Hydrodynamic Bearing Systems

Synopsis of Ph.D. Thesis

Submitted To

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1. Abstract

This study analyzes the effect of ferrofluid lubrication on the various types of bearings, where different types of surface roughness were considered.

However in the last part effect of ferrofluid lubrication was studied for a hydromagnetic squeeze film over longitudinally roughness rough triangular plates.

The roughness has been characterized by the stochastic model of the Christensen and Tonder for characterizing the surface roughness has been employed here. The related stochastically averaged Reynolds' type equation is solved to obtain the pressure distribution, leading to the derivation of load carrying capacity.

2. Brief description on the state of the art of the research topic

The present day machine technology is dependent on mechanisms involving kinetic pairs where mechanical power has to be transmitted between that are in relative motion. Friction and wear are two most important inherent phenomena associated with such a system. Friction resists relative motion of the surfaces and causes wear, which consumes and wastes energy due to noise and generation of local surface heat. Wear causes changes in dimensions and results in eventual breakdown of the machine. Consequently the entire machine and all that depend on it. The aspect of loss of energy and loss of material due to friction is surprisingly large. The word "Tribology" was introduced and defined as the science and technology of interacting surfaces in relative motion and of the practice related there to. A better definition of "Tribology" might be "The integrated study of friction, wear and lubrication".

It is well known that bearing surfaces particularly, after having some run in and wear develop roughness. Various methods have been proposed to study and analyze the effect of surface roughness of the bearing surfaces on the performance of squeeze film bearings. Several investigators have adopted a stochastic approach to mathematically model the randomness of the roughness. A comprehensive general analysis was presented by Christensen and Tonder [7, 8, 9] for surface roughness (both transverse as well as longitudinal) based on a general probability density function. Later on, this approach laid down the basis of the analysis to discuss the effect of surface roughness on the performance of the bearing system in a number of investigations. Prakash and Vij [18] investigated the load carrying capacity and time height relation for squeeze films between porous plates. Circular, annular, elliptic, rectangular, conical and truncated conical plates were investigated for the squeeze film performance. Prajapati [17] discussed the effect of hydromagnetic squeeze film between two conducting surfaces for various geometries. The effect of longitudinal surface roughness on hydrodynamic lubrication of slider bearing was discussed by Andharia [4]. Patel and Deheri [15] investigated the squeeze film behaviour between curved annular plates by considering the lower plate as well as the upper plate along the surfaces generated by hyperbolic function. Subsequently, Patel and Deheri [13] modified the approach to consider both plates along the surfaces determined by secant functions. Andharia and Deheri [2, 3] analyzed the longitudinal roughness effect on magnetic fluid based squeeze film betwwen conical plates and elliptical plates. Vadher et. al. [20] investigated the effect of transverse surface roughness on the performance of hydromagnetic squeeze film between conducting truncated conical plates.

Magnetic fluids are stable colloidal suspensions of magnetic metal nano particles in a carrier liquid such as hydrocarbon, water and mercury. Use of magnetic fluid as a lubricant modifying the performance of the bearing system has been very well recognized. Bhat and Deheri [5, 6] analyzed the performance of magnetic fluid based squeeze film behaviour between curved annular disks and curved circular plates and found that the performance with the magnetic fluid as lubricant was relatively better than with a conventional lubricant. Patel and Deheri [14] considered a magnetic fluid based squeeze film between rough annular plates. Magnetic fluid based short bearings have been analyzed in Patel et. al. [16] and the role of different forms of magnetic field has been emphasized. Deheri and Patel [10] evaluated the behavior of a magnetic fluid based squeeze film in a rough porous parallel plate slider bearing and the impact of the variance (- ve) in adding the positive performance of the bearing system has been discussed. Lin [11] studied effect of longitudinal roughness in magnetic fluid lubricated journal bearing. The effect of longitudinal surface roughness on hydromagnetic circular step bearing was analysed by Adeshara et.al.[1].

Liquid metals (like Sodium and Mercury) filled in between two conducting plates support heavy load by applying suitable magnetic field. The effect of external magnetic field on electromagnetic pressurization and corresponding load have been studied and scrutinized.

Hydromagnetic pressurization with regards to squeeze film performance has been investigated by many authors. In [17] Prajapati analyzed hydromagnetic squeeze film between conducting surfaces for various geometries. Vadher et. al. [21] investigated the performance of a hydromagnetic squeeze film between two conducting rough porous annular plates. Adeshara et. al. [1] studied the effect of longitudinal roughness on the performance of hydromagnetic squeeze film in circular step bearing. The hydromagnetization resulted in a relatively better performance for all values of the conductivity parameter. All the above investigations mentioned above established that the squeeze film enhanced due to magnetization. Besides, the conductivities of the plates play a key role in boosting the performance characteristics.

3. Objective and Scope of the work

Number of ways and means has been discussed to improve the performance of a bearing system. One of them is the use of magnetic fluid as a lubricant. Efforts were made to study and analyze effect of surface roughness on the performance of magnetic fluid based rough bearings.

Bearings after having some run-in and wear develop roughness. Various methods have been proposed to study the effect of surface roughness on the performance of a bearing system. It is well known that roughness in general, has an adverse impact on the performance of the bearing system. However, recently the research is carried out in the case of longitudinally rough bearings; one of the parameters characterizing the roughness affects the bearing system positively. So we tried to check the behavior of longitudinally rough bearings in particular and rough bearings (various shapes) in general. Efforts made to analyze the optimum performance of the bearing system, from this roughness point of view. Here the attention was paid to study rough bearings working with magnetic fluid in general and magnetic fluid based longitudinally rough and transversely rough bearings, which basically concentrate to investigate the following:

- How far the use of magnetic fluid as a lubricant compensates the adverse effect of roughness in general?
- Can there be considerably improved performance in the case of magnetic fluid based rough bearings?

4. Original contribution by the thesis

The thesis establishes that the adverse effect of roughness can be countered to a considerable extent by the ferrofluid lubrication even if there is absence of flow the bearing support some amount of load in spite of the presence of surface roughness.

5. Methodology of Research, Results / Comparisons

The stochastic averaging model of Christensen and Tonder regarding the transverse and longitudinal surface roughness characterization has been adopted here, which is used to obtained mean α, the standard deviation σ and the measure of symmetry parameter ε. Modified Reynolds' type equation has been considered to obtain the pressure distribution, which helps to get the load carrying capacity.

Simple model of Neuringer-Rosenweig [11] is adopted to describe the steady flow of magnetic fluids in presence of slowly changing external magnetic fields. The equations of model are as following:

$$\rho(\bar{q}.\nabla)\bar{q} = -\nabla p + \eta\nabla^2\bar{q} + \mu_0(\bar{M}.\nabla)\bar{H} \tag{1}$$

$$\nabla.(\bar{H} + \bar{M}) = 0 \tag{2}$$

$$\nabla.\bar{q} = 0 \tag{3}$$

$$\nabla \times \bar{H} = 0 \tag{4}$$

$$\bar{M} = \mu\bar{H} \tag{5}$$

where ρ is the density of fluid, η is the viscosity of fluid, $\bar{q} = (u, v, w)$ is fluid velocity in the film region, p is the film pressure, μ_0 is the permeability of free space, $\bar{M}$ is the magnetization vector, $\bar{H}$ is the external magnetic field and $\bar{\mu}$ is the magnetic susceptibility of the magnetic particles.

Using equations (4) and (5) in equation (1) it becomes

$$\rho(\bar{q}.\nabla)\bar{q} = -\nabla\left(p - \frac{\mu_0\bar{\mu}}{2}H^2\right) + \eta\nabla^2 q^- .$$

This shows that extra pressure $\frac{1}{2}\mu_0\bar{\mu}H^2$ is introduced into the Navier-Stocks equations when magnetic fluid is used as a lubricant, which leads us to modified Reynolds' equation as

$$\frac{\partial}{\partial x}\left[\left(h^3 + 12\bar{k}H^*\right)\frac{\partial}{\partial x}\left(p - \frac{1}{2}\mu_0\bar{\mu}H^2\right)\right] + \frac{\partial}{\partial y}\left[\left(h^3 + 12\bar{k}H^*\right)\frac{\partial}{\partial y}\left(p - \frac{1}{2}\mu_0\bar{\mu}H^2\right)\right] = 6\eta U\frac{\partial h}{\partial x} + 12\eta W_h \tag{6}$$

where H^* is thickness of porous facing, U is x-component of slider bearing W_h is z-component of fluid velocity at the upper porous region at z=h.

The modified equation for solid surfaces is obtained by setting $H^*=0$ in equation (6) as

$$\frac{\partial}{\partial x}\left[h^3\frac{\partial}{\partial x}\left(p - \frac{1}{2}\mu_0\bar{\mu}H^2\right)\right] + \frac{\partial}{\partial y}\left[h^3\frac{\partial}{\partial y}\left(p - \frac{1}{2}\mu_0\bar{\mu}H^2\right)\right] = 6\eta U\frac{\partial h}{\partial x} + 12\eta W_h \tag{7}$$

Also, the modified Reynolds' equation in cylindrical polar form for porous structure is given by

$$\frac{1}{r}\frac{\partial}{\partial r}\left[\left(h^3 + 12\bar{k}H^*\right)r\frac{\partial}{\partial r}\left(p - \frac{1}{2}\mu_0\bar{\mu}H^2\right)\right] = 12\eta\dot{h}_0 + 24\rho\bar{k}H^*\Omega_u^2 + \rho\left(\frac{3}{10}\Omega_r^2 + \Omega_r\Omega_l + \Omega_l^2\right)\frac{1}{r}\frac{d}{dr}(r^2h^3) \tag{8}$$

and for non-porous(solid) structure it is of the form

$$\frac{1}{r}\frac{\partial}{\partial r}\left[\left(h^3+12\bar{k}H^*\right)r\frac{\partial}{\partial r}\left(p-\frac{1}{2}\mu_0\bar{\mu}H^2\right)\right]=12\eta\dot{h_0}+24\rho\bar{k}H^*\Omega_u^2+\rho\left(\frac{3}{10}\Omega_r^2+\Omega_r\Omega_l+\Omega_l^2\right)\frac{1}{r}\frac{d}{dr}(r^2h^3) \quad (9)$$

Equations (6) to (9) were used and generalized roughness was introduced to it to obtained pressure distribution and using it load taking capacity is obtained. Results obtained from this are compared with the study done by researchers to confirm that ferrofluid lubrication helps to improvise the bearing capacity.

6. Conclusions

This study confirms that in general the effect of roughness is adverse, but the magnetization helps to reduce this effect. Also some suitable boundary conditions depending on magnetization parameter support to overcome the negative effect of roughness. Besides, the study establishes that the standard deviation supports the load taking capacity in the case of longitudinal roughness. The ferrofluid lubrication allows the bearing system to bear some quantity of load even if the flow is absent.

In the case of hydromagnetic lubrication, there is a possibility that the adverse effect of roughness can be completely overcome due to the positive effect of hydromagnetization with suitable choice of plate conductivities.

7. List of publication arising from the thesis

1. Hardik P. Patel, G. M. Deheri and R. M. Patel, “Ferro fluid based squeeze film in porous annular plates considering the effect of transverse surface roughness”, International Journal of Scientific & Engineering Research, Volume 6, Issue 8, August-2015, ISSN 2229-5518.
2. Hardik P. Patel, G. M. Deheri and R. M. Patel, “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, Volume 39, 2018, ISSN 2239-0227.
3. Hardik P. Patel, G. M. Deheri and R. M. Patel, “Squeeze film performance between a rectangular plate and a rough porous surface”, Journal of Applied Science and Computations, Vol 6, Issue 2,2019, ISSN 1076-5131.
4. Hardik P. Patel, G. M. Deheri and R. M. Patel, “Study of squeeze film in a ferrofluid lubricated longitudinally rough rotating plates” To be published in Advances in Intelligent Systems and Computing (Accepted).
5. Hardik P. Patel, G. M. Deheri and R. M. Patel, “Performance of a hydromagnetic squeeze film between longitudinally rough conducting triangular plates” To be published in Advances in Intelligent Systems and Computing (Accepted).

8. References

1. Adeshara, J. V., Prajapati, M. B., Deheri, G.M. and Patel, R.M.: A Study of Hydromagnetic Longitudinal Rough Circular Step Bearing. Advances in Tribology, Article ID 3981087, 7 pages (2018).
2. Andharia, P. I. and Deheri, G. M., Longitudinal roughness effect on magnetic fluid based squeeze film between conical plates, Industrial Lubrication and Tribology, 62(5), pp.285 – 291,2010.
3. Andharia, P. I. and Deheri, G. M., Performance of magnetic fluid based squeeze film between longitudinally rough elliptical plates, ISRN Tribology, Article ID482604, 6 pages, 2013.
4. Andharia, P. I., Gupta J. L. and Deheri, G. M., Effect of longitudinal surface roughness on hydrodynamic lubrication of slider bearings, Institute of Materials, 668, pp. 872-880, 1997.
5. Bhat M. V. and Deheri, G. M., Magnetic fluid based squeeze film in curved porous circular disks, Journal of Magnetism and Magnetic Material, 127, pp. 159-162, 1993.
6. Bhat M. V. and Deheri, G. M., Squeeze film behavior in porous annular disks lubricated with magnetic fluid, Wear, 152, pp. 123-128, 1993.
7. Christensen, H. and Tonder, K., The hydrodynamic lubrication of rough bearing surfaces of finite width ASME-ASLE Lubrication conference Cincinnati, Ohio, October 12-15, Lub-7, 1970.
8. Christensen, H. and Tonder, K., Tribology of rough surfaces, parametric study and comparison of lubrication models, SINTEF, Section for Machine Dynamics in Tribology, Technical University of Norway, Trondheim, Norway, Report No.22/69-18 1969b.
9. Christensen, H. and Tonder, K., Tribology of rough surfaces, Stochastic models of hydrodynamic lubrication, SINTEF, Section for

Machine Dynamics in Tribology, Technical University of Norway, Trondheinm, Norway, Report No.10/69-18, 1969a.

10. Deheri, G.M. and Patel J.R. Magnetic fluid based squeeze film in a rough porous parallel plate slider bearing, Annals of Faculty Engineering, Hunedora, Vol. 9(3), pp.443, 2013.

11. Lin, J. R., Longitudinal surface roughness effects in magnetic fluid lubricated journal bearing, Journal of Marine Science and Technology, 24(4), p.p. 711-716, 2016.

12. Neuringer, J. L. and Rosenweig, R. E., Magnetic fluid, Physics of Fluid, (1964), 7(12), pp. 1927, 1964.

13. Patel R. M. and Deheri, G. M., Magnetic fluid based squeeze film between two curved plates lying along the surfaces determined by secant functions", Indian Journal of Engineering and Material Sciences, 9, pp. 45-48, 2002.

14. Patel, R. M. and Deheri G. M., Magnetic fluid based squeeze film behaviour between annular plates and surface roughness effect, International Tribology Conference, Rome, Italy, pp. 14-17, 2004.

15. Patel, R. M. and Deheri, G. M., On the behavior of squeeze film formed by magnetic fluid between curved annular plates, Indian Journal of Mathematics, 44(3), pp. 353-359, 2002.

16. Patel, R. M., Deheri G. M. and Vadher P. A., Magnetic fluid based short bearing and roughness effect, Journal of Science 1(1), pp. 102-106, 2010.

17. Prajapati, B. L., On certain theoretical studies in hydrodynamic and electromagnet hydrodynamic lubrication. Ph.D. thesis, S. P. University, Vallabh Vidyanagar, (Gujarat), India, 1995.

18. Prakash, J. and Vij, S.K. Load capacity and time-height relation for squeeze film between porous plates, Wear, 24, 309-322, 1973.

19. Ting, L. L., A mathematical analog for determination of porous annular disks squeeze film behaviour including the fluid inertia effect, Journal of Basic Engineering, 94(2), p.p. 417, 1972.

20. Vadher, P. A., Deheri, G. M. and Patel, R. M., Effect of transverse surface roughness on the performance of hydromagnetic squeeze film between conducting truncated conical plates, Journal of Marine Science and Technology, 19(6), pp. 673-680, 2011.
21. Vadher, P. A., Vinodkumar, P. C., Deheri, G. M. and Patel, R. M., A study on behaviour of hydromagnetic squeeze film between two conducting rough porous annular plates, Proceeding of Pakistan Academy of Sciences, 45(2), pp. 81-95, 2008.