[1.]Sejal J. PATEL, [2.]G. M. DEHERI

SLIP EFFECT ON SHLIOMIS MODEL BASED MAGNETIC FLUID LUBRICATION OF A SQUEEZE FILM IN CIRCULAR CYLINDER NEAR A PLANE

[1.]Department of Mathematics, Sheth M. N. Science College, Patan, Gujarat, INDIA
[2.]Department of Mathematics, Sardar Patel University, Vallabh Vidyanagar, Anand, Gujarat, INDIA

Abstract: An endeavor has been made to study the performance of a ferrofluid based squeeze film in circular cylinder near a plane resorting to Shliomis model, considering slip velocity. The stochastic model of Christenson and Tonder has been brought in here to evaluate the effect of surface roughness. The associated stochastically averaged Reynolds type equation is solved to obtain the pressure distribution. Then load bearing capacity has been calculated. The results show that Shliomis model based ferrofluid lubrication is relatively better as compared to the Neuringer– Rosensweig model for magnetic fluid lubrication of this type of bearing system, even if the slip is higher. The adverse effect of roughness can be reduced considerably at least in the case of negatively skewed roughness with a suitable choice of curvature parameters. It is observed that this type of bearing system supports some amount of load even when there is no flow, unlike the case of conventional lubricants. Some of the results presented here establish that the adverse effect of slip velocity can be minimized with suitable magnetic strength, irrespective of the fact that the roughness induces adverse effect.
Keywords: circular cylinder, squeeze film, roughness, slip velocity, magnetic fluid, load bearing capacity, shliomis model

INTRODUCTION

It is recorded that hydraulic dampers, gears, braking units, synovial joints, and skeletal bearing use for a purpose of squeeze film mechanism. Generally, an electrically conducting fluid with high thermal and electrical conductivity is applied as a lubricant for squeeze film to work under such extreme circumstances. Also, an exploit of external magnetic field then advances the performance of lubrication.

Neuringer and Rosensweig [1964] proposed a quite simple model where the effect of magnetic body force was measured under the supposition of magnetization vector being parallel to the magnetic field vector. However, Shliomis [1972] consigned on a different formulation. He analyzed that the magnetic particles in the fluid had Brownian motion and their rotation affected the motion of magnetic fluids. Thus, Shliomis promoted the equation of motion for ferrofluids by considering internal angular momentum by cause of the self– rotation of particles. After that many researchers (Kumar et al. [1992], Singh and Gupta [2012], Patel and Deheri [2012], Lin et al. [2012], Lin [2013], Patel and Deheri [2013], Patel and Deheri [2014], Patel and Deheri [2014]) dealt with the model of Shliomis to examine the performance of different bearing's characteristics. All the above investigations analyze the steady state characteristics of the bearings lubricated with magnetic fluids, resorting to the flow model estimated by Shliomis.

The review of Shliomis [1974] discussed briefly the methods of preparation and stability problems of magnetic colloids. This review paper summarized the results of theoretical and experimental investigations of the effect of a magnetic field on the equilibrium conditions and on the character of the motion of the suspensions. Consideration was given to various effects caused by rotation of the particle, anisotropy of the viscosity and of the magnetic susceptibility, entrainment of the suspension by a rotating field and dependence of the kinetic coefficients on the field intensity.

Many investigations have been made regarding Circular cylinder (Bearman and Zdravkovich [1978], Zdravkovich [1985], Kawamura et al. [1986], Trahan et al. [1999], Price et al. [2002], Dipankar and Sengupta [2005], Lin et al. [2013], Patel and Deheri [2016]).

Stochastic model of Tzeng and Saibel [1967] was developed by Christensen and Tonder [[1969a, 1969b, 1970] to study the effect of surface roughness. Various techniques were deployed to measure the roughness effect. The effect of roughness has been studied in various squeeze film bearing systems (Tseng and Seibel [1967], Kawamura et al. [1986], Deheri et al. [2005], Abhangi and Deheri [2012], Patel et al. [2019]).

Beavers and Joseph [1967] constructed a simple theory to replace the effect on the boundary layer, with a slip velocity proportional to the exterior velocity gradient. The result obtained from this theory was found to be in good agreement with the experimental results. Various squeeze film bearing systems have been studied considering the effect of slip velocity (Wu [1972], Sparrow et al. [1972], Prakash and Vij [1976], Patel [1980], Thakkar et al. [2008], Patel and Deheri [2011], Patel and Deheri [2013], Patel and Deheri [2014 a], Patel and Deheri [2014 b], Patel and Deheri [2014 c], Barik et al. [2016], Acharya et al. [2017], Patel and Patel [2020], Patel et al. [2022]).

The effect of porosity has been examined in various squeeze film bearing systems (Wu [1971], Prajapati [1992], Bhat and Deheri [1993], Patel and Deheri[2003], Deheri and Patel [2006], Patel et al. [2011], Naduvinamani et al. [2012], Shimpi and Deheri[(2013], Patel and Deheri [2014], Shimpi and Deheri [2015], Patel et al. [2018], Shah [2022]).

Patel and Deheri [2016] considered combined effect of slip velocity and transverse surface roughness on the performance of a squeeze film for a circular cylinder near a plane. Therefore, in the present article it has been mooted to study the combine effect of slip velocity and transverse surface roughness on the Shliomis model based magnetic fluid lubrication of a squeeze film for circular cylinder near a plane.

ANALYSIS

The following figure presents the bearing configuration.

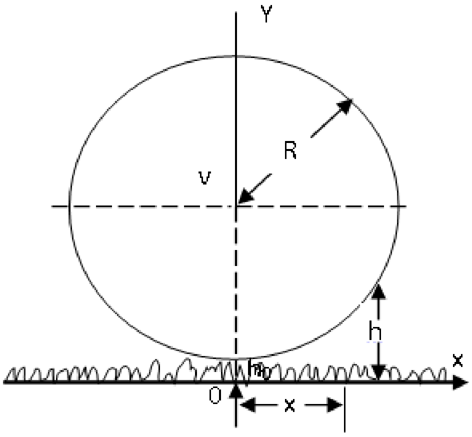

Figure 1. A Cylinder Near a plane

Majumdar informs that the Reynolds equation concern in an isoviscous incompressible fluid is given by

$$\frac{\partial}{\partial x}\left(h^3\frac{\partial p}{\partial x}\right)+\frac{\partial}{\partial z}\left(h^3\frac{\partial p}{\partial z}\right)=-12\,\eta_a V \qquad (1)$$

where V is the squeeze velocity $-\frac{dh}{dt}$ and $\eta_a=\eta(1+\tau)$ is the viscosity of the lubricant.

The length of the cylinder is assumed to be large as compared to the radius of the cylinder, so that the side leakage can be neglected. Equation (1), then reduced as to

$$\frac{d}{dx}\left(h^3\frac{dp}{dx}\right)=-12\,\eta(1+\tau)V \qquad (2)$$

The film thickness h is determine by the relation

$$h=h_0+R-\sqrt{R^2-x^2}$$

which approximately equals

$$h_0+\frac{1}{2}\frac{x^2}{R}$$

considering the series expansion.

Following Christensen and Tonder (1970), the thickness $h(x)$ of the lubricant film is considered to be

$$h(x)=\bar{h}(x)+h_s \qquad (3)$$

Here, $\bar{h}$ 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 is assumed to be stochastic in nature and governed by the probability density function $F(h_s)$, which is defined by

$$F(h_s)=\begin{cases}\frac{32}{35c}\left(1-\frac{h_s^2}{c^2}\right)^3 & ;-c\le h_s\le c\\ 0 & ;\text{otherwise}\end{cases} \qquad (4)$$

The following relationships decide the mean α,the standard deviation σ and the measure of symmetryεrespectively, while Estands for the expected value define by equation (6).

$$\alpha=E(h_s);\ \sigma^2=E[(h_s-\alpha)^2];\ \ \varepsilon=E[(h_s-\alpha)^3] \quad (5)$$

$$E(R)=\int_{-c}^{c}R\,F(h_s)dh_s \qquad (6)$$

The details can be seen from Christensen and Tonder [1969(a),1969(b), 1970]. In order to describe the steady flow of magnetic fluids in the presence of slowly changing magnetic fields a mathematical model was proposed by Neuringer–Rosensweig in1964. This model and related aspects has been widely discussed in Bhat [2003].

Christensen and Tonder [1969(a), 1969(b), 1970] augmented the method of Tzeng and Seibel [1967] and described the surface roughness in terms of a random variable having non zero mean, variance and skewness. Using the model of Christensen and Tonder and the procedure given in Gupta and Deheri, equation (2) transform to

$$\frac{d}{dx}\left(g(h)\frac{dp}{dx}\right)=-12\,\eta(1+\tau)V \qquad (7)$$

where

$$g(h)=h^3+4(\sigma^2+\alpha^2)h+2\alpha^2h+2\alpha^3+3\sigma^2\alpha+\varepsilon$$

It is found that the role of standard deviation is much more as compared to the other two parameters and therefore one gets

$$g(h)\cong h^3+4\sigma^2h$$

Lastly, making use of (Beavers and Joseph, 1967) slip model one arrives at the stochastically averaged Reynolds' type equation, governing the film pressure, in dimensionless form as

$$\frac{d}{dx}\left(\left(\frac{4+\bar{S}}{2+\bar{S}}\right)\left(\bar{h}^3+4\bar{\sigma}^2\bar{h}\right)\frac{dP}{dx}\right)=-12(1+\tau) \quad (8)$$

wherein the dimensionless quantities are

$$\bar{S}=s\bar{h},\ P=\frac{ph^3}{\eta V R},\ \bar{\sigma}=\frac{\sigma}{h}$$

The non–dimensional boundary conditions associated with the bearing system are

$$\frac{dP}{d\bar{x}}=0 \text{ at } \bar{x}=0 \qquad (9)$$

where

$$\bar{x} = \frac{x}{R}$$

Solving equation (8) with the aid of boundary conditions (9) one gets the expression for non–dimensional pressure distribution:

$$\bar{P} = -\frac{3(1+\tau)}{\left(\frac{4+\bar{S}}{2+\bar{S}}\right)\bar{\sigma}^2}\log\left[\frac{\bar{h}}{\sqrt{\bar{h}^2+4\bar{\sigma}^2}}\right] \qquad (10)$$

Then, the load carrying capacity of the bearing system in non–dimensional form is found to be

$$\bar{W} = \frac{(1+\tau)}{\left(\frac{4+\bar{S}}{2+\bar{S}}\right)}\left[\log 4\bar{\sigma}^2 + \frac{1}{4\bar{\sigma}^2} + \frac{1}{12\bar{\sigma}^2}\left(\frac{C_0}{h_0}\right)^2\left(\frac{h_0}{R}\right) + \frac{1}{80}\left(\frac{C_0}{h_0}\right)^4\left(\frac{h_0}{R}\right)^2\frac{1}{\bar{\sigma}^2}\right] \qquad (11)$$

where $\bar{W} = \frac{h_0{}^3\, w}{\eta V R L C_0}$

L being the length of the bearing.

RESULTS AND DISCUSSION

The magnetization enhances viscosity of the lubricant, which results in increased load bearing capacity. Mathematically also this can be seen clearly as the expression (10) is linear with respect to τ. The sharp increase in load carrying capacity can be seen from figures 2–3.

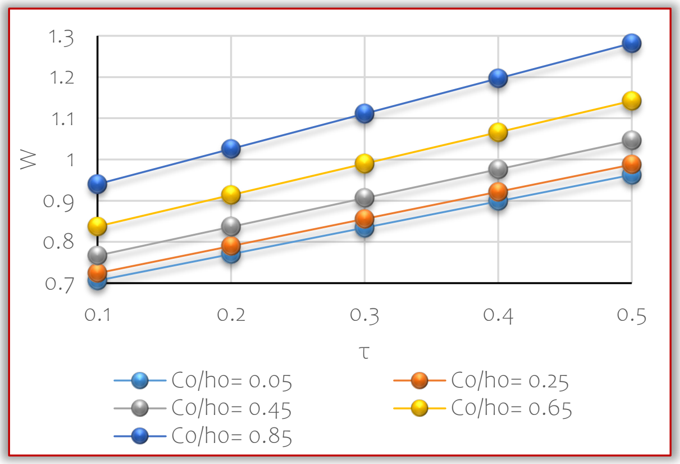

Figure 2. Variation of Load carrying capacity with respect to τ and C_0/h_0.

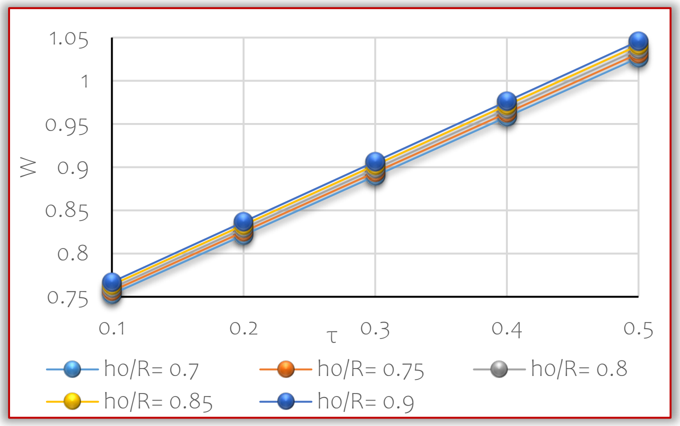

Figure 3. Variation of Load carrying capacity with respect to τ and h_0/R.

The profile of load carrying capacity with respect to the standard deviation presented in the Figures 4–6 asserts the load carrying capacity gets lowered. But, the influence of h_0/R on the variation of load carrying capacity with respect to $\bar{\sigma}$ stays nominal.

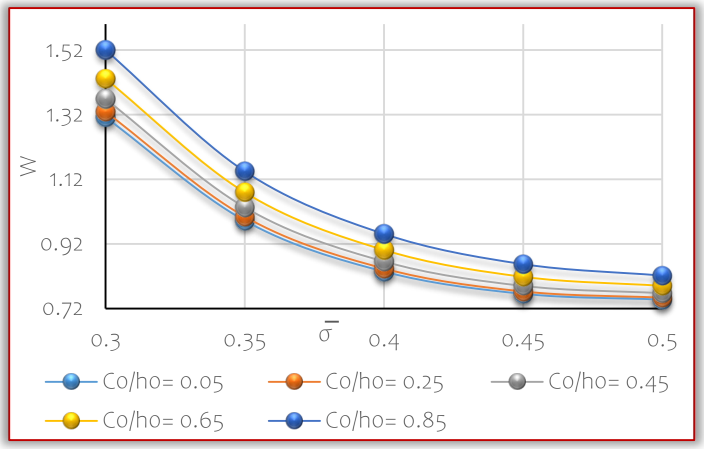

Figure 4. Variation of Load carrying capacity with respect to $\bar{\sigma}$ and C_0/h_0.

In fact the effect of h_0/R on the load bearing capacity with respect to standard deviation is almost negligible. At the same time the initial values of C_0/h_0 registers a negligible effect.

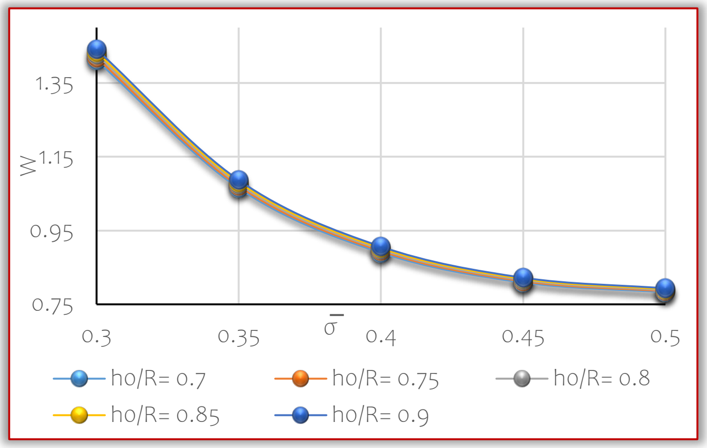

Figure 5. Variation of Load carrying capacity with respect to $\bar{\sigma}$ and h_0/R.

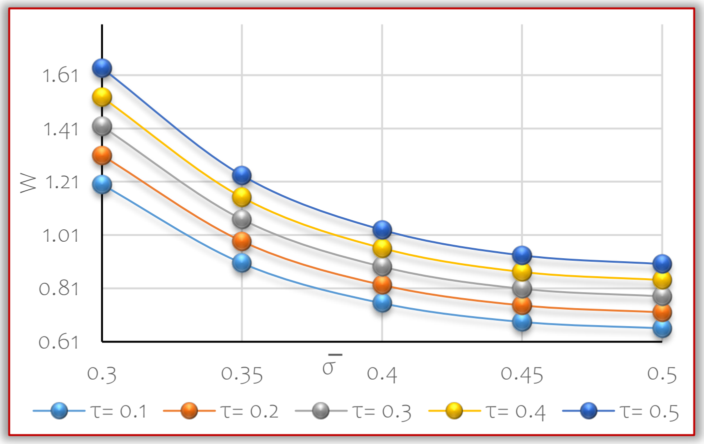

Figure 6. Variation of Load carrying capacity with respect to $\bar{\sigma}$ and τ.

Lastly, it is observed from Figures 7–10 that for a better performance, the slip is required to be kept at low level.

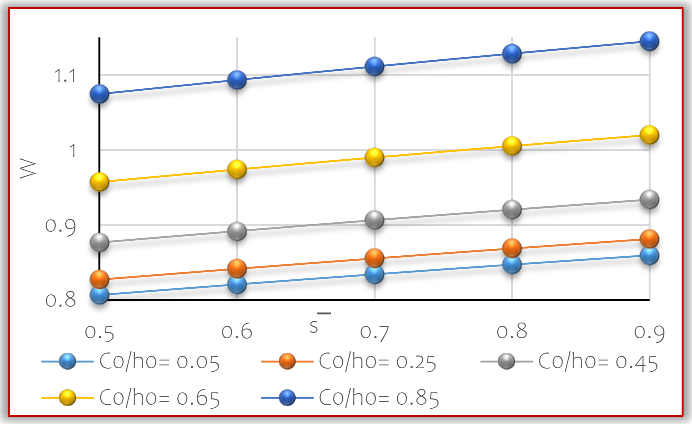

Figure 7. Variation of Load carrying capacity with respect to $\bar{s}$ and C_0/h_0.

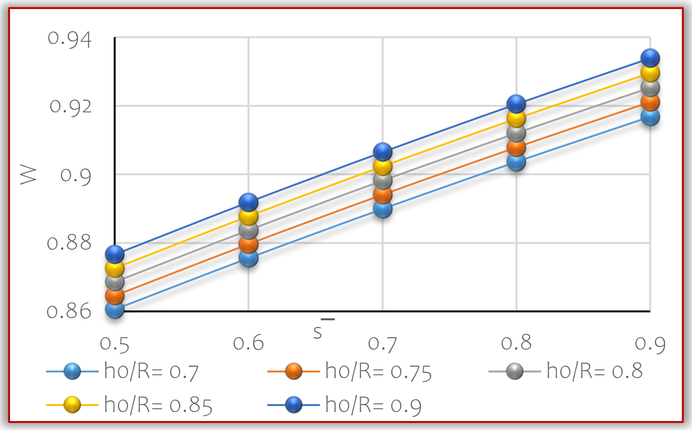

Figure 8. Variation of Load carrying capacity with respect to $\bar{s}$ and h_0/R.

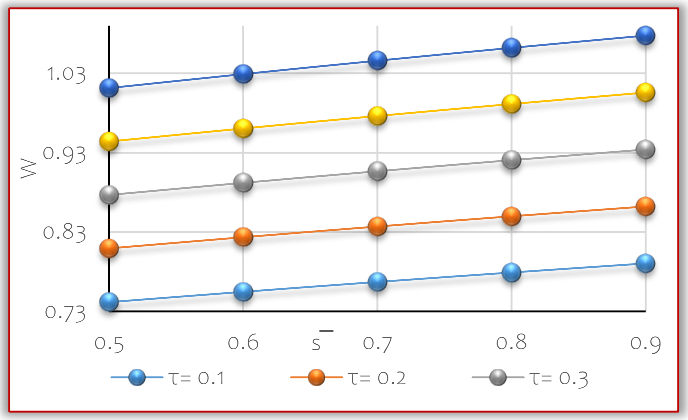

Figure 9. Variation of Load carrying capacity with respect to $\bar{s}$ and τ.

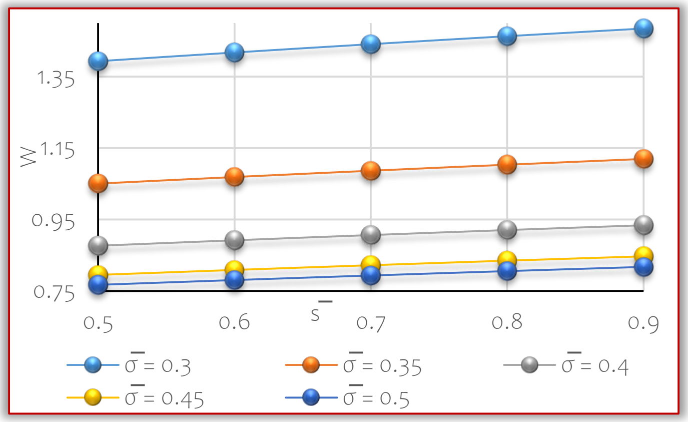

Figure 10. Variation of Load carrying capacity with respect to $\bar{s}$ and $\bar{\sigma}$.

CONCLUSION

This investigation opines that the Shliomis model is relatively suitable for this type of bearing system in comparison with the Neuringer–Rosensweig model. The graphical results mandate that the roughness–slip need to be given priority while designing the system, even if the slip is at reduced level. It is seen that some amount of load remains present in the absence of fluid flow, which does not happen in conventional lubricant.

References:

[1] Abhangi ND, Deheri GM: Numerical modeling of squeeze film performance between rotating transversely rough curved circular plates under the presence of a magnetic fluid lubricant, ISRN Mechanical Engineering, 2012, Article ID 873481, 2012.
[2] Acharya AS, Patel RM, Deheri GM: Ferro Fluid Squeeze Film in Rough Porous Circular plates considering the effect of viscosity variation and velocity Slip, International Journal of Theoretical and Applied Mechanics, 12 (4), 797–804, 2017.
[3] Barik M, Mishra SR, Dash GC: Effect of sinusoidal magnetic field on a rough porous hyperbolic slider bearing with ferrofluid lubrication and slip velocity, Pages, Tribology–Materials, Surfaces & Interfaces, 10 (3), 131–137, 2016.
[4] Bearman PW, Zdravkovich MM: Flow around a circular cylinder near a plane boundary, Journal of Fluid Mechanics, 89 (1), 33–47, 1978.
[5] Beavers GS, Joseph DD: Boundary conditions at a naturally permeable wall, Journal of Fluid Mechanics, 30(01), 197, 1967.
[6] Bhat MV: Lubrication with a magnetic fluid, Team spirit Pvt. Ltd., India, 2003.
[7] Bhat MV, Deheri GM: Magnetic–fluid based squeeze film in curved porous circular discs, Journal of Magnetism and Magnetic Materials, 127 (1–2), 159–162, 1993.
[8] Cameron A: Basic Theory of Lubrication, John Willy & Sons, New–York: Ellis Harwood Limited, Halsted Press, 1972.
[9] Christensen H, Tonder KC: The hydrodynamic lubrication of rough bearing surfaces of finite width, ASME–ASLE lubrication conference, paper No.70–Lub–7, 1970.
[10] Christensen H, Tonder KC: Tribology of rough surfaces: Parametric study and comparison of lubrication models, SINTEF, Report No. 22/69–18, 1969 a.
[11] Christensen H, Tonder KC: Tribology of rough surfaces: Stochastic models of hydrodynamic lubrication, SINTEF, Report No. 10/69–18, 1969 b.
[12] Deheri GM, Andharia PI, Patel RM: Transversely rough slider bearings with squeeze film formed by a magnetic fluid, Int. J. of Applied Mechanics and Engineering, 10 (1), 53–76, 2005.
[13] Deheri GM, Patel RM: Squeeze film based magnetic fluid in between porous circular disks with sealed boundary, Int. J. of Applied Mechanics and Engineering, 11(4), 803–812, 2006.
[14] Dipankar A, Sengupta TK: Flow past a circular cylinder in the vicinity of a plane wall, Journal of Fluids and Structures, 20(3), 403–423, 2005.
[15] Kawamura T, Takami H, Kuwahara K: Computation of high Reynolds number flow around a circular cylinder with surface roughness, Fluid Dynamics Research, 1(2), 1986.
[16] Kumar D, Sinha P, Chandra P: Ferrofluid squeeze film for spherical and comical bearings, Int. J. Engg. Sci. 30(5), 645–656, 1992.
[17] Lin JR: Fluid inertia effects in ferrofluid squeeze film between a sphere and a plate, Applied Mathematical Modeling, 37(7), 5528–5535, 2013.
[18] Lin JR, Lin MC, Hung TC, Wang PY: Effects of fluid inertia forces on the squeeze film characteristics of conical plates—ferromagnetic fluid model, Lubrication Science, 429–439, 2012.
[19] Lin JR, Lu RF, Lin MC, Wang PY: Squeeze film characteristics of parallel circular disks lubricated by ferrofluids with non–Newtonian couple stresses, Tribology International, 61,56–61, 2013.

[20] Naduvinamani NB, Hanumagowda BN, Fathima ST: Combined effects of MHD and surface roughness on couple–stress squeeze film lubrication between porous circular stepped plates, Tribology international, 56, 19– 29, 2012.

[21] Neuringer JL, R.E. Rosensweig RE: Magnetic Fluid, Physics of Fluids, 7(12) 19–27, 1964.

[22] Patel HP, Deheri GM, Patel RM: Combined effect of magnetism and roughness on a ferrofluid squeeze film in porous truncated conical plates: effect of variable boundary conditions, Italian Journal of Pure and Applied Mathematics – n. 39 (107–119), 107, 2018.

[23] Patel HP, Deheri GM, Patel RM: Numerical Modeling of Hydromagnetic Squeeze Film in Conducting Longitudinally Rough Annular Plates, International Journal of Research and Analytical Reviews, 6 (2), 2019 (E–ISSN 2348–1269, P– ISSN 2349–5138).

[24] Patel JR, Deheri GM: Effect of various porous structures on Shliomis model based magnetic fluid lubrication of a squeeze film in rough Porous circular plates upper one being Curved, Journal of Tribology and surface engineering; Hauppauge, 3(3–4), 137–160, 2012.

[25] Patel JR, Deheri GM: Shliomis model based magnetic fluid lubrication of a squeeze film in rotating rough curved circular plates, Carib.j.SciTech, 1, 138–150, 2013.

[26] Patel JR, Deheri GM: Combined effect of surface roughness and slip velocity on Jenkins model based magnetic squeeze film in curved rough circular plates, International J. of computational mechanics, 2014, 9 pages, 2014.

[27] Patel JR, Deheri GM: Effect of slip velocity and roughness on the performance of Jenkins model based on magnetic squeeze film in curved rough circular plates, J. of Serbian society for computational mechanics, 8(1), 45–63, 2014.

[28] Patel JR, Deheri GM: Shliomis model–based magnetic squeeze film in rotating rough curved circular plates: a comparison of two different porous structures, Int. J. of Computational Materials Sci. and Sur. Eng. 6 (1), 29– 49, 2014.

[29] Patel JR, Deheri GM: Theoretical study of Shliomis model based magnetic squeeze film in rough curved annular plates with assorted porous Structures, FME Transactions, 42 (2), 56–66, 2014.

[30] Patel JR, Patel ND, Deheri GM: Influence of slip and roughness on a ferrofluid squeeze–film between a sphere and flat porous plate, Materials Today: Proceedings, 50 (5), 1308–1314, 2022.

[31] Patel KC: The hydromagnetic squeeze film between porous circular disks with velocity slip, Wear, 58 (2), 275–281, 1980.

[32] Patel NC, Patel JR: Magnetic fluid–based squeeze film between curved porous annular plates considering the rotation of magnetic particles and slip velocity, Journal of the Serbian Society for Computational Mechanics, 14(2), 69–82, 2020.

[33] Patel ND, Deheri GM: Effect of Surface Roughness on the Performance of a Magnetic Fluid Based Parallel Plate Porous Slider Bearing with Slip Velocity, Journal of the Serbian Society for Computational Mechanics, 5 (1), 104–118, 2011.

[34] Patel RM, Deheri GM: A study of magnetic fluid based squeeze film behaviour between porous circular plates with a concentric circular pocket and effect of surface roughness, Industrial Lubrication and Tribology, 55(1), 32–37, 2003.

[35] Patel RM, Deheri GM, Patel HC: Effect of surface roughness on the behavior of a magnetic fluid– based squeeze film between circular plates with porous matrix of variable thickness, Acta Polytechnica Hungarica, 8(5), 171–190, 2011.

[36] Patel RU, Deheri GM: Effect of Slip Velocity on the Performance of a Short Bearing Lubricated With a Magnetic Fluid, Acta Polytechnica, Journal of Advanced Engineering, 53(6), 2013.

[37] Patel SJ, Deheri GM: Ferrofluid lubrication of a squeeze film in rough porous parallel circular disks, considering slip velocity, Journal of Mechanical and Industrial Engineering Research, 3 (2), 9–24, 2014.

[38] Patel SJ, Deheri GM: Combined effect of slip velocity and transverse surface roughness on the performance of a squeeze film for a circular cylinder near a plane, Annals of the faculty of engineering Hunedoara – International Journal of engineering, 14(3), 231–236, 2016.

[39] Patel SJ, Deheri GM, Patel JR: Combined Effect of Slip Velocity and Surface Roughness on a Magnetic Squeeze Film for a Sphere in a Spherical Seat: A Comparison of Two Different Porous Structures, Advances in Natural and Life Sciences, United Scholars Publications, USA, Vol. 2, pp. 190–229, 2016.

[40] Prajapati BL: Squeeze film behavior between rotating porous circular plates with a concentric circular pocket: Surface roughness and elastic deformation effects, Wear, 152(2), 301–307, 1992.

[41] Prajapati BL: On certain Theoretical Studies in Hydrodynamic and Electro–magneto–hydrodynamic Lubrication, Ph.D. Thesis: Sardar Patel University, Gujarat, 1995.

[42] Prakash J, Vij SK: Effect of velocity slip on the squeeze film between rotating porous annular discs, Wear, 38 (1), 73–85, 1976.

[43] Price SJ, Sumner D, Smith JG, Leong K, Paidoussis MP: Flow visualization around a circular cylinder near to a plane wall, Journal of Fluids and Structures, 16(2), 175–191, 2002.

[44] Shah RC: Ferrofluid lubrication of porous–rough circular squeeze film bearings, The European Physical Journal Plus, 137, Article number: 190, 2022.

[45] Shimpi ME, Deheri GM: Ferrofluid lubrication of rotating curved rough porous circular plates and effect of bearing's deformation, Arab. J. Sci. Eng., 38(10), 2865–2874, 2013.

[46] Shimpi ME, Deheri GM: Surface Roughness and Deformation Effects on the Behaviour of a Magnetic Fluid Based Squeeze Film in Rotating Curved Porous Circular Plates, American Journal of Marine Science, 3 (1), 1–10, 2015.

[47] Shliomis MI: Effective viscosity of magnetic suspensions, Sov. Physics JETP, 34(6), 1291–1294, 1972.

[48] Shliomis MI: Magnetic Fluids, Soviet Physics Uspekhi, 17(2), 153, 1974.

[49] Singh UP, Gupta RS: Dynamic performance characteristics of a curved slider bearing operating with ferrofluid, Advances in Tribology, Article Id 278723, 2012.

[50] Sparrow EM, Beavers GS, Hwang IT: Effect of Velocity Slip on Porous–Walled Squeeze Films, Journal of Tribology, 94(3), 260–264, 1972.

[51] Thakkar SB, Patel HC, Deheri GM, Patel RM: Effect of transverse surface roughness on the performance of squeeze film behavior between rotating porous circular plates having concentric circular pocket with velocity slip, International Colloquiam Tribology, Lubricants, Materials and Lubrication Engineering, 31 pages, 2008.

[52] Trahan JF, Hussey RG, Roger RJ: The velocity of a circular disk moving edgewise in quasi–steady Stokes flow toward a plane boundary, Physics of Fluids, 11, 1999.

[53] Tzeng ST, Saibel E: Surface roughness effect on slider bearing lubrication, Trans. ASLE 10, 334–342, 1967.

[54] Wu H: Effect of velocity–slip on the squeeze film between porous rectangular Plates, Wear, 20 (1), 67–71, 1972.

[55] Wu H: The Squeeze film between rotating porous annular disks, Wear, 18(6), 461–470, 1971.

[56] Zdravkovich MM: Forces on a circular cylinder near a plane wall, Applied Ocean Research, 7(4), 197–201, 1985.

ISSN: 2067–3809
copyright © University POLITEHNICA Timisoara,
Faculty of Engineering Hunedoara,
5, Revolutiei, 331128, Hunedoara, ROMANIA
http://acta.fih.upt.ro