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Magnetic Fluid Lubrication of Finite Journal Bearing; 3-D Analysis Using FDM

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

Research Article

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ABSTRACT

An endeavour has been made to analyze the hydrodynamic magnetic fluid based finite journal bearing by making use of finite difference method and MATLAB. Under the assumptions of hydromagnetic lubrication the Reynold's equation is derived, in turn, which is solved resorting to finite difference method for Sommerfeld boundary conditions. Basically, 3-D representation of the pressure profile obtained using MATLAB underlines the dependence on various parameters. It is needless to say that, this article offers an additional degree of freedom from design point of view. The graphical representation of the results establishes that the performance of the bearing system enhances significantly due to magnetic fluid lubrication. Further, this investigation reveals that the role of eccentricity ratio is a predominant factor for an overall improved performance of the bearing system. Equally crucial is the role of the aspect ratio.

Keywords: Magnetic fluid; 3-D analysis; finite journal bearing; MATLAB.

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1. INTRODUCTION

Fedor [1] studied developed a method for the solution of Reynold's differential equation applied to finite journal bearings. The method adopted here eased out the algebraic complexity occurring in the Sommerfeld solution. Latif and Ammam [2] adopted a numerical iterative scheme for the calculation of performance characteristics of a finite journal bearing with longitudinal and transverse rough surfaces. It was shown that when the bearing operated at its hydrodynamic limit the bearing behavior was greatly influenced by the surface roughness. Lin [3] presented a theoretical study of squeeze film performance for a couple stress fluid based finite journal bearing. Here, it was shown that the couple stress effect improved the performance characteristics of the finite journal bearing. Chasalevris and Sfyris [4] evaluated the finite journal bearing performance characteristics using the analytical solution of the Reynold's equation. Patel et al. [5] analyzed the performance of a ferrofluid based short journal bearing. It was established that the load carrying capacity increased nominally while the coefficient of friction decreased significantly because of magnetic fluid lubrication. Patel et.al. [6] discussed the magnetic fluid lubrication of a hydrodynamic short porous journal bearing. The results indicated that the magnetic fluid turned in a better performance of the bearing system as compared to a conventional lubricant. Interestingly, the coefficient of friction decreased significantly.

In the present study it has been proposed to launch an investigation in to the performance of a magnetic fluid based finite journal bearing considering the 3-D representation of the pressure profile using finite difference method and MATLAB.

2. METHODOLOGY

The well-known Reynolds equation associated with finite hydrodynamic bearing is

$$\frac{\partial}{\partial x}\left(h^3\frac{\partial p}{\partial x}\right)+\frac{\partial}{\partial z}\left(h^3\frac{\partial p}{\partial z}\right)=6\,\eta\,\mathrm{U}\frac{dh}{dx} \tag{1}$$

For magnetic fluid based bearing above equation becomes (Bhat and Deheri [7], Bhat [8])

$$\frac{\partial}{\partial x}\left(h^3\frac{\partial}{\partial x}\left(p-\frac{\mu_0\bar{\mu}M^2}{2}\right)\right)+\frac{\partial}{\partial z}\left(h^3\frac{\partial}{\partial z}\left(p-\frac{\mu_0\bar{\mu}M^2}{2}\right)\right)=6\,\eta\,\mathrm{U}\frac{dh}{dx}- \tag{2}$$

In view of the geometry of journal bearing, usually it is considered that

$$h=C(1+\varepsilon\cos\theta)\ \text{ and }\ x=R\theta \tag{3}$$

On differentiation, one is led to

$$dx=Rd\theta \tag{4}$$

and

$$\frac{dh}{dx}=\frac{1}{R}\frac{dh}{d\theta}=\frac{-C\varepsilon\sin\theta}{R} \tag{5}$$

The non-dimensional term,

$$\bar{Z} = \frac{2z}{L}$$

on differentiation gives

$$L\,\partial\bar{Z} = 2\partial z \tag{6}$$

Substitution of the values from Eq.(4),(5),(6) in the eq.(2), leads to

$$\frac{\partial}{R\partial\theta}\left(h^3\frac{\partial}{R\partial\theta}\left(p-\frac{\mu_0\bar{\mu}M^2}{2}\right)\right)+\frac{2}{L}\frac{\partial}{\partial\bar{Z}}\left(h^3\frac{2}{L}\frac{\partial}{\partial\bar{Z}}\left(p-\frac{\mu_0\bar{\mu}M^2}{2}\right)\right)=-\frac{6\eta UC\varepsilon\sin\theta}{R} \tag{7}$$

For magnetic fluid based journal bearing, the magnitude of the magnetic field is given by (Agrawal [9])

$$M^2 = k\theta(2\pi-\theta) \tag{8}$$

where, k is a suitably chosen constant so as to suit the dimension and the magnetic strength Introducing the dimensionless quantities

$$\mu^* = \frac{k\mu_0\bar{\mu}c^2}{\eta UR} \quad \bar{h} = 1+\varepsilon\cos\theta \quad , \quad P = p.\frac{c^2}{6\eta UR} \tag{9}$$

one arrives at

$$\frac{\partial^2\bar{P}}{\partial\theta^2}+\left(\frac{D}{L}\right)^2.\frac{\partial^2\bar{P}}{\partial\bar{Z}^2}-\frac{3\varepsilon\sin\theta}{\bar{h}}.\frac{\partial\bar{P}}{\partial\theta}+\frac{\varepsilon\sin\theta}{\bar{h}}\frac{\mu^*}{2}\left(\pi-\frac{\theta}{2}\right)+\frac{\mu^*}{6}=-\frac{\varepsilon\cos\theta}{\bar{h}^3} \tag{10}$$

This is the non-dimensional formulation of two dimensional Reynold's equation considering magnetic fluid based hydrodynamic finite journal bearing.

In FDM approach, the following scheme is adopted

$$\frac{\partial^2\bar{P}}{\partial\theta^2} = \frac{P_{i+1,j}-2P_{i,j}+P_{i-1,j}}{\Delta\theta^2}$$

$$\frac{\partial\bar{P}}{\partial\theta} = \frac{P_{i+1,j}-P_{i-1,j}}{2\Delta\theta}$$

$$\frac{\partial^2\bar{P}}{\partial\bar{Z}^2} = \frac{P_{i,j+1}-2P_{i,j}+P_{i,j-1}}{\Delta\bar{Z}^2}$$

Substituting above values in eq.(10) ,one obtains

$$\frac{P_{i+1,j}-2P_{i,j}+P_{i-1,j}}{\Delta\theta^2}+\left(\frac{D}{L}\right)^2.\frac{P_{i,j+1}-2P_{i,j}+P_{i,j-1}}{\Delta\bar{Z}^2}-\frac{3\varepsilon\sin\theta}{2\bar{h}_i}.\frac{P_{i+1,j}-P_{i-1,j}}{\Delta\theta}+\frac{\varepsilon\sin\theta_i}{\bar{h}_i}\frac{\mu^*}{2}\left(\pi-\frac{\theta_i}{2}\right)$$

$$+\frac{\mu^*}{6}=-\frac{\varepsilon\sin\theta_i}{\bar{h}_i{}^3} \tag{11}$$

where, $P_{i,j}$ is the pressure at any mesh point (i,j)
$\bar{h}_i$ is the film thickness at any mesh point (i,j)
$P_{i+1,j}$, $P_{i-1,j}$, $P_{i,j+1}$ & $P_{i,j-1}$ are pressure at four adjacent points

On further simplification the pressure distribution is determined by

$$P_{i,j} = \frac{\left[\left\{\left(\Delta\bar{Z}^2/_2\right) - 3\varepsilon sin\theta_i\Delta\theta\Delta\bar{Z}^2\right\}/4\bar{h}_i\right]P_{i-1,j} + \left[\left\{\left(\Delta\bar{Z}^2/_2\right) - 3\varepsilon sin\theta_i\Delta\theta\Delta\bar{Z}^2\right\}/4\bar{h}_i\right]P_{i+1,j} + \left[\frac{1}{2}\cdot\left(\frac{D}{L}\right)^2\Delta\theta^2\left(P_{i,j-1}+P_{i,j+1}\right)\right] + \left[\frac{\mu^*}{4}\left(\frac{\varepsilon sin\theta_i}{h_i}\left(\pi - \frac{\theta_i}{2}\right) + \frac{1}{3}\Delta\theta^2\Delta\bar{Z}^2\right)\right] + \frac{\varepsilon sin\theta_i\Delta\theta^2\Delta\bar{Z}^2}{2\bar{h}_i^{\,3}}}{\left[\Delta\bar{Z}^2 + \left(\frac{D}{L}\right)^2\Delta\theta^2\right]} \quad (12)$$

Now using this FDM equation, it is intended to make the MATLAB program to find out pressure distribution of finite magnetic fluid based hydrodynamic journal bearing.

3. RESULTS AND DISCUSSION

The one dimensional pressure distributions gives only center line pressure profile, while 3-D pressure profile presents the pressure variations throughout the width. The domes of pressure in the 3-D representation get significantly altered with respect to various parameters found in the equation (12). The 3-D picturization provides a better idea for the location of the position of the center of pressure in case of finite bearing. The variation of non-dimensional pressure distribution is presented in equation (12). A theoretical comparison with the conventional lubricant based hydrodynamic finite journal bearing suggests that the non-dimensional pressure gets increased by

$$\left[\frac{\mu^*}{4}\left(\frac{\varepsilon sin\theta_i}{h_i}\left(\pi - \frac{\theta_i}{2}\right) + \frac{1}{3}\Delta\theta^2\Delta\bar{Z}^2\right)\right]$$

.

Setting the magnetization parameter to be zero this study reduces to the discussion of Majumdar [10] for conventional fluid based finite journal bearing. It is clear that the expression is linear in magnetization parameter and hence increasing values of magnetization would lead to increased pressure as shown in Figs. 1-4. Figs. 5-7 show pressure distribution for different values of eccentricity ratio from which it is clear that the effect of eccentricity ratio on the pressure is significant. Further, the position of center of pressure changes with respect to the eccentricity ratio. Figs. 8-9 represent the pressure distribution for different values of L/D ratio. L/D ratio induces substantial increase in the pressure. Therefore, the role of L/D ratio becomes quite crucial from design point of view.

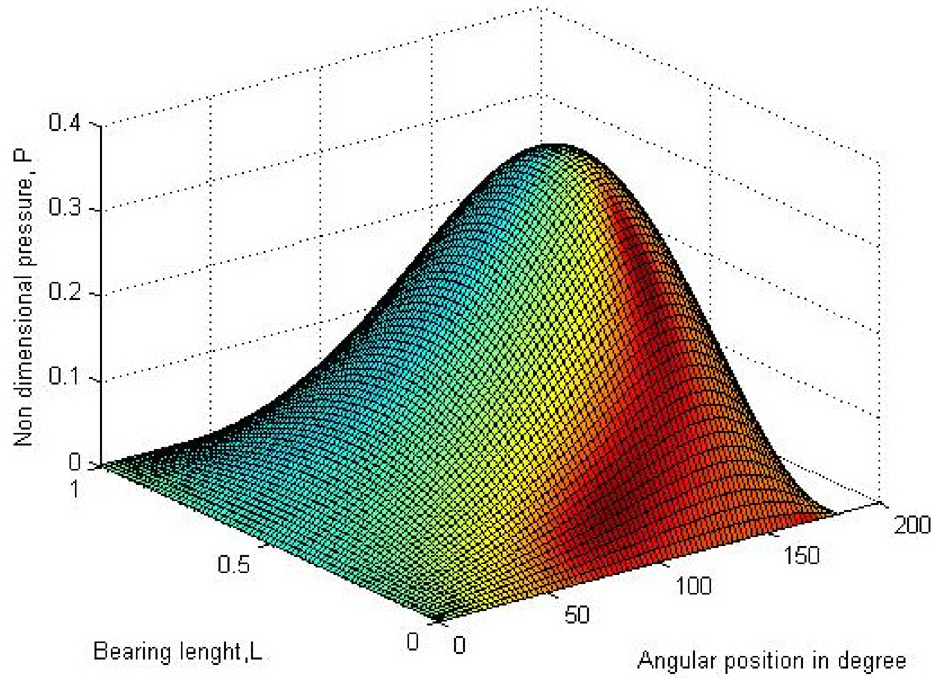

Fig. 1. Non-dimensional pressure distribution P for μ*=0, L/D=1, ε=0.5

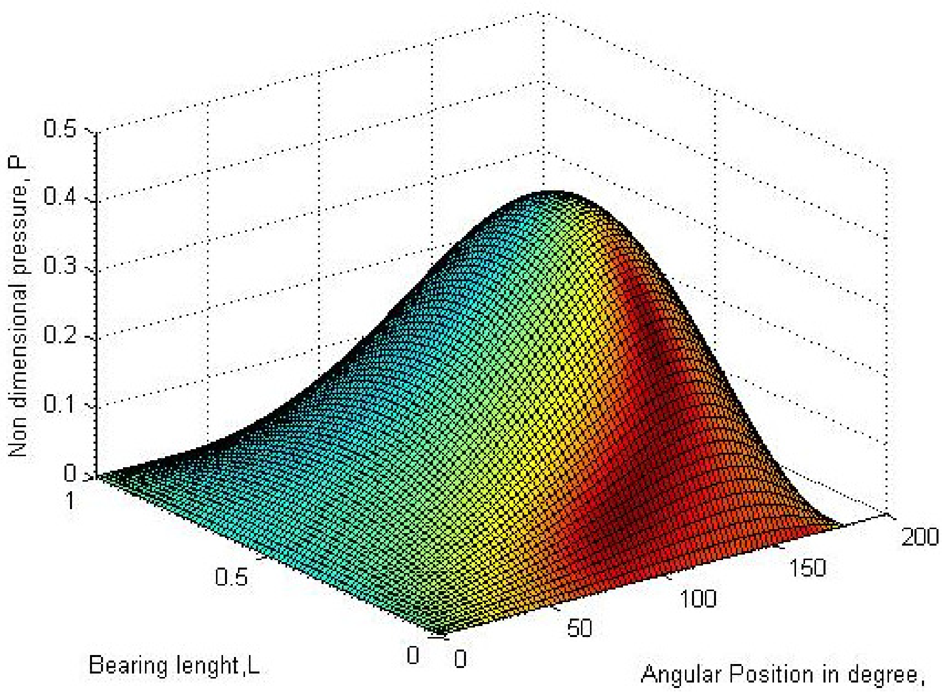

Fig. 2. Non-dimensional pressure distribution P for μ*=0.5, L/D=1, ε=0.5

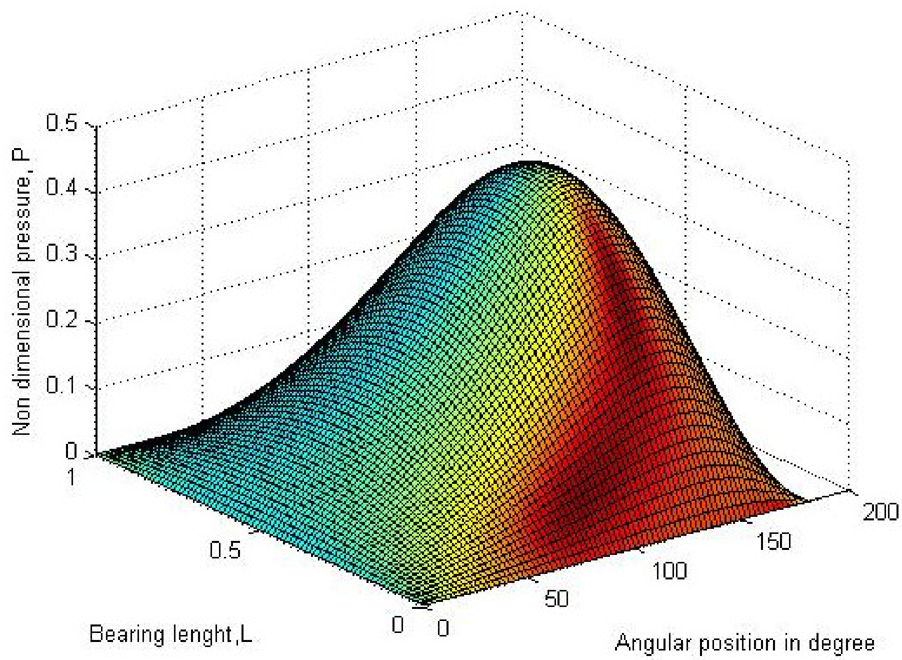

Fig. 3. Non-dimensional pressure distribution P for μ*=1.0, L/D=1, ε=0.5

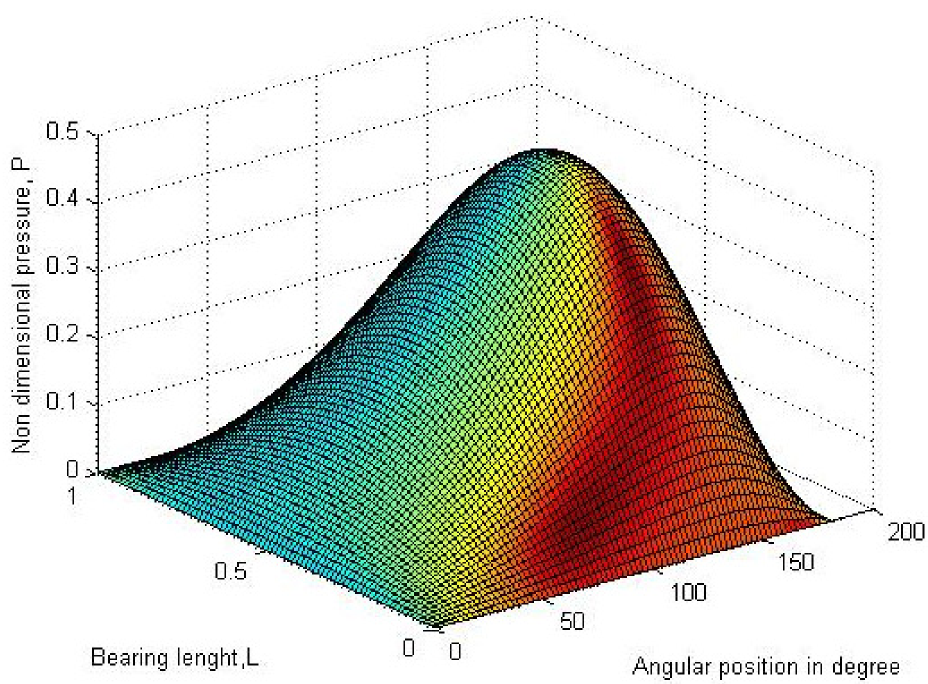

Fig. 4. Non-dimensional pressure distribution P for μ*=1.5, L/D=1, ε=0.5

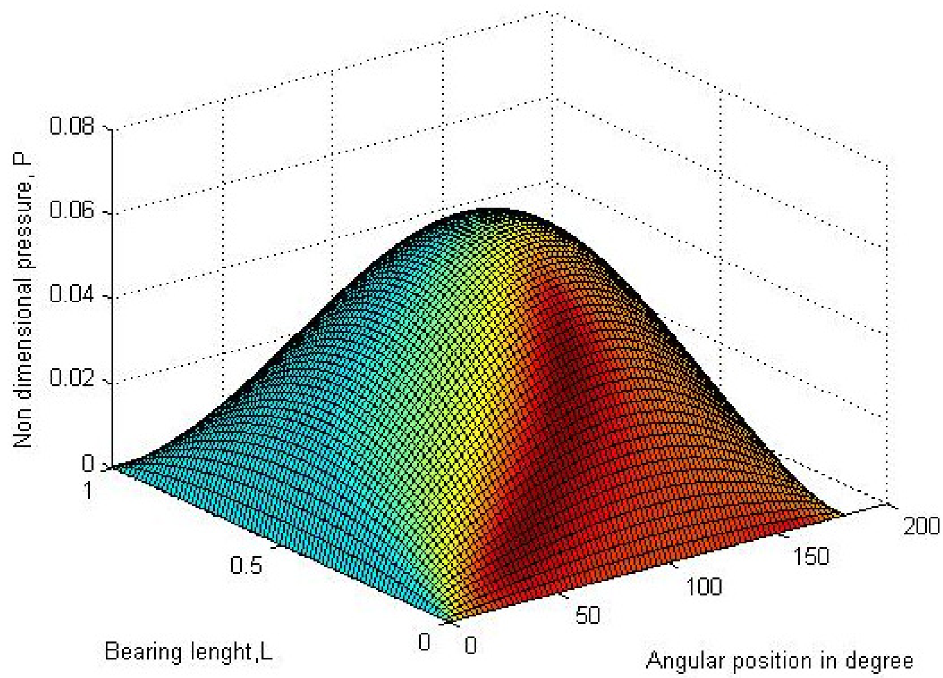

Fig. 5. Non-dimensional pressure distribution P for μ*=1.0, L/D=1, ε=0.1

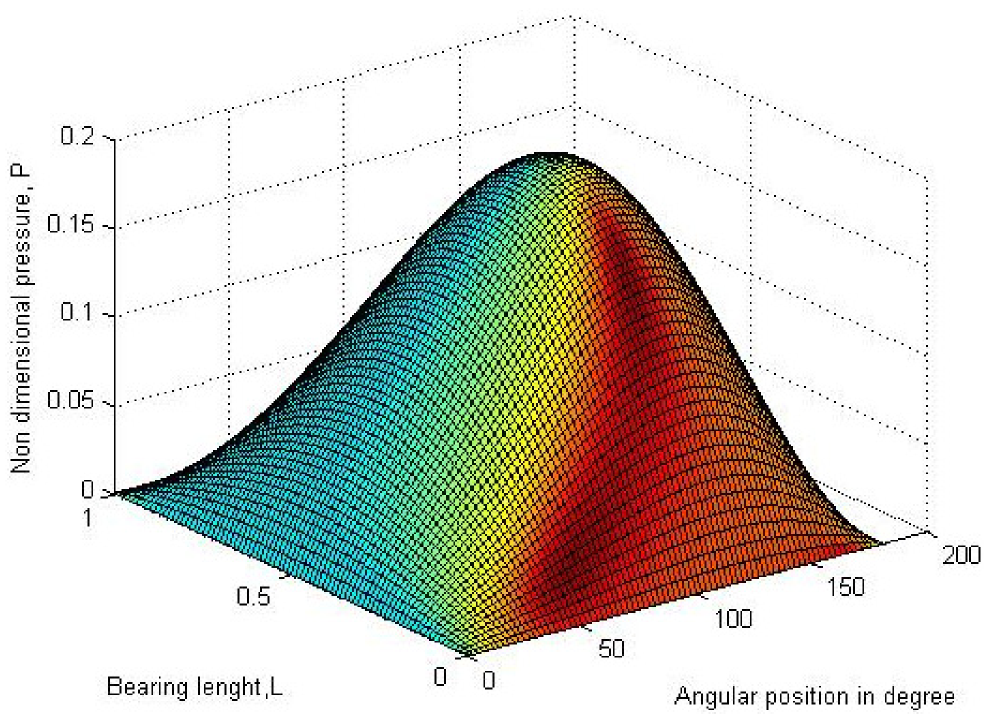

Fig. 6. Non-dimensional pressure distribution P for μ*=1.0, L/D=1, ε=0.3

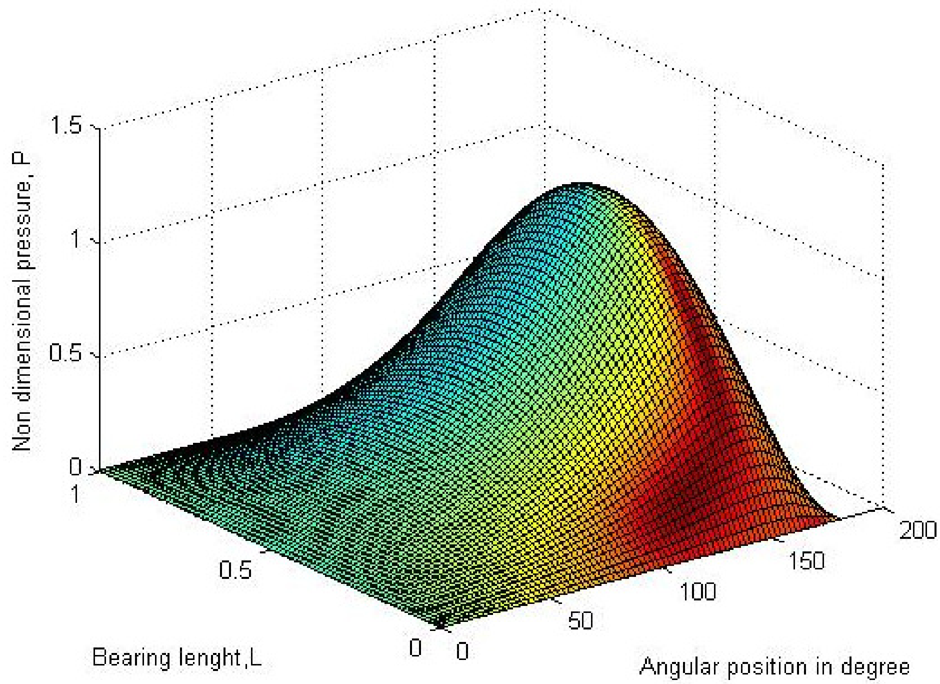

Fig. 7. Non-dimensional pressure distribution P for μ*=1.0, L/D=1, ε=0.7

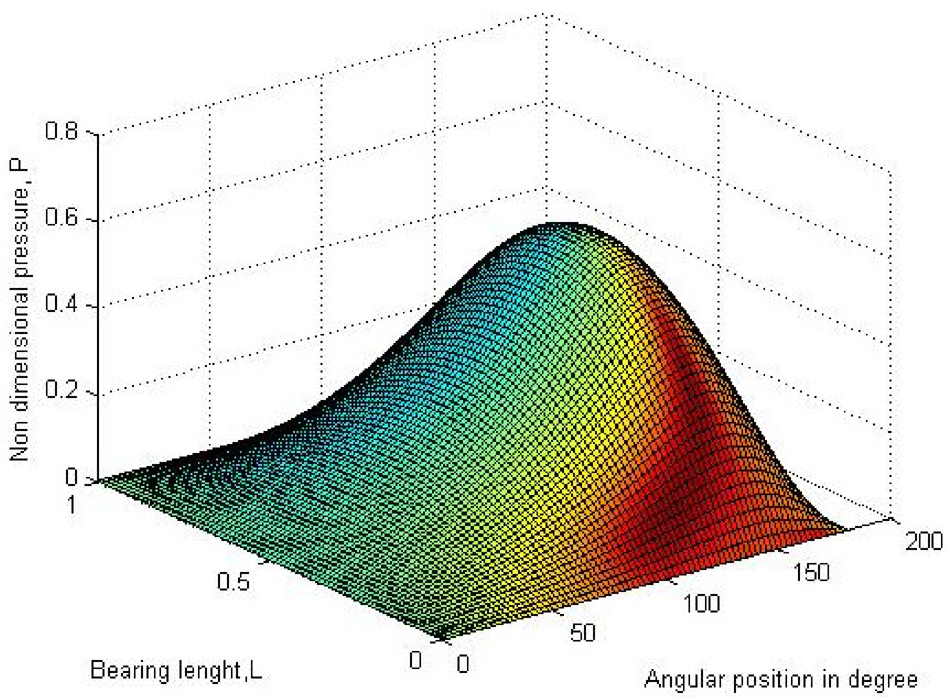

Fig. 8. Non-dimensional pressure distribution P for μ*=0, L/D=2.0, ε=0.5

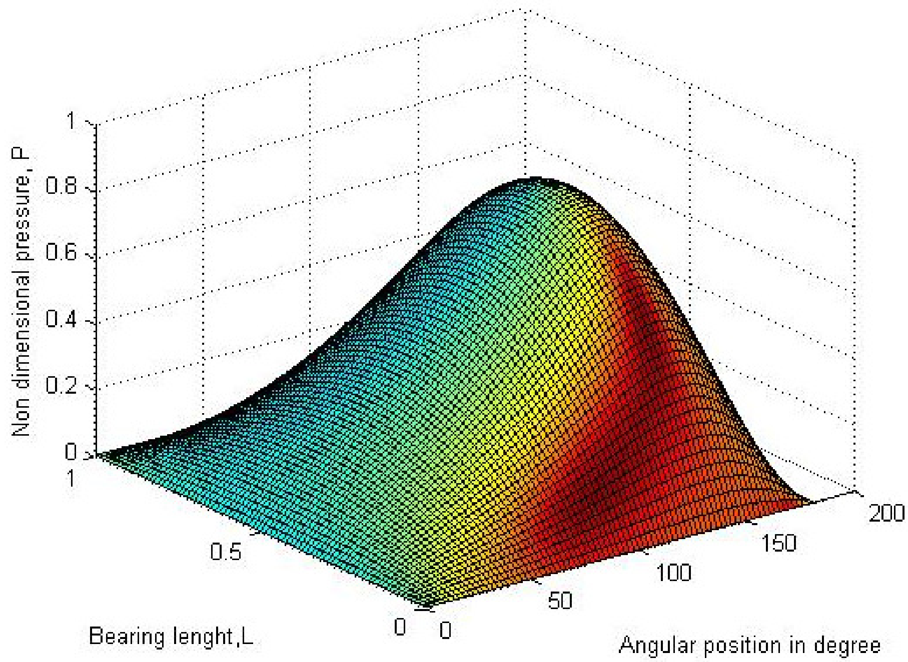

Fig. 9. Non-dimensional pressure distribution P for μ*=1.0, L/D=2.0, ε=0.5

4. CONCLUSION

Even in the absence of flow there remains certain amount of pressure due to the magnetic fluid lubricant which does not happen in the case of traditional lubricants. Besides, it is noticed that by a suitable combination of eccentricity ratio and aspect ratio, the pressure can be enhanced by almost 20% as compared to the conventional fluid.

NOMENCLATURE

D	Diameter of the bearing (mm)
L	Length of the bearing (mm)
H^2	Strength of magnetic field (A^2 m^{-2})
p	Lubricant pressure (N/m^2)
P	Dimensionless pressure
μ_0	Permeability of free space (kg m $s^{-2}A^{-2}$)
$\overline{\mu}$	magnetic susceptibility
μ^*	Dimensionless magnetization parameter
η	Lubricant viscosity ($N.S/m^2$)
e	Eccentricity (m)
c	Radial clearance(m)
ε	Eccentricity ratio(=e/c)
L/D	Aspect ratio
h	Film thickness (m)

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Fedor JV. A Sommerfeld solution for finite bearings with circumferential grooves. Journal of basic engineering. 1960;82(2):321-326.
2. Dr.-Ing. habil. Lotfie Ahmed Abdel-Latif, Dr.-Ing. Abdel-Monem A. Ammam. Analysis of finite journal bearings with longitudinal and transversal rough surfaces. 1986;52(4):111-116.
3. Lin JR. Squeeze film characteristics of finite journal bearings: couple stress fluid model. 1998;31(4):201-207.
4. Chasalevris A, Sfyris D. Evaluation of the finite journal bearing characteristics, using the exact analytical solution of the Reynolds equation. 2013;57:216-234.
5. Patel NS, Vakharia DP, Deheri GM. A Study on the performance of a magnetic-fluid-based hydrodynamic short journal bearing, ISRN Mechanical Engineering. 2012;7 pages.
6. Patel NS, Vakharia DP, Deheri GM. A Study on the performance of a magnetic fluid based hydrodynamic short porous journal bearing. Journal of the Serbian society for computational mechanics. 2012;6(2):28-44.
7. Bhat MV, Deheri GM. Squeeze film behavior in porous annular discs lubricated with magnetic fluid.Wear. 1991;151:123-128.
8. Bhat MV. Hydrodynamic lubrication of a porous composite slider bearing. Japanese Journal of Applied Physics. 1978;17:479-481.
9. Agrawal VK. Magnetic fluid based porous inclined slider bearing. WEAR. 1986;107:133-139.
10. Majumdar BC. Introduction to tribology of bearings. S. Chand & Company Ltd; 2010.

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