film, according to discussions of Christensen and Tonder ((Andharia and Deheri, 2010), (Shimpi and Deheri, 2014), Patel and Deheri, 2016)), is assumed as to be

$$h=\bar{h}+h_{s}$$

Where h_s is hypothetical to be stochastic in nature and governed by the probability density function

$$f(h_{s})=\begin{cases}\frac{35}{32c}\left(1-\frac{h_{s}^{2}}{c^{2}}\right)^{3}, & -c\le h_{s}\le c\\ 0, elsewhere\end{cases}$$

Following the theory of averaging process discussed in (Andharia and Deheri, 2010), equation (1) turns out to be of the form:

$$\frac{1}{x}\frac{d}{dx}\left[xm\left(\bar{h}\right)^{-1}\frac{d}{dx}\left(p-\frac{1}{2}\mu_{0}\bar{\mu}M^{2}\right)\right]=\frac{12\mu\dot{h}_{0}}{\sin^{2}\omega} \tag{2}$$

Where p is the expected value of the lubricant pressure while

$$m(\overline{h}) = \left(h + p_a p' \delta\right)^{-3}\Big[1 - 3\left(h + p_a p' \delta\right)^{-1}\alpha + 6\left(h + p_a p' \delta\right)^{-2}\left(\sigma^2 + \alpha^2\right)$$

$$-20\left(h + p_a p' \delta\right)^{-3}\left(3\sigma^2\alpha + \alpha^3 + \varepsilon\right)\Big]$$

The associated boundary conditions are,

$$p(a\cos ec\omega) = 0, \left(\frac{dp}{dx}\right)_{x=0} = 0 \tag{3}$$

Using these boundary conditions, equation (2) takes the form,

$$\frac{d}{dx}\left(p - \frac{1}{2}\mu_0\overline{\mu}M^2\right) = \frac{6\mu\dot{h}_0}{\sin^2\omega}xm(\overline{h}) \tag{4}$$

Introducing the non dimensional quantities,

$$H = \frac{h}{h_0}, X = \frac{x}{a\cos ec\omega}, K(H) = h_0^3 m(\overline{h}), \overline{\sigma} = \frac{\sigma}{h_0},$$

$$\overline{\alpha} = \frac{\alpha}{h_0}, \overline{\varepsilon} = \frac{\varepsilon}{h_0^3}, P = -\frac{h_0^3 p}{\mu\dot{h}_0 A}, \mu^* = -\frac{\mu_0\overline{\mu}h_0^3}{\mu\dot{h}_0},$$

$$\overline{p} = p_a p', \overline{\delta} = \frac{\delta}{h} \tag{5}$$

Wherein

$$A = \frac{a^2\pi}{\sin\omega}.$$

The P under the boundary condition $P = 0$ at $X = 1$ can be found to be,

$$P = \frac{\mu^* X^2\sin\left(1 - X^2\right)\sin\omega}{\pi} + \frac{3K(H)}{\pi\sin^3\omega}\left(1 - X^2\right) \tag{6}$$

where

$$K(H) = H^{-3}\left(1 + \overline{p}\overline{\delta}\right)^{-3}\Big[1 - 3H^{-1}\left(1 + \overline{p}\overline{\delta}\right)^{-1} + 6H^{-2}\left(1 + \overline{p}\overline{\delta}\right)^{-2}\left(\overline{\sigma}^2 + \overline{\alpha}^2\right)\alpha$$

$$-20H^{-3}\left(1 + \overline{p}\overline{\delta}\right)^{-3}\left(3\overline{\sigma}^2\overline{\alpha} + \overline{\alpha}^3 + \overline{\varepsilon}\right)\Big]$$

The dimensionless W is obtained as,

$$W = -\frac{wh_0^3}{\mu\dot{h}_0 A^2} = \int_0^1 PdX$$

$$= \frac{\mu^*\sin\omega}{\pi}\int_0^1 X^2\sin\left(1 - X^2\right)dx + \frac{2K(H)}{\pi\sin^3\omega}$$

$$= \frac{\mu^*\sin\omega}{\pi}(0.125101) + \frac{2K(H)}{\pi\sin^3\omega} \tag{7}$$

where

$$w = 2\pi \int_{0}^{a\cos ec\omega} xp(x)dx$$

3 Results And Discussion

To It can be noticed that the expression involved in the equation (7) is linear with respect μ^* and hence an increase in μ^* would lead to increase load carrying capacity. In the absence of deformation this study reduces to the investigation of (Andharia and Deheri, 2010).

The effect of $\overline{\delta}$ given in Figures 2-6 tells that there occurs a considerable load decrease due to the bearing deformation. However, the effect of roughness parameters on the load carrying capacity with respect to deformation remains negligible.

The fact that $\overline{\sigma}$ increases the load carrying capacity nominally, is depicted in Figures 7-8. Further the combined effect of $\overline{\sigma}$ and negatively skewed roughness turns to significantly positive [Figure 8], as the load rises sharply.

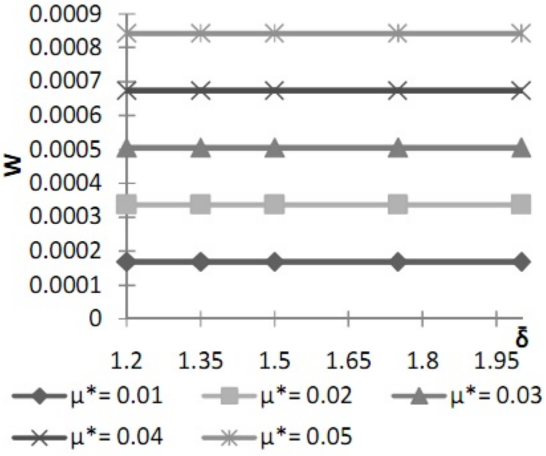

Figure 2: Variation of W with respect to $\overline{\delta}$ and μ^* .

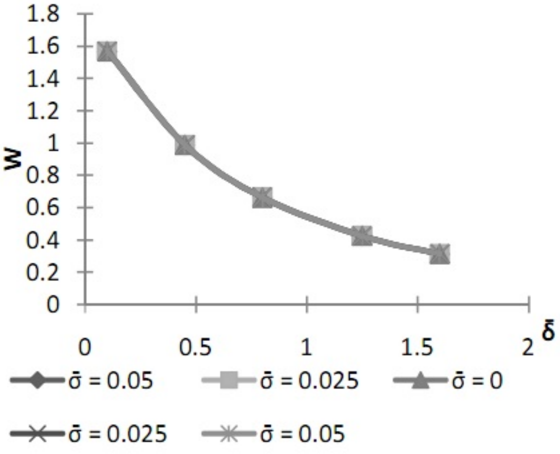

Figure 3: Variation of W with respect to $\overline{\delta}$ and $\overline{\sigma}$.

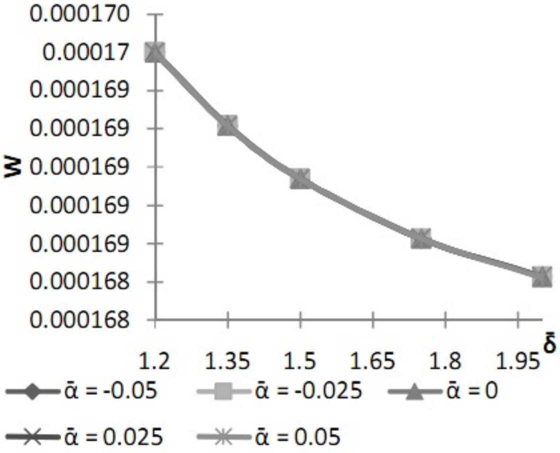

Figure 4: Variation of W with respect to $\overline{\delta}$ and $\overline{\alpha}$.

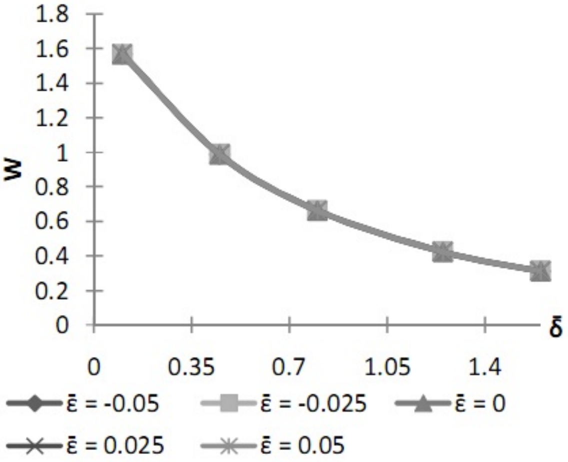

Figure 5: Variation of W with respect to $\overline{\delta}$ and $\overline{\varepsilon}$.

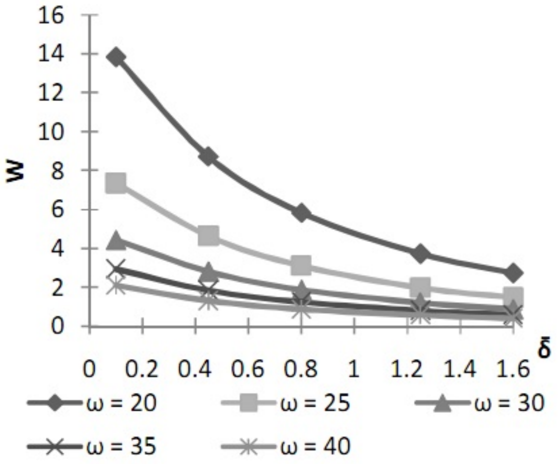

Figure 6: Variation of W with respect to $\overline{\delta}$ and ω .

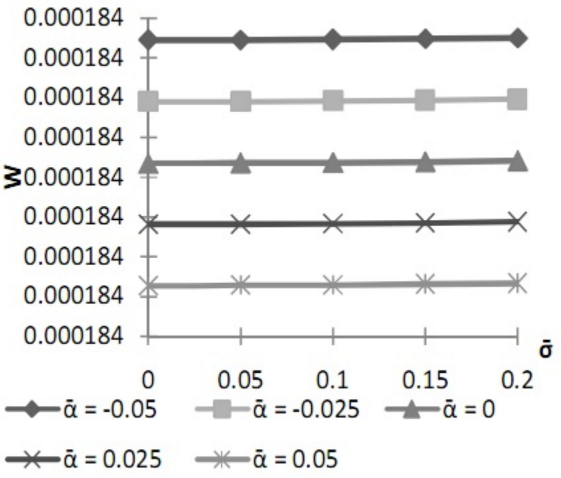

Figure 7: Variation of W with respect to $\overline{\sigma}$ and $\overline{\alpha}$.

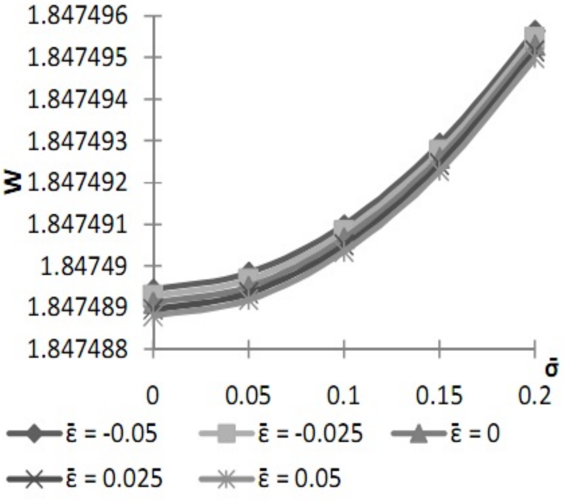

Figure 8: Variation of W with respect to $\overline{\sigma}$ and $\overline{\varepsilon}$.

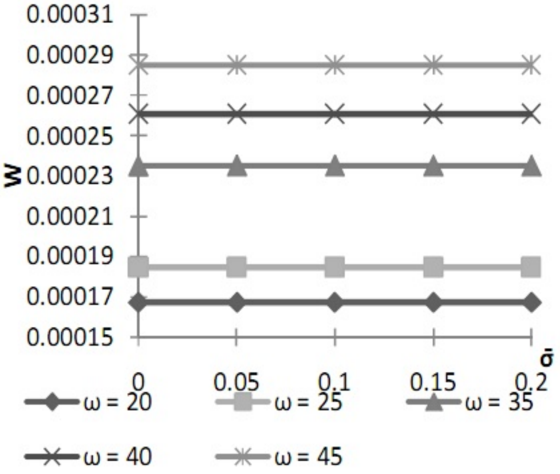

Figure 9: Variation of W with respect to $\overline{\sigma}$ and ω .

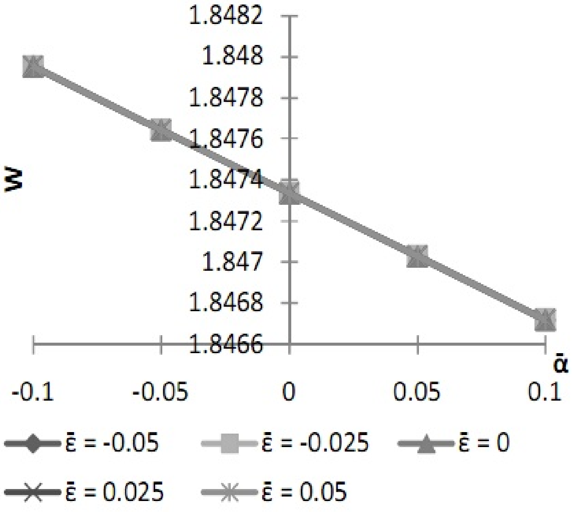

Figure 10: Variation of W with respect to $\overline{\alpha}$ and $\overline{\varepsilon}$.

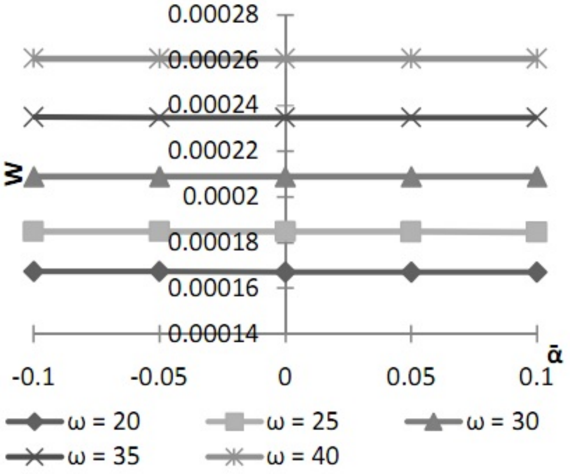

Figure 21: Variation of W with respect to $\overline{\alpha}$ and ω .

It is appealing to note that the effect of skewness on load carrying capacity with respect to variance is negligible which rarely happens. This is a study in contrast as can be seen from (Shimpi and Deheri, 2014) and (Patel and Deheri, 2016).

The variance effect is marginal [Figures 9] however, load carrying capacity decreases with variance (+ve) while load is observed to be more in the case of variance (-ve).

4 Conclusion

It is found that in most of the situations the effect of surface roughness and deformation is relatively adverse, this investigation proves that magnetism has a sobering effect especially, when negatively skewed roughness is involved and variance (-ve) occurs. But, this positive effect of magnetization may not go a long way in mitigating the negative effect of roughness. Therefore, the roughness aspects need to be addressed for a good bearing design.

Nomenclature

Symbol	**Name**	**Symbol**	**Name**	**Symbol**	**Name**
p	Lubricant pressure	μ_0	The permeability of free space	ε	Skewness
w	Load carrying capacity	P	Dimensionless pressure	μ	Viscosity of lubricant
α	Variance	W	Dimensionless load carrying capacity	δ	Deformation
σ	Standard deviation	$\bar{\alpha}$	Variance in non-dimensional form	p_a	The reference ambient pressure
$\bar{\sigma}$	Dimensionless standard deviation	$\bar{\varepsilon}$	Non-dimensional skewness	μ^*	Dimensionless magnetization parameter
$\bar{\delta}$	Dimensionless deformation	a	Dimension of the bearing	ω	Semi-vertical angle of cone
h	film thickness	$\bar{\mu}$	The magnetic susceptibility	$\bar{h}$	The mean film thickness
h_s	The deviation from the mean film thickness	c	The maximum deviation from the mean film thickness		

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