Study of effect of various types of bearing on load capacity

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Contents

1. Abstract ........................................................................................................................................1
2. Brief description on the state of the art of the research topic ..................................................3
3. Definition of the problem ...........................................................................................................4
4. Objective and scope of the work .................................................................................................5
5. Original contribution by the thesis .............................................................................................5
6. Methodology of Research and Results/Comparisons .................................................................6
7. Achievements with respect to objectives ....................................................................................7
8. Conclusion ...................................................................................................................................8
9. List of Publications ......................................................................................................................8
References ........................................................................................................................................9
1. Abstract

The current thesis is devoted to study the effect of various types of bearing on load capacity. In this theoretical study mathematical model has been developed for various types of squeeze film bearing systems such as circular, parallel stepped, conical, circular parallel stepped. Ferrofluid is used as a lubricant in these bearings. Tribology is one of the most important subject dealing with friction, wear and lubrication. If we could control and reduce main constituents friction and wear of tribology, automatically it increased the service life of machine elements. This in turn, saves currency. The identification of tribological problems and their solutions can increase to significant savings. To reduce the friction, lubrication plays an important role. Selection of suitable lubricant in machine can extend machine’s life period as well.

In recent years, extensive research work has been carried out to study the influence of ferrofluid lubrication on bearing performance. This field has gained wide range of devotion due to its extensive use in technological applications like dynamic sealing, heat dissipation, damping and medical applications like, drug targeting, hyperthermia and cell separation. In the recent years surface roughness and its effects on machine design has been important features which have been widely studied. Some methods have been suggested to study the consequence of surface roughness on the bearing performance. Due to the random structure of the surface roughness, a stochastic model for the study of hydrodynamic lubrication has been developed by Christensen and Tonder. So, the present thesis purposes to analyse the combined influence of ferrofluid and surface roughness on various types of porous bearings. The generalized Reynolds type equation is derived to obtain the pressure distribution. With appropriate boundary conditions, the associated Reynolds type equation is solved to get pressure in film region which, in turn gives the load bearing capacity. Obtained results are presented in graphical forms as well as tabular forms. In the presence of ferrofluid the system shows better performance.

The work has been summaries in the form of various chapters. Thesis consist of eight chapters. The first chapter introductory in nature and contains motivation for the study. Chapter II represents the brief discussion on the basic need of lubrication theory and tribology. It includes properties of fluid, classification of fluids and basic governing equations.

A theoretical study of ferrofluid lubrication of rough porous parallel stepped plates with the presence of couple stress effect is analyzed in chapter III. Expression for film pressure and
load bearing capacity has been achieved as a function of various parameters and deliberated from different viewpoints. It is observed from the study that load capacity of bearing is enhance due to magnetic effect. Roughness and porosity affect on bearing’s load capacity adversely, but this contrary influence can be compensated up to certain level with proper choice of couple stress parameter and magnetic parameter.

Chapter IV deals with performance of ferrofluid based longitudinally rough porous parallel stepped plates with couple stress. Obtained results are compared with conventional lubricant based bearing system. The graphical and tabular representation emphasizes that combined impact of magnetization and couple stress is to increase the load bearing capacity irrespective of the circumstances.

Chapter V represents the influence of a doubled layered porous conical bearing with two different forms of transverse roughness. Also, comparison is made between two roughness patterns. Computed results are presented graphically with regards to various parameters. It is found that load bearing capacity enhances due to doubled layered plates.

Chapter VI makes an effort to study the combined influence of slip velocity and surface roughness on ferrofluid based double layered porous circular plates. Influence of slip velocity is governing by Beavers and Joseph’s slip model. The results presented in the graphical forms establish that the magnetization offers a limited scope in holding the contrary influence of roughness, porosity, and slip velocity. Though, the situation improves when negatively skewed roughness occurs. But for any type of development in the bearing performance the slip has to be kept at reduced level even if variance (-ve) is involved.

Chapter VII analyse the performance of rough porous circular stepped plates lubricated with ferrofluid. Neuringer–Roseinweig model has been employed for magnetic fluid. Stochastic modeling of Christensen and Tonder has been employed for the effect of roughness of the bearing surface. Stokes microcontinum theory has been employed for couple stress influence. According to the graphical and tabular results obtained, influence of ferrofluid lubrication combined with the couple stress effect improves the load capacity of bearing compare to couple stress fluid based bearing system.

Chapter VIII covers the overall conclusion and future scope of the work.

On the whole, the present study investigates the performance of ferrofluid based squeeze film lubrication in different types of rough porous bearing geometries with couple stress effect.
2. Brief description on the state of the art of the research topic

A scientific approach to friction is given by Leonardo Da Vinci [1452-1519]. He has deduced the basic laws of friction and presented the idea of coefficient of friction as the fraction of the friction force to normal load. A theoretically study of lubrication of bearings was made by (Obsorne Reynolds, 1986) and he derived very well-known general equation for fluid film lubrication known as Reynolds equation.

Porous bearing is used very widely in many devices such as Vacuum cleaners, extractor fans, motorcar starters, hair dryer etc. They are also used in business machines, farm and construction equipment and aircraft automotive accessories. In addition, porous bearing can work hydrodynamically longer short of maintenance and steadier than the conventional bearing. Also, in these bearings’ friction is less as compared to the non-porous bearings. Over the ancient spans, an extensive number of theoretic models have been proposed on the performance features of the porous bearings by numerous investigators. The hydrodynamic model of porous journal bearings based on Darcy model was investigated initially by (Morgan & Cameron, 1957). Prakash and VIJ (1973) analyzed the performance of various porous plates like circular, conical, truncated conical, elliptical, recant angular etc. and compared with conventional lubricant based bearing system. Uma Srinivasan (1977) has almost extended above work by considering doubled layered porous plates. Cusano (1972) conducted the study of an infinitely long double layered porous bearing. Verma (1983) investigated the influence of doubled layered porous slider bearing.

Representation of surface roughness is a significant feature in applications including friction, wear and lubrication. The study of the influence of surface roughness on hydrodynamic lubrication of different bearing systems has been a focus of developing attention, because, in the reality, most of the bearing surfaces are not smooth. The bearing surface tend to be rough after having some run-in and wear. Christensen and Tonder (1969a, 1969b,1970) made a comprehensive model using polynomial probability distribution function for transverse as well as longitudinal surface roughness. In order to increase ability of the bearing performances many theoretical and experimental researches have been carried out on design point of view of bearing as well as lubricating substances. One of the main inventions towards the lubricant is development of ferrofluid and associated progress. Neuringer–Rosensweig (1964) model describes the basics hydrodynamic equations leading the flow of magnetic fluid. They focused on the influence of the magnetic body force on a paramagnetic fluid characterised by a symmetric Newtonian stress tensor and considered thermo-mechanical
phenomena in this model. Dinesh Kumar et. al. (1992) studied the influence of ferrofluid on spherical and conical bearings using perturbation analysis. Prajapati (1995) studied the effect of magnetic fluid on porous squeeze film bearings. Bhat and deheri (1993) made a theoretical study on squeeze film based curved porous circular disk lubricated with ferrofluid. Shah (2003) analysed the ferrofluid lubrication in step bearing. Numerous researchers have analysed the effect of surface roughness with existence of ferrofluid lubrication, for various bearing geometries. (Patel et al., 2011; Gupta & Deheri,1996; Patel et al., 2008; Patel & Deheri, 2007; Patel & Deheri, 2016a; Andhariya & Deheri, 2011; Patel & Deheri, 2016b; Shimpi & Deheri, 2014). All these studies revealed that there is a substantial increase in load due to magnetic fluid relative to conventional lubricant case.

Now a day it is well known that the use of Newtonian fluids mixed with additives introduces a development in the bearing performances as related to the Newtonian lubricants. In fact, owing to the existence of additives a nonlinear relation is created between the shear stress and strain rate. Stokes (1966) proposed a microcontinuum theory for the couple stress fluids is the generalization of traditional Newtonian fluid principle and it accounts for the polar effects such as the couple stresses, body couples and asymmetric tensors. Numerous researchers have analysed the impact of couple stress using Stokes micro-continuum theory for various types of bearing systems (Elkouh & Yang, 1991; Lin, 1998; Bujurke et al., 1990; Lin et al., 2006; Guha, 2004; Ramanaiah & Sarkar, 1978; Ramanaiah & Dubey, 1975; Maiti, 1973; Naduvinamani & Siddangouda, 2007; Naduvinamani & Siddangouda, 2009; Biradar, 2012; Biradar, 2013). All the above studies discovered the importance of non-Newtonian fluid in squeeze films and presented that this non-Newtonian fluid contributed improved performance in hydrodynamic lubrication compared to Newtonian lubricant.

3. Definition of the Problem

The present effort is made for theoretic study of surface roughness and ferrofluid lubrication for various porous bearing geometries. Under the traditional assumptions of hydrodynamic lubrication generalized Reynolds type equation is solved for parallel stepped plates, circular plates and conical plates bearing. The goal of the work is to observe the influence of ferrofluid with couple stress on bearing’s load capacity. Impact of transverse and longitudinal surface roughness is studied with roughness parameters like, standard deviation, variance and skewness.
4. Objective and Scope of the work

The aim of research in the field of tribology is to lessen and eliminate the losses resulting from friction and wear at all stages of technology which includes the rubbing of surfaces. Research in Tribology leads to larger efficiency, improved performance, less collapses and substantial savings.

The key purpose of this investigation is to analyze the combined influence of magnetic fluid and surface roughness on bearing’s load capacity by using (Neuringer- Rosenweig,1964) model and (Christensen & Tonder; 1969a, 1969b, 1970) model. Various types of bearing geometries are considered for the study like parallel stepped plates, circular plates, conical plates and circular stepped plates etc. Also, the aim is to find closed form solution for fluid film pressure and bearing’s load capacity.

Current study opens up new extent of research and improvement in several directions as follows:

- In the present study Neuringer Rosenweig model for ferrofluid lubrication is used. Influence of surface roughness may be study with Shliomis and Jenkins model for ferrofluid lubrication.
- Influence of bearing deformation can be study for various types of bearing. Investigation can be made by using porous models of Kozeny-Carman’s and Irmay’s.
- Effect of transverse and longitudinal roughness can be considered for multi stepped bearings. Additionally, the results obtained in this thesis may be extended to more complex geometries associated with practical applications.
- Investigation may be carried out by considering Rabinowitsch fluid model for different bearing geometries.

5. Original contribution by the thesis

The original contribution by the thesis is based on mathematical modelling of parallel stepped plates, conical plates, circular plates and circular stepped bearing which analyses:

- Combined influence of roughness and ferrofluid on porous parallel stepped plates with couple stress effect.
- Influence of double layered porous conical plates with two different patterns of transverse roughness.
- Impact of slip velocity and surface roughness on ferrofluid based double layered porous circular plates.
Performance of longitudinally rough porous circular stepped plates with existence of ferrofluid and couple stress effect. The analytic solution of such problems is obtained and results are plotted graphically. Comparisons are given between ferrofluid based bearing system and conventional lubricant based bearing system.

6. Methodology of Research and Results/Comparisons

The inspiration of the current work arises from the observation of occurrence of lubrication phenomenon in numerous applications like automotive and aircraft engines, bearings, dampers, gears, clutches, turbomachinery and skeletal joints. Due to these extensive applications of lubrications many researches were made on the phenomenon by several investigators from different perspectives.

Following traditional assumptions of hydrodynamic lubrication are made for study.

- The incompressible lubricant with constant velocity and constant viscosity is considered.
- Flow of the lubricant is laminar and steady. Properties of fluid do not change with respect to time.
- The fluid film thickness is deliberated very small in comparison with the dimensions of the bearings.
- Body forces are ignored, i.e. there are no outer fields of force acting on the fluid.
- Porous region is supposed to be homogeneous and isotropic.

Under the above assumptions of hydrodynamic lubrication, on the basis of the Stokes microcontinuum theory for couple stress fluid the generalized Reynolds type equation for parallel stepped plates is derived with no slip boundary conditions for smooth bearing is given by (Biradar, 2012)

\[
\frac{dp}{dx} = -12\mu Vx \frac{G_i(h_l, l)}{G_i(h_l, l)}
\]

(1)

where,

\[
G_i(h_l, l) = h_l^3 + 12I^2h_l + 24I^3tanh\left(\frac{h_l}{2l}\right)
\]

The equation (1) is modified to obtain the surface roughness effect and magnetization effect. The bearing surface’s roughness effect is obtained on the basis of (Christensen & Tonder, 1969a, 1969b, 1970,) model for hydrodynamic lubrication of rough surfaces. Transverse and longitudinal roughness with nonzero mean has been considered for the study. Fluid in the film
region are described by (Neuringer–Rosensweig, 1964) model for ferrofluid lubrication. Porous surface is deliberated because of getting benefit of self-lubricating property. Porosity is governed by the Darcy’s law.

The modified Reynolds equation for double layered porous plates is given by (Srinivasan, 1977)

\[
\frac{\partial}{\partial x} \left[ \left( h^3 + 12 \phi_1 H_1 + 12 \phi_2 H_2 \right) \frac{\partial p}{\partial x} \right] + \frac{\partial}{\partial z} \left[ \left( h^3 + 12 \phi_1 H_1 + 12 \phi_2 H_2 \right) \frac{\partial p}{\partial z} \right] = 6 \mu U \frac{dh}{dx} + 12 \mu V h \tag{2}
\]

The modified Reynolds equation for double layered porous plates in polar coordinates is given by

\[
\frac{1}{r} \frac{\partial}{\partial r} \left[ \left( h^3 + 12 \phi_1 H_1 + 12 \phi_2 H_2 \right) r \frac{\partial p}{\partial r} \right] + \frac{1}{r^2} \frac{\partial}{\partial \theta} \left[ \left( h^3 + 12 \phi_1 H_1 + 12 \phi_2 H_2 \right) r \frac{\partial p}{\partial \theta} \right] = 6 \mu U \left( \cos \theta \frac{dh}{dr} - \frac{\sin \theta \, dh}{r \, d\theta} \right) + 12 \mu V \tag{3}
\]

The fluid flow becomes axisymmetric in the case of circular plates so equation (3) turns out to be

\[
\frac{1}{r} \frac{d}{dr} \left( r \frac{dp}{dr} \right) = \frac{12 \mu \frac{dh}{dt}}{h^3 + 12 \phi_1 H_1 + 12 \phi_2 H_2} \tag{4}
\]

For conical plates bearing modified Reynolds equation is

\[
\frac{1}{x} \frac{d}{dx} \left( x \frac{dp}{dx} \right) = \frac{12 \mu \frac{dh}{dt} \sin \omega}{h^3 \sin^3 \omega + 12 \phi_1 H_1 + 12 \phi_2 H_2} \tag{5}
\]

In the present study equation (4) and (5) are modified to obtain the surface roughness influence in the presence of ferrofluid as a lubricant. Closed form solutions are achieved for film pressure and bearing’s load capacity in terms of various parameters and presented graphically.

### 7. Achievements with respect to objectives

Deploying a theoretic approach study of solving squeeze film flow problems is carried out. The generalized Reynolds equation is solved with no slip boundary conditions and modified to achieve our objectives. In all the current investigations modified Reynolds equation leading the pressure distribution is averaged with regards to the roughness parameter. The equation for dimensionless load bearing capacity is found in the form of roughness parameters.
magnetization parameter and couple stress parameter. Graphical and tabular results indicate improved performance due to ferrofluid lubrication relative to conventional lubricant.

8. Conclusion

Present thesis represents combined influence of surface roughness and ferrofluid lubrication on bearing’s load capacity. Modified Reynolds equation leading to pressure distribution is stochastically averaged using polynomial probability distribution function with regards to roughness parameter representing the non zero mean, standard deviation and skewness. The standard deviation can take only positive values while mean and skewness assumes both the values positive and negative. The influence of ferrofluid and surface roughness are analyzed for various geometries of the bearing. The load bearing capacity is boosted by ferrofluid lubrication.

From all investigations presented in the thesis concluded that with respect to transverse roughness all the roughness parameters affect the bearing system adversely, while in the case of longitudinal roughness we can observe from the present analysis that mean and skewness tend to drop the load capacity and a noticeable fact is that standard deviation grows the bearing’s load capacity.

Roughness and porosity affect the bearing system adversely. The investigation for parallel plates bearing suggest that from design point of view position of step and roughness features play an important role. Adverse influence of roughness and porosity can be compensated with proper selection of magnetization parameter and couple stress parameter when variance (-ve) is in place. Analysis of double layered porous bearing suggest that porosity of the outer layer influences more as compared to the inner layer even in the presence of a mild magnetic strength. Obtained results are compared with nonmagnetic case and found that load bearing capacity improves in the case of magnetic case compare to nonmagnetic case.

9. List of Publications


**References**


