

Parametric Optimization of Surface Roughness in Longitudinally Rough Short Bearings

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Abstract:

A magnetic fluid was used as a lubricant to investigate how well a longitudinally short bearing operates. Surface roughness is a stochastic random variable with values larger than zero for mean, variance, and skewness. As a result of solving the modified Reynolds equation presented with this, the pressure distribution is formed, which leads to the computation of how much weight is supported. The findings are provided visually as well as in tabular form. Magnetisation is an established way to improve the performance of bearing systems. Furthermore, roughness has been shown to have a detrimental impact on bearing performance. According to the study's findings, the beneficial effect of the magnetisation parameter may be sufficient to outweigh the negative impact of roughness. Furthermore, it has been shown that mixing the roughness parameters in an appropriate manner improves performance.

Keywords:

Short bearing, Longitudinal roughness, Magnetic fluid, Reynolds equation, Load carrying capacity.

1 Introduction:

The slider bearing is the simplest and most common kind of hydrodynamic bearing. In a slider bearing, the film is continuous and does not diverge. These bearings are intended to withstand axial loads. Several publications and research articles provide specific solutions to Reynold's equation for slider bearings with different basic film shapes (Lord Rayleigh [1918], Archibald [1956]). Prakash and Vij [1973] investigated the hydrodynamic lubrication of a plane inclined slider bearing using different geometries and found that the quality of being porous reduced friction and load-carrying capacity. Patel and Gupta [1983] expanded Prakash and Vij's [1973] research by integrating slide velocity and demonstrated that in order to improve bearing system performance, the slide parameter value should be minimised. However, the manufacturing process, wear, and impulsive damage may all cause roughness on bearing surfaces. To further understand the influence of surface roughness, Christensen

[1969-70, 1971] developed a stochastic notion and used an average film model to lubricate surfaces with striated roughness. Several researchers have used a stochastic approach to simulate random roughness (Tzeng and Seibel [1967], Christensen and Tonder [1969a, 1969b, 1970]). Christensen and Tonder [1969a, 1969b, 1970] developed an all-inclusive general analysis for surface roughness based on a generic probability density function, updating and developing Tzeng and Seibel's technique [1967]. As a result, many studies have been conducted to investigate the effect of surface roughness, including those by Taranga et al. [1999], Christensen and Tonder [1971], and Andharia et al. [2001]. In all of these investigations, straight lubricant was utilised. The use of magnetic fluid as a lubricant to change the performance of the bearing has been well recognised. Agrawal [1986] investigated the configuration of Prakash and Vij [1973] in the presence of a magnetic fluid lubricant and found that it performed better than the one with a straight lubricant. Bhat and Deheri [1991] enhanced Agrawal's [1986] research by investigating a magnetic fluid-based porous composite slider bearing. Bhat and Deheri [1995] investigated a generic porous slider bearing with a squeeze film created by a magnetic fluid. Patel and Deheri [2013] described the behaviour of a transversely rough magnetic fluid-based porous short bearing. Also, Andharia et al. [2014] investigated the performance of a magnetic fluid-based longitudinally rough short bearing. Andharia et al. [2015] have shown the influence of surface roughness from transverse patterns on short bearing performance. It has been suggested to research and test the performance of a longitudinally rough short bearing using a magnetic fluid as a lubricant.

2. Analysis:

The geometry and configuration of bearing is shown in Figure 1, which is infinite in Z -direction.

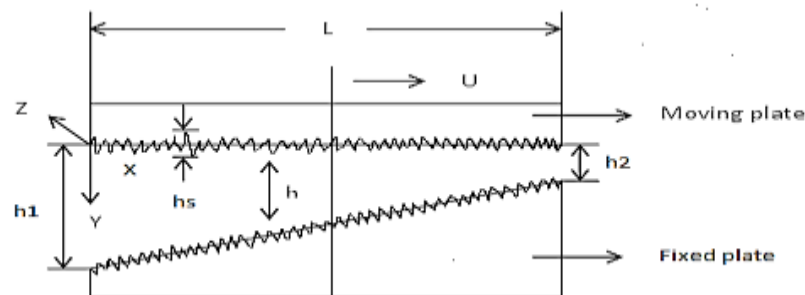


Figure 1: Geometry and configuration of the longitudinally rough short bearing (infinite in Z -direction)

The slider moves with the uniform velocity U in X -direction. The length of bearing L and breadth B is in Z -direction, where $B \ll L$. The pressure gradient $\partial p / \partial z$ is very larger than pressure gradient $\partial p / \partial x$. The maximum and minimum film thicknesses are h_1 and h_2 respectively. The assumptions of usual hydrodynamic lubrication theory are taken into consideration in the development of the analysis.

The lubricant film is supposed to be iso-viscous and incompressible and the flow is laminar. The magnetic field is oblique to the stator as in Agrawal [1986]. Following discussions carried out by Prajapati [1995] regarding the effect of various forms of magnitude of magnetic field is expressed as

$$M^2 = KB^2 \left\{ \left(\frac{1}{2} + \frac{z}{B} \right) \sin \left(\frac{1}{2} - \frac{z}{B} \right) + \left(\frac{1}{2} - \frac{z}{B} \right) \sin \left(\frac{1}{2} + \frac{z}{B} \right) \right\} \quad (1)$$

Where B is the breadth of bearing and K is a suitably chosen constant from dimensionless point of view (Bhat and Deheri [1995])

The bearing surfaces are assumed to be transversely rough. The thickness h of the lubricant film is given by

$$h = \bar{h} + h_s \quad (2)$$

Where \bar{h} is 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 Considered as stochastic in nature and governed by probability density function $f(h_s)$, $-c \leq h_s \leq c$, where c is the maximum deviation from the mean film thickness.

The mean α , the standard deviation σ and the measure of symmetry ϵ the random variable h_s are defined by the relationship :

$$\alpha = E(h_s) \quad (3)$$

$$\sigma^2 = E[(h_s - \alpha)^2] \quad (4)$$

and

$$\epsilon = E[(h_s - \alpha)^3] \quad (5)$$

Where E is the expectancy operator defined by

$$E(R) = \int_{-c}^c f(h_s) dh_s \quad (6)$$

Wherein (Tzeng and Saibel [1967])

$$f(h_s) = \frac{35}{32c^7} (c^2 - h^2)^3, -c \leq h \leq c$$

$$= 0, \quad \text{elsewhere} \quad (7)$$

It is easily observed that α , σ and ε are independent of x .

The standard deviation, the mean and the measure of symmetry play important role. Therefore with the usual notations of hydrodynamic lubrication, the modified Reynolds equation for film pressure (Bhat [2003], Prajapati [1995], Deheri, Andharia and Patel [2004]) is given by

$$\frac{d^2}{dz^2} \left(p - \frac{\mu_0 \bar{\mu} M^2}{2} \right) = 6\mu U \mathcal{l}(h) \frac{d}{dx} \left(\frac{1}{n(h)} \right) \quad (8)$$

Where $h = h_2 \left\{ 1 + m \left(1 - \frac{x}{L} \right) \right\}$

$$\mathcal{l}(h) = h^{-3} [1 - 3\alpha h^{-1} + 6h^{-2}(\alpha^2 + \sigma^2) - 10h^{-3}(\varepsilon + 3\sigma^2\alpha + \alpha^3)]$$

$$n(h) = h^{-1} [1 - \alpha h^{-1} + h^{-2}(\alpha^2 + \sigma^2) - h^{-3}(\varepsilon + 3\sigma^2\alpha + \alpha^3)]$$

$$\text{Where in } m = \frac{h_1 - h_2}{h_2}$$

While μ_0 is the magnetic susceptibility, $\bar{\mu}$ is the free space permeability and μ is the lubricant viscosity

The associated boundary conditions are

$$p = 0; \quad z = \pm \frac{B}{2} \quad \text{and} \quad \frac{dp}{dz} = 0; \quad z = 0 \quad (9)$$

By integrating Eq. (8) with respect to z

$$\frac{d}{dz} \left(p - \frac{\mu_0 \bar{\mu} M^2}{2} \right) = 6\mu U \mathcal{l}(h) \frac{d}{dx} \left(\frac{1}{n(h)} \right) z + C_1 \quad (10)$$

Where C_1 is a constant

$$\text{At } z = 0; \quad \frac{dp}{dz} = 0; \quad \frac{d}{dz} (M^2) = 0 \quad \text{and} \quad C_1 = 0$$

Again by integrating Eq. (10) with respect to z

$$p - \frac{\mu_0 \bar{\mu} M^2}{2} = 6\mu U \mathcal{l}(h) \frac{d}{dx} \left(\frac{1}{n(h)} \right) \frac{z^2}{2} + C_2 \quad (11)$$

Where C_2 is a constant

$$\text{At } z = \pm \frac{B}{2}; p = 0; M^2 = 0$$

$$\text{and } C_2 = -3\mu U \left[(h) \frac{d}{dx} \left(\frac{1}{n(h)} \right) \frac{B^2}{4} \right]$$

By Eq. (11), the pressure distribution is

$$p = \frac{\mu_0 \bar{\mu} M^2}{2} - 3\mu U \left[(h) \frac{d}{dx} \left(\frac{1}{n(h)} \right) B^2 \left(\frac{1}{4} - \frac{z^2}{B^2} \right) \right] \quad (12)$$

Introducing the following dimensionless quantities

$$Z = \frac{z}{B}, X = \frac{x}{L}, m = \frac{h_1 - h_2}{h_2}, \mu^* = \frac{h_2^3 K \mu_0 \bar{\mu}}{\mu U}, P = \frac{h_2^3}{\mu U B^2}, \bar{\alpha} = \frac{\alpha}{h_2}, \bar{\sigma} = \frac{\sigma}{h_2}, \\ \bar{\varepsilon} = \frac{\varepsilon}{h_2}, \bar{L} = \frac{L}{h_2}, \bar{B} = \frac{B}{h_2} \quad (13)$$

The pressure distribution in dimensionless form as

$$P = \frac{\mu^*}{2} \left[\left(\frac{1}{2} + Z \right) \sin \left(\frac{1}{2} - Z \right) + \left(\frac{1}{2} - Z \right) \sin \left(\frac{1}{2} + Z \right) \right] + \frac{3m}{\bar{L}} \left(\frac{1}{4} - Z^2 \right) G(H) \quad (14)$$

Where

$$G(H) = \frac{A_1^3 - 5\bar{\alpha}A_1^2 + (15\bar{\alpha}^2 + 9\bar{\sigma}^2)A_1 - (35\bar{\alpha}^3 + 63\bar{\alpha}\bar{\sigma}^2 + 14\bar{\varepsilon}) + (50\bar{\alpha}^4 + 132\bar{\alpha}^2\bar{\sigma}^2 + 18\bar{\sigma}^4 + 32\bar{\alpha}\bar{\varepsilon})A_1^{-1} - (54\bar{\alpha}^5 + 216\bar{\alpha}^3\bar{\sigma}^2 + 54(\bar{\alpha}^2 + \bar{\sigma}^2)\bar{\varepsilon} + 162\bar{\alpha}\bar{\sigma}^4)A_1^{-2} + 40(\bar{\alpha}^3 + 3\bar{\alpha}\bar{\sigma}^2 + \bar{\varepsilon})^2 A_1^{-3}}{[A_1^3 - \bar{\alpha}A_1^2 + (\bar{\alpha}^2 + \bar{\sigma}^2)A_1 - (\bar{\alpha}^3 + 3\bar{\alpha}\bar{\sigma}^2 + \bar{\varepsilon})]^2}$$

Where in $A_1 = 1 + m(1 - x)$

The load carrying capacity of the bearing is given by

$$W = \int_{-\frac{B}{2}}^{\frac{B}{2}} \int_0^1 p(x, z) dx dz \quad (15)$$

Dimensionless load carrying capacity is obtained as

$$W = \frac{\bar{L}}{\bar{B}} \int_{-\frac{1}{2}}^{\frac{1}{2}} \int_0^1 P \, dX \, dZ \quad (16)$$

3. Results and Discussions:

It is observed that Eq. (14) and Eq. (16) represent the dimensionless pressure distribution and dimensionless load carrying capacity respectively. These performance characteristics depend on several parameters such as magnetization parameter μ^* , length ratio L/h_2 , breadth ratio B/h_2 , aspect ratio m , roughness parameters σ , α and ε etc. Eq. (16) is integrated using numerical method for different values of μ^* , σ , α and ε . Here the results are presented graphically as well as in Table form.

Figures 2 - 4 represent the variation of load carrying capacity with respect to magnetization parameter μ^* for various values of L/h_2 , B/h_2 , σ/h_2 respectively. These figures suggest that the load carrying capacity increases sharply due to magnetization.

Figures 5 - 7 represent the variation of load carrying capacity with respect to σ/h_2 for various values of L/h_2 , B/h_2 , α/h_2 respectively. From these figures it is seen that the load carrying capacity increases significantly. However, the effect of σ/h_2 was described negative in the case of transverse surface roughness [2015].

Figures 8 - 10 represent the variation of load carrying capacity with respect to α/h_2 for various values of L/h_2 , ε/h_2 and m respectively. From these figures it is clear that the load carrying capacity decreases due to α/h_2 .

Figure 11 shows that the variation of load carrying capacity with respect to ε/h_2 for various values of m . From this figures it is clear that the load carrying capacity decrease due to ε/h_2 .

Figure 12 represents the variation of load carrying capacity with respect to L/h_2 for various values of B/h_2 . It shows that the load carrying capacity increases considerably due to L/h_2 .

Figure 13 shows the variation of load carrying capacity with respect to B/h_2 and m . From the figure it is clearly shown that load carrying capacity decreases due to B/h_2 .

Figure 14 presents the variation of load carrying capacity with respect to m for various values of B/h_2 and m respectively. It is clear that the load carrying capacity increases due to m .

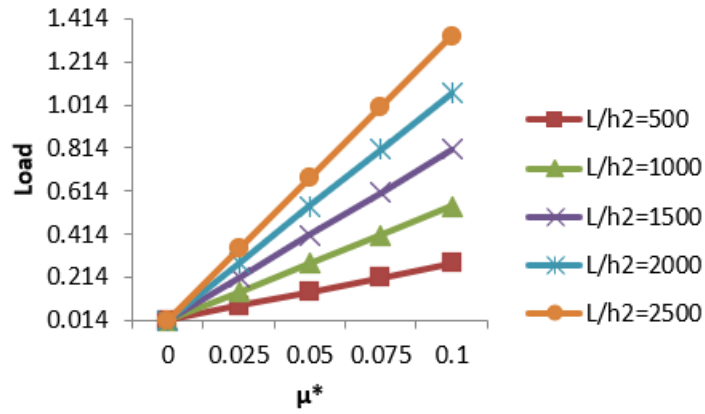


Figure 2: Variation of load carrying capacity with respect to μ^* and L/h_2

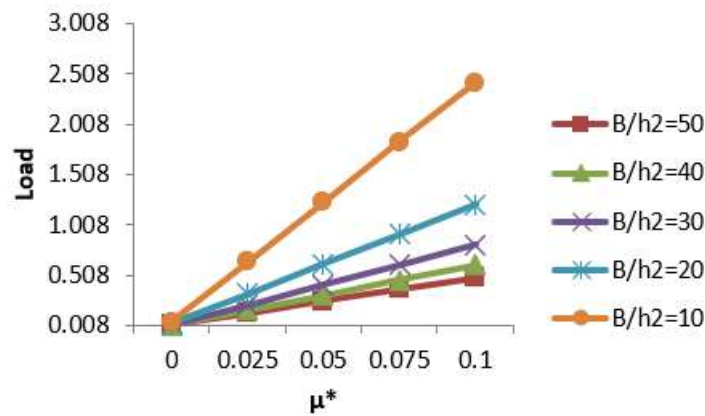


Figure 3: Variation of load carrying capacity with respect to μ^* and B/h_2

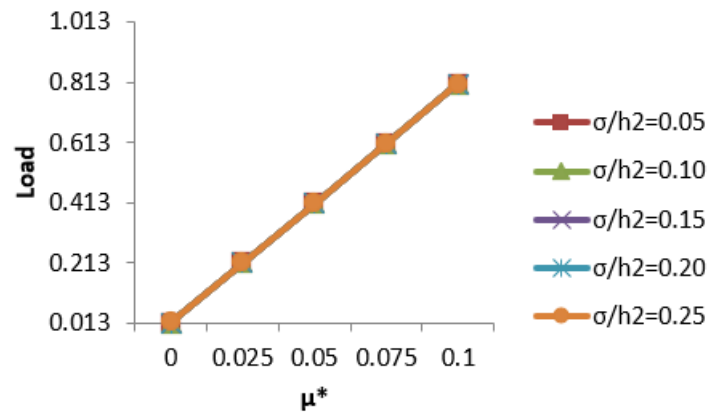


Figure 4: Variation of load carrying capacity with respect to μ^* and σ/h_2

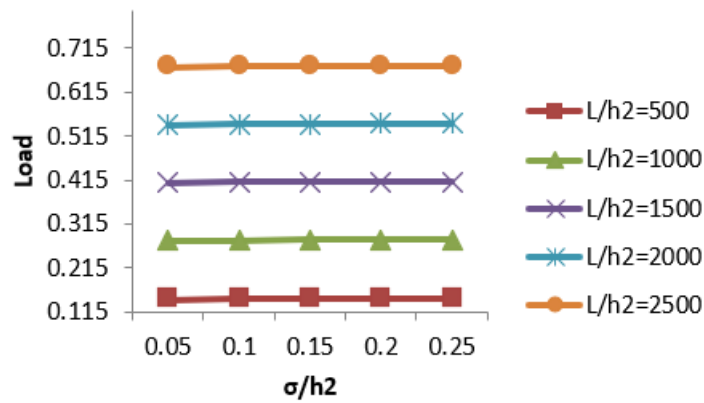


Figure 5: Variation of load carrying capacity with respect to σ/h_2 and L/h_2

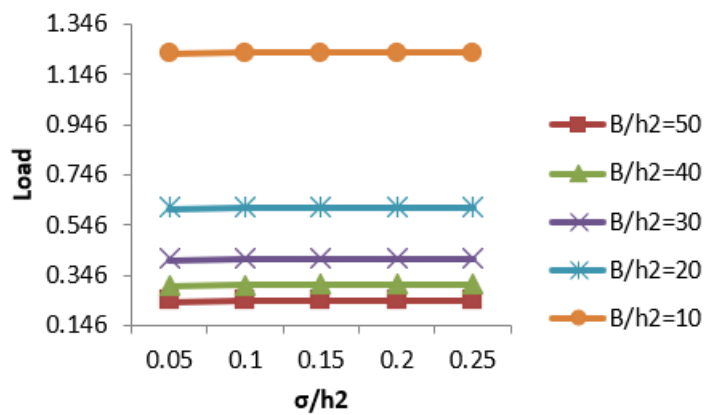


Figure 6: Variation of load carrying capacity with respect to σ/h_2 and B/h_2

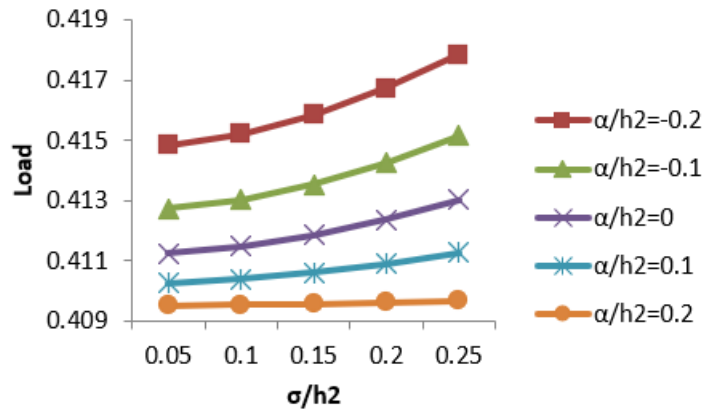


Figure 7: Variation of load carrying capacity with respect to σ/h_2 and α/h_2

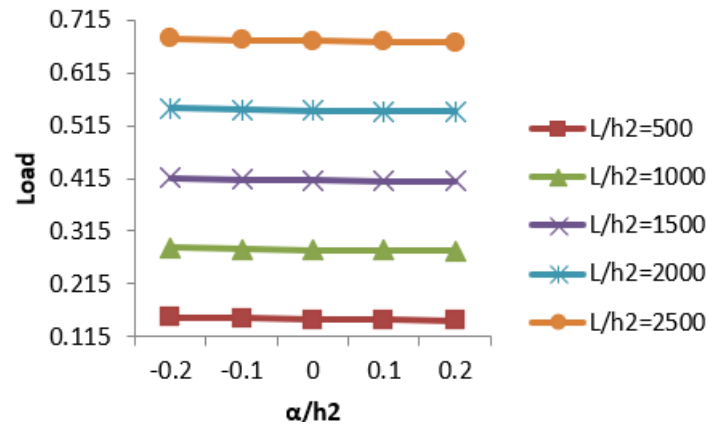


Figure 8: Variation of load carrying capacity with respect to α/h_2 and L/h_2

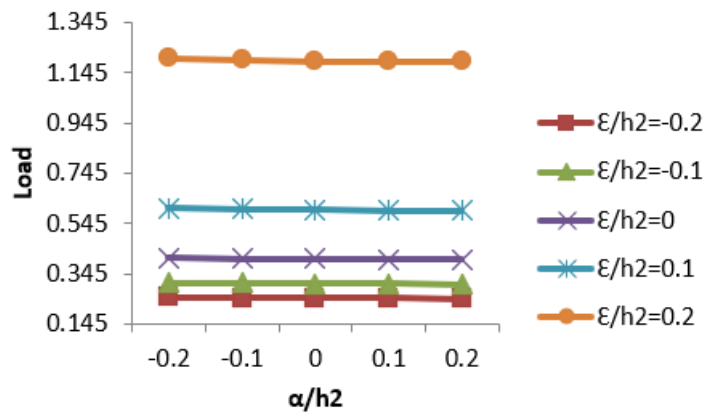


Figure 9: Variation of load carrying capacity with respect to α/h_2 and ϵ/h_2

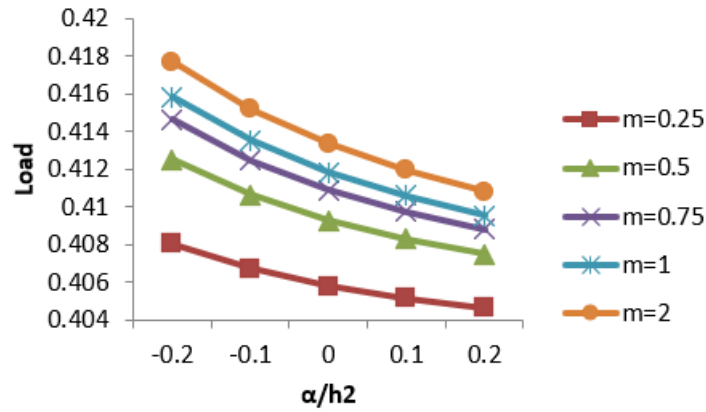


Figure 10: Variation of load carrying capacity with respect to $\alpha/h2$ and m

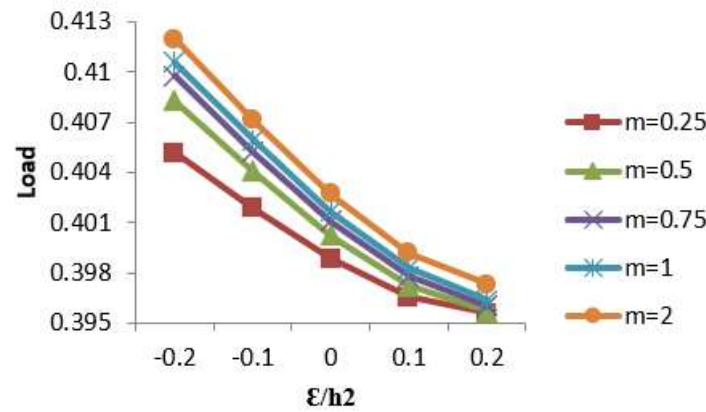


Figure 11: Variation of load carrying capacity with respect to $\epsilon/h2$ and m

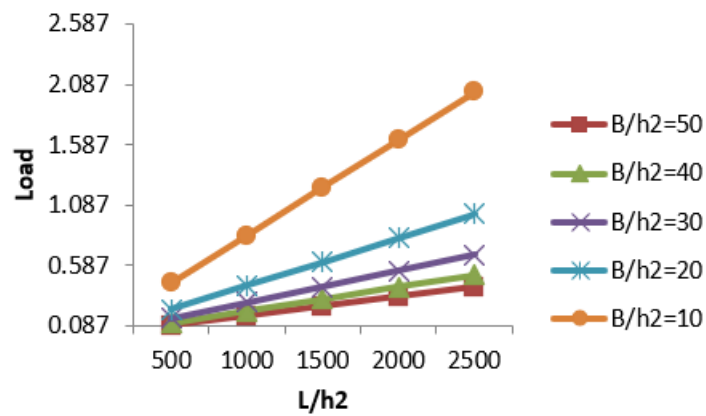


Figure 12: Variation of load carrying capacity with respect to $L/h2$ and $B/h2$

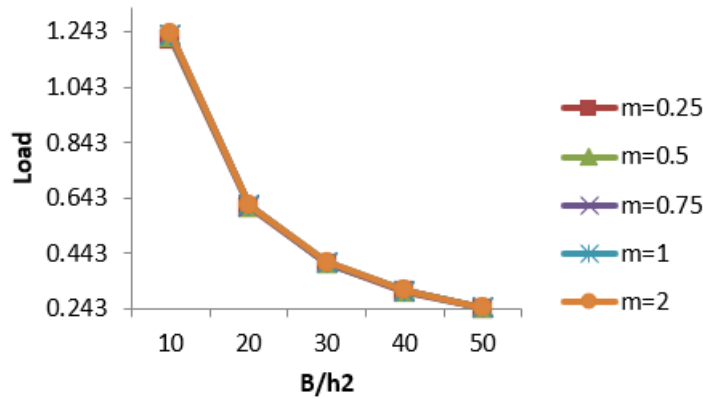


Figure 13: Variation of load carrying capacity with respect to B/h2 and m

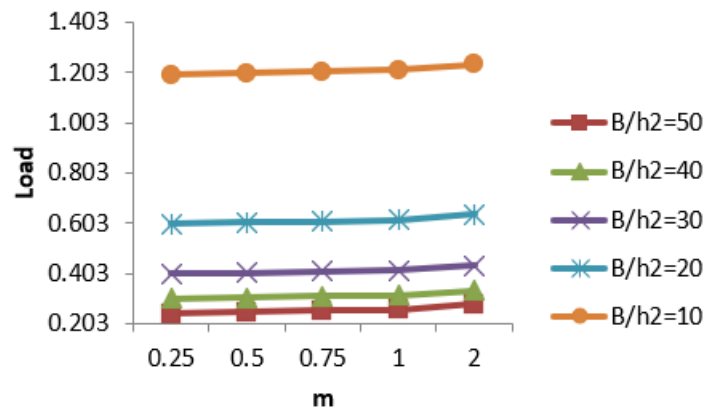


Figure 14: Variation of load carrying capacity with respect to B/h2 and m

Tables 1 – 3 present the variation of load carrying capacity with respect to magnetization parameter μ^* for various values of α/h_2 , ϵ/h_2 and m respectively. These tables suggest that the load carrying capacity increases sharply due to magnetization.

Tables 4 & 5 represent the variation of load carrying capacity with respect to σ/h_2 for various values of ϵ/h_2 and m respectively. From these tables it is seen that the load carrying capacity increases significantly with σ/h_2 , but this increase is very less

Table 6 shows that the variation of load carrying capacity with respect to α/h_2 for various values of B/h_2 . It is clear that the load carrying capacity decreases due to α/h_2 .

Tables 7 & 8 represent the variation of load carrying capacity with respect to ϵ/h_2 for various values of L/h_2 , B/h_2 . From this table it is clear that the load carrying capacity decrease marginally due to ϵ/h_2 .

Table 9 presents the variation of load carrying capacity with respect to L/h_2 for various values of m . It is observed that the load carrying capacity increases considerably due to L/h_2 .

Table 1: Variation of load carrying capacity with respect to μ^* and α/h_2

| μ^* | Load | | | | |
|---------|-------------------|-------------------|----------------|------------------|------------------|
| | $\alpha/h_2=-0.2$ | $\alpha/h_2=-0.1$ | $\alpha/h_2=0$ | $\alpha/h_2=0.1$ | $\alpha/h_2=0.2$ |
| 0 | 0.01952 | 0.017217 | 0.015519 | 0.014263 | 0.013236 |
| 0.025 | 0.217682 | 0.21538 | 0.213681 | 0.212425 | 0.211399 |
| 0.05 | 0.415845 | 0.413542 | 0.411844 | 0.410588 | 0.409561 |
| 0.075 | 0.614007 | 0.611705 | 0.610006 | 0.60875 | 0.607724 |
| 0.1 | 0.81217 | 0.809867 | 0.808169 | 0.806913 | 0.805886 |

Table 2: Variation of load carrying capacity with respect to μ^* and ε/h_2

| μ^* | Load | | | | |
|---------|------------------------|------------------------|---------------------|-----------------------|-----------------------|
| | $\varepsilon/h_2=-0.2$ | $\varepsilon/h_2=-0.1$ | $\varepsilon/h_2=0$ | $\varepsilon/h_2=0.1$ | $\varepsilon/h_2=0.2$ |
| 0 | 0.014263 | 0.0096 | 0.005354 | 0.001927 | 2.71E-05 |
| 0.025 | 0.212425 | 0.207763 | 0.203517 | 0.200089 | 0.19819 |
| 0.05 | 0.410588 | 0.405925 | 0.401679 | 0.398252 | 0.396352 |
| 0.075 | 0.60875 | 0.604088 | 0.599842 | 0.596414 | 0.594515 |
| 0.1 | 0.806913 | 0.80225 | 0.798004 | 0.794577 | 0.792677 |

Table 3: Variation of load carrying capacity with respect to μ^* and m

| μ^* | Load | | | | |
|---------|----------|----------|----------|----------|----------|
| | $m=0.25$ | $m=0.5$ | $m=0.75$ | $m=1$ | $m=2$ |
| 0 | 0.008826 | 0.011971 | 0.013442 | 0.014263 | 0.015642 |
| 0.025 | 0.206989 | 0.210134 | 0.211604 | 0.212425 | 0.213805 |
| 0.05 | 0.405151 | 0.408296 | 0.409767 | 0.410588 | 0.411967 |
| 0.075 | 0.603314 | 0.606459 | 0.607929 | 0.60875 | 0.61013 |
| 0.1 | 0.801476 | 0.804621 | 0.806092 | 0.806913 | 0.808292 |

Table 4: Variation of load carrying capacity with respect to σ/h_2 and ε/h_2

| σ/h_2 | Load | | | | |
|--------------|------------------------|------------------------|---------------------|-----------------------|-----------------------|
| | $\varepsilon/h_2=-0.2$ | $\varepsilon/h_2=-0.1$ | $\varepsilon/h_2=0$ | $\varepsilon/h_2=0.1$ | $\varepsilon/h_2=0.2$ |
| 0.05 | 0.410248 | 0.405581 | 0.401358 | 0.398007 | 0.396284 |
| 0.1 | 0.410376 | 0.40571 | 0.401478 | 0.398097 | 0.396307 |
| 0.15 | 0.410588 | 0.405925 | 0.401679 | 0.398252 | 0.396352 |
| 0.2 | 0.410883 | 0.406225 | 0.401962 | 0.398473 | 0.39643 |
| 0.25 | 0.411259 | 0.40661 | 0.402326 | 0.398766 | 0.396552 |

Table 5: Variation of load carrying capacity with respect to σ/h_2 and m

| σ/h_2 | Load | | | | |
|--------------|----------|----------|----------|----------|----------|
| | $m=0.25$ | $m=0.5$ | $m=0.75$ | $m=1$ | $m=2$ |
| 0.05 | 0.404956 | 0.408016 | 0.409447 | 0.410248 | 0.411605 |
| 0.1 | 0.40503 | 0.408122 | 0.409567 | 0.410376 | 0.411741 |
| 0.15 | 0.405151 | 0.408296 | 0.409767 | 0.410588 | 0.411967 |
| 0.2 | 0.40532 | 0.40854 | 0.410044 | 0.410883 | 0.412282 |
| 0.25 | 0.405535 | 0.40885 | 0.410398 | 0.411259 | 0.412685 |

Table 6: Variation of load carrying capacity with respect to α/h_2 and B/h_2

| α/h_2 | Load | | | | |
|--------------|------------|------------|------------|------------|------------|
| | $B/h_2=50$ | $B/h_2=40$ | $B/h_2=30$ | $B/h_2=20$ | $B/h_2=10$ |
| -0.2 | 0.249507 | 0.311883 | 0.415845 | 0.623767 | 1.247534 |
| -0.1 | 0.248125 | 0.310157 | 0.413542 | 0.620313 | 1.240627 |
| 0 | 0.247106 | 0.308883 | 0.411844 | 0.617766 | 1.235531 |
| 0.1 | 0.246353 | 0.307941 | 0.410588 | 0.615882 | 1.231763 |
| 0.2 | 0.245737 | 0.307171 | 0.409561 | 0.614342 | 1.228683 |

Table 7: Variation of load carrying capacity with respect to ε/h_2 and L/h_2

| ε/h_2 | Load | | | | |
|-------------------|-------------|--------------|--------------|--------------|--------------|
| | $L/h_2=500$ | $L/h_2=1000$ | $L/h_2=1500$ | $L/h_2=2000$ | $L/h_2=2500$ |
| -0.2 | 0.146371 | 0.278479 | 0.410588 | 0.542696 | 0.674804 |
| -0.1 | 0.141709 | 0.273817 | 0.405925 | 0.538034 | 0.670142 |
| 0 | 0.137463 | 0.269571 | 0.401679 | 0.533788 | 0.665896 |
| 0.1 | 0.134035 | 0.266143 | 0.398252 | 0.53036 | 0.662468 |
| 0.2 | 0.132135 | 0.264244 | 0.396352 | 0.52846 | 0.660569 |

Table 8: Variation of load carrying capacity with respect to ε/h_2 and B/h_2

| ε/h_2 | Load | | | | |
|-------------------|------------|------------|------------|------------|------------|
| | $B/h_2=50$ | $B/h_2=40$ | $B/h_2=30$ | $B/h_2=20$ | $B/h_2=10$ |
| -0.2 | 0.246353 | 0.307941 | 0.410588 | 0.615882 | 1.231763 |
| -0.1 | 0.243555 | 0.304444 | 0.405925 | 0.608888 | 1.217776 |
| 0 | 0.241008 | 0.301259 | 0.401679 | 0.602519 | 1.205038 |
| 0.1 | 0.238951 | 0.298689 | 0.398252 | 0.597378 | 1.194755 |
| 0.2 | 0.237811 | 0.297264 | 0.396352 | 0.594528 | 1.189056 |

Table 9: Variation of load carrying capacity with respect to L/h_2 and m

| L/h_2 | Load | | | | |
|---------|----------|----------|----------|----------|----------|
| | $m=0.25$ | $m=0.5$ | $m=0.75$ | $m=1$ | $m=2$ |
| 500 | 0.140935 | 0.14408 | 0.14555 | 0.146371 | 0.14775 |
| 1000 | 0.273043 | 0.276188 | 0.277658 | 0.278479 | 0.279859 |
| 1500 | 0.405151 | 0.408296 | 0.409767 | 0.410588 | 0.411967 |
| 2000 | 0.53726 | 0.540405 | 0.541875 | 0.542696 | 0.544075 |
| 2500 | 0.669368 | 0.672513 | 0.673983 | 0.674804 | 0.676184 |

4. Conclusion:

The study shows that surface roughness reduces the performance of longitudinally rough short bearings, while magnetisation enhances it. The positive effect of magnetisation can offset the adverse impact of roughness, and an optimal mix of roughness parameters further improves load-carrying capacity. This highlights the potential of magnetic fluid lubrication for efficient bearing design.

The investigation specifies that the effect of roughness parameters is insignificant. This susceptible effect rises with the larger values of σ/h_2 and L/h_2 . The effects show that the adverse effect of B/h_2 , α/h_2 and ε/h_2 can be minimized to a larger extent by the positive effect of magnetization parameter μ^* and L/h_2 , choosing a suitable values of aspect ratio m .

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