SOME BEARING PROBLEMS IN TRIBOLOGY

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by

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1. ABSTRACT

All the research in the field of roughness bearing system aims to enhance the designing quality of products and process. The measurement specification of a system's roughness and their analysis helps to understand the concept of roughness and related aspects better. A lot of phenomena are possible, impacted by roughness of bearing systems which can be better understood through such research.

Surface roughness plays vital role in the field of Tribology. To measure a random distribution of the height of the surface is known as its roughness. The roughness of various surfaces at the concentric position of their slope can be sampled and averaged to find a mean absolute slope. A relative number of the micro contact areas can be found through this calculation. The surface roughness is expressed in terms of a stochastically random variable that has a mean, skewness and variance as non-zero.

Liquids like mercury or hydrocarbon, that are also known as carried liquids, have suspended magnetic metal particles, rather nano-particles, which are stable and colloidal in nature. A constant magnetic field can be used to give a stabilized position to the magnetic fluid. This makes a magnetic fluid a good lubricant. Due to such properties, the expansion of magnetic fluid leads to utilized in sealing computer hard disks or drives, shaft and rods rotations, rotating x-ray tubes etc. These fluids also serve as highly efficient as heat controllers in various systems like electric motors and even hi-fi speaker systems. One of the liquids that display strong magnetization when exposed to a magnetic field is ferrofluid. A ferrofluid can be developed using three materials; magnetic particles that have a colloidal size, a liquid that can act as a carrier and a surfactant. Lot of devices that have a magnetic fluid design including pressure transducers, accelerometers, sensors and others make use of ferrofluids. Actuating machines such as energy converters and even electromechanical converters use ferrofluids.

Not only engineering, but the applications of magnetic fluids are also relevant and popular in biomedicine. Some studies have shown significant results by using magnetic fluids for cancer treatment. The concept here is to soak the tumor in a magnetic fluid with the help of a changing magnetic field and then heating the tumor.

Fluid dynamics has the no-slip condition in viscous fluids suggests that by maintaining a solid boundary, a state of zero relative velocity between the fluid and the boundary can be

achieved. However, some scientists reported cases where this wasn't always the case. It was general phenomenon which called slip velocity, where the fluid posses some velocity with respect to solid boundary; this velocity is identified as a slip velocity. When the difference in the mean velocities of two separate fluids that are in a pipe, flowing together, is calculated, the slip velocity of the two fluids can be found. The key characteristic that changes the slip velocity of a fluid is its density as compared to the other fluid. When the flow is ascending vertical in nature, the fluid with the lower density moves with higher speed than another one.

This study has attempted to scrutinize the bearing performance of a rough bearings assisted by ferrofluid with the help of numerical modelling of Shliomis model as well as Neuringer and Rosensweig. The transverse and longitudinal roughness are calculated stochastically by averaging the Christensen and Tonder model. A non-zero mean is assumed for the probability density function for the random variable that determines the roughness of the bearing which is symmetrical. One of the equations that can aid the calculation of dependent permeability which is influenced by factors like pore shape, porosity, tortuosity and specific surface is Kozeny-Carman's model. The Beavers and Joseph model is used to study the effects caused by slip velocity. The Tipei model and the Shliomis model have been used to derive a new structure for the Reynolds equation which can be used to calculate thermal variation.

The attempt is made to create a more pragmatic and applicable situation. Expressions that can signify dimensionless form of pressure and bearing load carrying capacity are found using Reynolds' equation. The load carrying capacity equation is then solved numerically with the help of Simpson's 1/3 rule to analyze the impact on the bearing system. From the graphical study representation, it can be concluded that a ferrofluid lubrication based on the Shliomis model can significantly neutralize the negative effects of the bearing's roughness on its load carrying capacity.

2. BRIEF DESCRIPTION ON THE STATE OF THE ART OF THE RESEARCH TOPIC

The discipline that studies the phenomenon occurring when two objects that are relatively moving and are in contact with each other is known as Tribology. A UK-based committee in 1966 first used the term "Tribology" (Dowson, 1979).

A very noteworthy work in the field, "History of Tribology-the Bridge between classical antiquity and the 21st century" was given by (Bartz, 2001). This work gave an extensive account of the history of Tribology and the way it has evolved through the years. Tribology, which is interestingly amongst the earliest phase of engineering sciences, has been compared to various classical disciplines. When early humans started looking for ways to reduce manual labor in load carrying, the science of Tribology began. In fact, this science has been relevant since the time the first wheel was invented.

The research tries to come over with various applications through different bearings which can be utilized in digitalize world. Various industrial applications including aerospace and aeronautical industries, nuclear and civil engineering, modern construction engineering amongst others make use of conical plates as crucial constitutional elements. The dynamic response of these conical plates is significantly impacted by various fluids (stationary or flowing) that they work with. That is why, it is crucial to study the behavior generated by different load types in order to ensure safe functioning in applications. It is also clear that same as the conical bearing, Slider bearing has its own metallic aspects, a lot of applications in various fields including clutch plates, automobile transmissions and domestic appliances. On the other hand porous bearings are also used in horsepower motors of hair dryers, record players, vacuum cleaners, tape recorders, sewing machines, water pumps, etc. (Patel & Deheri, 2018).

Christensen and Tonder (1969a,b, 1970) used a stochastic concept and came up with a new model for lubricated surfaces with striated roughness using an averaging film. They derived the stochastic Reynolds' equation and used the results to study the impact of surface roughness on the load bearing capacity in a rough bearing system. Many famous books of the field (Bhat, 2003; Hamrock, 1994; Majumdar, 2008) discuss the Reynolds' equation and try to derive an exact solution to it by using different basic film geometries. The last decade has seen a considerable shift wherein many tribological researches have been dedicated to study surface roughness and its impact of hydrodynamic lubrication. This is because every solid surface carries some amount of surface roughness, the height of which is usually parallel to the mean separation between lubricated contacts. As many researchers have suggested, studying surface roughness will help to improve the performance of bearing system. Due to this reason, many researchers (Andharia et al., 2001; Naduvinamani et al., 2015; Patel et al., 2012; Shukla & Deheri, 2017; Thakkar et al., 2019) studied the performance of various bearing systems using the stochastic concept of (Christensen & Tonder, 1969a,b, 1970).

All the particles undergo a body force when subjected to a magnetic field, resulting in the drag to flow. Therefore, for industrial application, the study of different combination of materials with magnetic fluid is of primary importance (Patel et al., 2017). Some researchers (Bhat & Deheri, 1991; Neuringer & Rosensweig, 1964; Shah & Bhat, 2002; Shimpi & Deheri, 2012; Snyder, 1962) have also used magnetic fluid as a lubricant in order to aid the tribological performance of a sliding interface.

Furthermore, porosity was introduced in an attempt to decrease the friction. Morgan and Cameron (1957) were the first investigators to study the hydrodynamic lubrication theory of bearings with porous structure. Darcy's law is generally used to determine the porosity. Porous metallic materials have a lot of applications including vibration and sound absorption, light materials, heat transfer media, sandwich core for different panels, various membranes and during the last years as suitable biomaterial structures for design of medical implants. Beavers and Joseph (1967) provide some boundary conditions that were empirical in nature which gave a coefficient of slip known as ζ. These conditions can be used to calculate the non-zero type of interfacial velocity when the flow in a porous medium increases significantly. In the given context, the efficiency of the thermal impact cannot be marginalized which is why, Tipei (1962) performed an experimental study which suggested that the viscosity-temperature relationship is substitutable by a establishing a relationship between the viscosity and the film thickness. The study also suggested that least film thickness is associated with highest temperature. In the modern age efficacy of thermal effect also introduced with new shape.

3. DEFINITION OF THE PROBLEM

When there is an increased amount of contact between two metallic surfaces that are non-lubricated or dry, it causes friction which leads to wear and tear. This not only leads to energy wastage due to friction but even the system's material is compromised due to the wear and tear. Lubricants like viscous fluid or liquid metal or others are used to reduce the friction. These substances create a space between the two surfaces in which they can function smoothly with minimal efforts. The type of lubrication to be used is based on different aspects including, the surface geometry, the load to be carried, relative velocity of both the surfaces and the characteristics of the lubricant amongst other.

This study aims to explore the impact created by slip velocity, porosity, assorted porous structure (Carman, 1937) and variation in viscosity along with the roughness longitudinal as well as transverse of a bearing surface on a ferrofluid lubrication of different magnetic fluid flow model i.e. Shliomis model and Neuringer-Rosensweig model for various bearing system.

The average pressure of a slider bearing with a rough surface is calculated using the given averaged Reynolds' equation and is explained by (Bhat, 2003).

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

4. OBJECTIVE AND SCOPE OF WORK

4.1. RESEARCH OBJECTIVES

This study aims to understand the way pressure and system's load bearing capacity of this mathematical model function when a ferro-lubricant is used instead of a conventional or regular lubricant.

The effect of slip velocity is going to be examined in:

- Ferrofluid lubrication of a rough porous inclined slider bearing.
- Ferrofluid squeeze film in longitudinally rough truncated conical plates.
- Magnetic fluid based squeeze film in rotating transversely rough curved circular plates.
- Ferrofluid based longitudinally rough porous plane slider bearing.

It is tried to carry out new dimension with the help of Shliomis model and claim with better result, and which is going to one hand experience in mentioned here,

- Ferrofluid lubrication performance in rough short bearing.
- Lubrication of rough short bearing by ferrofluid considering viscosity variation effect.

This research tries and experienced with different film geometries to check the potency of bearing system and its result.

Furthermore, our goal in the concluding chapter is a detailed scrutiny of ferrofluid lubrication, most effectively on the basis of rough sine film slider bearing with assorted porous structure.

4.2. SCOPE OF THE STUDY

This study aims to perform a comprehensive analysis of the following:

- The impact caused by deformation in the load bearing capacity of different bearing systems can be studied.
- The models of magnetic fluid flow (Jenkins, 1972; Neuringer & Rosensweig, 1964; Shliomis, 1974) can be compared so as to know in which particular model load bearing capacity is in high proportion.
- We may focus on applying double layered porous structure to the various bearings.
- Possibilities for the application of hydromagnetic lubrication to the bearings to improvise their load carrying capacity can be examined.
- It is also possible to study the theoretical implications concerning the impact of a system's roughness on the type and features of lubrication used with the help of micropolar fluid.
- Ample of scope to front forward with profile of the piston top compression ring face is assumed to be a parabola is also found.
- The Jenkins model of fluid flow may be used in order to study the ways in which deformation can impact different types of bearing systems.
- The impact caused by couple stress can be studied with the help of magnetic fluid flow.
- To explore the research on annular plates with all the parameters which are utilized in the study.
- Analysis of the bearing system's surface topology.

By focusing on such a diverse range of topics, this study becomes relevant to various different streams of engineering and science including physics, material science, mechanical engineering, mathematics, etc.

5. ORIGINAL CONTRIBUTION BY THE THESIS

This thesis modifies and adapts a mathematical model which helps study:

- Effect of slip velocity on a magnetic fluid based squeeze film in rotating transversely rough curved porous circular plates.

- Analysis of rough porous inclined slider bearing lubricated with a ferrofluid considering slip velocity.
- Influence of ferrofluid lubrication on longitudinally rough truncated conical plates with slip velocity.
- Effect of slip velocity on a ferrofluid based longitudinally rough porous plane slider bearing.
- Numerical modelling of Shliomis model based ferrofluid lubrication performance in rough short bearing.
- Lubrication of rough short bearing on Shliomis model by ferrofluid considering viscosity variation effect.
- A study of ferrofluid lubrication based rough sine film slider bearing with assorted porous structure.

The graphical method is used to calculate the results. These results are also compared holistically in order to find the various criteria that would increase the system's performance.

6. METHODOLOGY OF RESEARCH, RESULTS/COMPARISONS

The following assumptions were considered (Deheri & Patel, 2006)

- The lubricant flow is considered laminar and lubricant film is assumed to be isoviscous.
- There are no external fields of force acting on the fluid. While magnetic and electric forces are not present in the flow of non conducting lubricants, forces due to gravitational attraction are always present. However, these forces are small compared to the viscous force involved.
- The flow is considered steady and temperature changes of the lubricant are neglected.
- The bearing surfaces are assumed to be perfectly rigid so that elastic deformations of the bearing surfaces may be neglected.
- Bearing surfaces are assumed to be perfectly smooth or even when there is surface roughness it is of very small order of magnitude in comparison with the minimum film thickness.
- The thickness of the lubricant film is very small when compared to the dimensions of the bearing.

- The lubricant velocity along the transverse direction to the film is considered small enough.
- Velocity gradients and indeed the second derivatives along the direction transverse to the film are predominant as compared to those in the plane of the film.
- The lubricant inertia is considered negligible.
- The porous matrix of the bearing surface is assumed to be homogeneous and isotropic.
- Darcy's law is assumed to govern the lubricant flow within the porous matrix, while no slip condition is taken at the porous matrix-film interface.

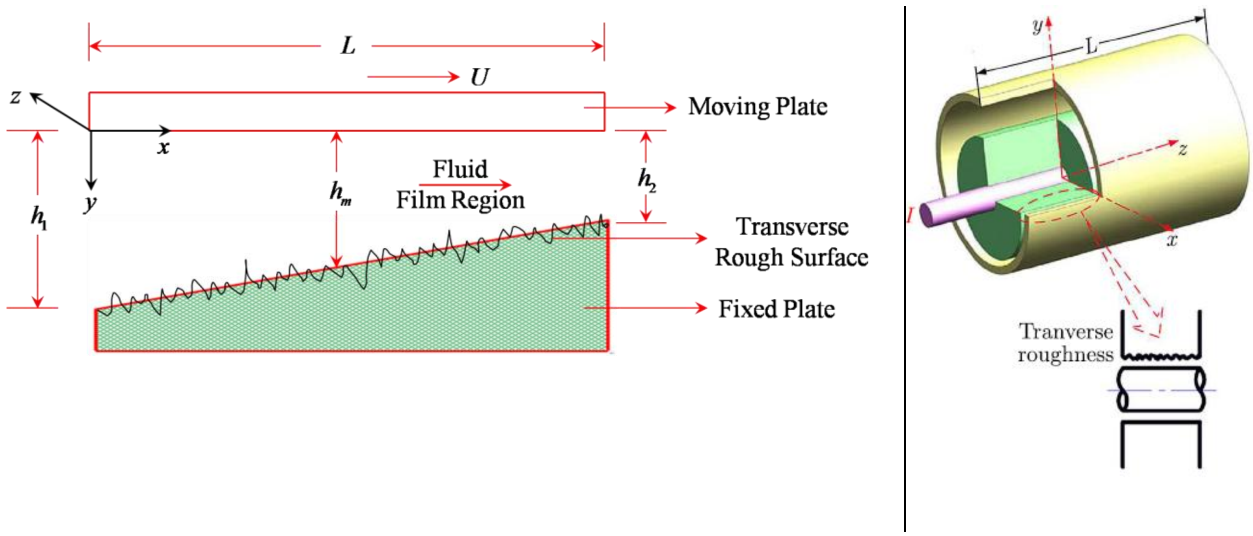

FIGURE 1 Configuration of the bearing system (Patel & Deheri, 2013)

Thus, it is considered to be 1-D problem. Various parameters of roughness are added at different stages, like mean, standard deviation and skewness, roughness pattern parameter for transverse and longitudinal as well, of the rough surface and magnetization parameters. This allows the calculation of an average pressure for the system present on the area of contact. We can derive the system's load carrying capacity along with the pressure through this calculation. Existing researches have been used to verify and justify the findings of this study. Simpson's one-third rule having step size 0.2 is used to work on the calculations of the integrals. The findings of the study along with the relations found between parameters are plotted on a graph and are also represented tabular.

7. ACHIEVEMENTS WITH RESPECT TO OBJECTIVES

The model of eq. (1) by (Bhat, 2003) has been adapted to achieve the aim:

The adapted model has been solved while maintaining appropriate boundary conditions including parameters of roughness (e.g. mean, standard deviation, skewness), roughness pattern (e.g. longitudinal or transverse), lubricant type (e.g. magnetic lubricant or conventional lubricant), magnetic parameter, shape of bearing geometry etc. The study and analysis of different models revealed some noteworthy findings which are:

- The longitudinally surface roughness can be more adoptable as compare to transverse surface roughness when no slip is involved.
- Magnetic strength in appropriate measures can be used to nullify the impact of the thermal effect.
- When we used magnetic fields, ferrofluid increase the capacity of various bearings in contrast to the systems functioning with conventional bearing.
- At the time when a sine film profile is used to design the slider bearing, it enhances the bearing capacity than in the case of inclined slider bearing.
- On the contrary thing to be understood is that a constant magnetic field shows a positive effect on the bearing capacity in the Shliomis model while the same is not true for Neuringer-Rosensweig ferrofluid flow model.

8. CONCLUSIONS

In nutshell, it is proved that the research come up with the various notion by keep in mind to enhance and enable the capacity of bearing system. The study explores and identifies that though transverse surface roughness has a negative impact on the load bearing capacity in general, the performance can be improved by using negatively skewed roughness along with negative variance. In a further research it is also found that, the attempts made to neutralize the adverse impacts of surface roughness; porosity and slip velocity with the help of magnetization are considerable limited. However, the negative impact of roughness displays more variation in this situation despite the fact that standard deviation raises the load bearing capacity.

This research tries to carry out new concept by performing and applying the various theories as well as pattern and model to explore the new concept of research horizon. The focus is to develop the capacity of bearing system by the help of stochastic averaging roughness model which was introduced by Christensen and Tonder. The researcher also sets the aim to get positive effect and so, they utilized the concept of magnetic fluid flow models of Shliomis and Neuringer-Rosensweig. The assorted porous structure by Kozeny-Carman's model was also experimented in the study.

Interrogation of study, try not to limit its' boundary however also performs with the surface roughness should be a primary concern with the designs of magnetic fluid based bearing system. The rotation and curvature parameters are to be selected carefully even if the slip is at the minimum level. The report also suggests that for a 'no flow' situation, the bearing can endure only a specific load amount.

It is also the part of result that, the life period perspective, this study is beneficial sine which aids the process of choosing the ideal aspect ratio, angle. Such an angle can in turn, reduce the negative effects of roughness slip combine, even for moderate magnetic field.

Shliomis' ferrofluid flow provides relevant insights on the impact of rotations of the career liquid and magnetic particles. Further, a varying magnetic field provides the benefit of creating the maximum field according to the necessary contact area of the bearing. Further, this study can create a new pathway for ensuring maximum utilization of a bearing system. It also clearly proposes that by managing the lubricant loss, the life span of a load bearing system can be increased substantially.

Here, researcher also concludes with that, the study determines when Kozeny-Carman's model is appropriate, the surface roughness must be studied properly in order to design a more efficient and effective bearing system. Additionally, in fluid dynamics, the Kozeny-Carman equation plays a major role in calculating the pressure drop when working with fluid flowing in a packed bed of solids.

The study also focuses on thermal effect and its vital role as well because it represents the nonmetallic effect. The Shliomis model of ferrofluid and the stochastic theory by Christensen have been used as the basis of this study to analyze the impact of changes in ferrofluid lubrication viscosity in the case of short bearings. Thermal effect has a negative impact on a system's load bearing capacity. Magnetic strength in appropriate measures can be used to nullify the impact of the thermal effect.

The study related to effects of slip velocity is calculated by using the slip model of Beavers and Joseph not only that, the model of Morgan and Cameron introduced hydrodynamic lubrication theory of bearings with porous structure also included in research, In addition Tipei model represented Viscosity Variation Effect in same manner. Concluded with, if the accuracy and appropriacy works hand to hand the result can be found in a positive manner.

The researcher believes that research is not a profession but it is a passion and so he tries to deal with his best.

9. LIST OF PUBLICATIONS

LIST OF PUBLICATIONS ARISING FROM THE THESIS

1. Effect of Slip Velocity on a Magnetic Fluid Based Squeeze Film in Rotating Transversely Rough Curved Porous Circular Plates. *Industrial Engineering Letters, 7(8),* 28-42, 2017. http://www.iiste.org/Journals/index.php/IEL/article/view/40253/41400
2. Analysis of Rough Porous Inclined Slider Bearing Lubricated With a Ferrofluid Considering Slip Velocity. *International Journal of Research in Advent Technology, 7(1),* 387-396, 2019. doi.org/10.32622/ijrat.71201977
3. A Study of Ferrofluid Lubrication Based Rough Sine Film Slider Bearing With Assorted Porous Structure. *Acta Polytechnica, 59(2),* 144-152, 2019. doi.org/10.14311/ap.2019.59.0144
4. Lubrication of Rough Short Bearing on Shliomis Model by Ferrofluid Considering Viscosity Variation Effect. *International Journal of Mathematical, Engineering and Management Sciences, 4(4),* 982-997, 2019. doi.org/10.33889/IJMEMS.2019.4.4-078
5. Influence of Ferrofluid Lubrication on Longitudinally Rough Truncated Conical Plates with Slip Velocity. *Mathematical Journal of Interdisciplinary Sciences, 7(2),* 93-101, 2019. doi.org/1015415/mjis.2019.72012

LIST OF ACCEPTED ARTICLES

1. Numerical Modelling of Shliomis Model Based Ferrofluid Lubrication Performance in Rough Short Bearing. *Journal of Theoretical and Applied Mechanics, 57(4),* 2019.

2. Effect of Slip Velocity on a Ferrofluid based Longitudinally Rough Porous Plane Slider Bearing. *Proceeding of 8th International conference on Soft Computing for Problem Solving-SocProS 2018,* VIT-Vellore, Tamil Nadu, India, 17-19 December 2018. Germany: Advances in Intelligent Systems and Computing series of Springer, 2019.

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