Chapter 1
Introduction

Contents

1.1 Introduction of Ferrofluid (or Magnetic Fluid)

A ferrofluid (FF) or magnetic fluid (MF) is a colloidal dispersion of nano magnetic particles in a non-conducting carrier liquid. When the angular velocities of rotations of the carrier liquid as well as magnetic particles are different, frictional forces arise. These forces cause an increase in the effective viscosity of the FF. Shliomis [1] studied the above effects of rotations of the carrier liquid as well as magnetic particles in the FF flow description in addition to magnetic body force. Jenkins [2-4] presented isothermal static equilibrium theory for FFs. Here, the spin component, which is parallel to the magnetization, is ignored. In comparison with Neuringer-Rosensweig (NR) FF flow model [5], Jenkins model distinguishes the volume force density (due to the self-field) from the external body force. NR model considers only magnetic body force and did not consider any rotation effect. Due to important property of FFs to adhere to any desired location on the surface in presence of magnetic field, they gained widespread popularity among the researchers working on lubrication theory of bearings. Thus, the use of FF lubrication also adds an additional importance from nano science point of view. Huge amount of work on NR as well as Jenkins models have been carried out on lubrication theory as compared to Shliomis model. For recent updates on FF lubrication, the following section gives brief literature review related to above three models.

1.2 Brief Literature Review

This section includes review of different bearing designs by three different models of FF flows – Rosensweig, Jenkin and Shliomis.

Slider bearings, in general, are the oldest and simplest bearing technology with wide range of applications. It is generally used as a part in the composite system of machine used in many applications, for example – construction machinery, machines with atomic resolution, propeller, pumps, engines and automobile industries, etc. It has good resistance to wear, fatigue and corrosion with sufficient strength to support the load. The simplest hydrodynamic system is the plane slider used in the thrust bearings, journal bearing, etc. However, slider bearings have disadvantage of higher lubricant requirement due to large contact area. But with the use of FF lubricant this disadvantage can be discarded because of tendency of FF to retain at the required active contact zone under the influence of magnetic field effect.

Journal bearings are the bearings which consist of a journal which rotates freely in a supporting metal sleeve (or shell) with a layer of lubricant separating these two parts. The designs of these types of bearings are simple but are widely used in industry because of reduction of load friction, low wear and good damping characteristics, for example, in internal combustion engines, centrifugal pumps, crankshaft of an automobile engines, etc.

Agrawal [6] studied the effects of MF on a porous inclined slider bearing. It is shown that the load-carrying capacity increases without affecting the friction on the moving slider due to the effect of magnetization of the magnetic particles in the lubricant. Shukla and Kumar [7] used Shliomis model to study the slider and squeeze film bearings with uniform transverse magnetic field by neglecting relaxation time of particle rotation. They derived the pressure equation under the assumptions that the FF is saturated so that the saturation magnetization is independent of the applied magnetic field, and the magnetic moment relaxation time is negligible. Chi *et. al.* [8] studied new type of FF lubricated journal bearing consists of three pads (one of them is a deformable elastic pad). The theoretical analysis and experimental investigation shows the better performance of the bearing as compared to ordinary bearings (which uses conventional lubricant). Prajapati [9] analyzed effect of MF on different shapes of squeeze film bearing designs like circular, annular, elliptic, conical, etc. It is shown that the load-carrying capacity increases with the increase of magnetization parameter. Ram and Verma [10] used Jenkins model to study FF lubrication of a porous inclined slider bearing. They found that due to the effects of FF and material parameter, the pressure and load-carrying capacity increases. Shah and Bhat [11] analyzed FF lubricated squeeze film in a long journal bearing and concluded that as compared to Jenkins model, load-carrying capacity and response time are more in NR model. Also, it is shown that when magnetic field is uniform, the rotational viscosity parameter of Shliomis model causes increase in the load-carrying capacity and response time. Moreover, the non-uniform case of magnetic field is also studied. Shah and Bhat [12] derived the pressure equation without the assumptions given in [7] of Shukla and Kumar. The case of squeeze film between curved annular plates bearing is studied. It is concluded that the load-carrying capacity and approaching time of squeeze film can be enhanced by increasing the volume concentration of the solid phase in FF and the intensity of external magnetic field. Shah [13] extended the analysis of [12] with the insertion of rotation effect of the upper plate, and studied different shapes (secant, exponential and flat) of the upper plate. The results showed that load-carrying capacity and response time increases with the increase of volume fraction of the particles and rotation of the upper plate. Also, it was shown that, load-carrying capacity and response time increases with the increase of curvature of the exponential plate, whereas it decreases with the increase of curvature of the secant shape. Montazeri [14] numerically discussed FF lubricated hydrodynamic journal bearings. It was shown that compared to conventional lubricant, FF improves hydrodynamic characteristics and provides a higher load capacity with the reduction in friction coefficient. Singh and Gupta [15] studied FF based curved slider bearing with the effect of transverse magnetic field. It is shown that the effects of rotation and volume concentration of the magnetic particles improve the stiffness and damping capacities of the bearing. Lin [16] derived Reynolds equation for MF lubricated slider bearings using transverse magnetic field. It is shown that load-carrying capacity, dynamic stiffness and damping characteristics are improved. Patel and Deheri [17] discussed

FF lubrication of squeeze film in rotating rough curved circular discs with assorted porous structures. It was concluded that even if suitable magnetization is in force, roughness aspect must be accorded priority while designing the bearing system. Shah and Patel [18] studied slider bearing with the effects of slip and squeeze velocity using Jenkins model. It is concluded that load-carrying capacity can be improved substantially in the presence of squeeze velocity for smaller values of permeability parameter and increasing values of magnetic field strength. Shah and Parikh [19] discussed different shapes of slider bearings. The dimensionless load-carrying capacity with and without using the effect of squeeze velocity are compared. It is concluded that the load capacity of all bearings remains constant with the increase of Langevin's parameter, whereas it has an increasing tendency with the increase of volume concentration of the particles. Hsu *et. al.* [20] studied long journal bearings with the effects of surface roughness and magnetic field. They showed that bearing can suppress side leakage. Shah and Patel [21] studied squeeze step bearing lubricated with MF. It is concluded that the load-carrying capacity increases with the increase of length of the first step as well as with the increase of magnetic field strength. Lin *et. al.* [22] studied effects of circumferential and radial rough surfaces on a non-Newtonian MF lubricated squeeze film. It was concluded that circumferential roughness effect increases the mean load-carrying capacity and lengthen the mean approaching time as compared to smooth discs. However, the radial roughness pattern showed the reverse trend. Huang and Wang [23] presented comprehensive review on FFs lubrication with some experimental studies. Nargund and Asha [24] studied load-carrying capacity of hyperbolic slider bearings and showed the better performance of the system. Shah and Kataria [25] theoretically discussed FF based squeeze film between a sphere and a flat plate. It is concluded that loss in the dimensionless load-carrying capacity due to the effect of porosity is almost zero because of using FF as lubricant for smaller values of thickness parameter of the porous layer and radial permeability parameter. Shah and Patel [26] studied squeeze film characteristics between a rotating sphere and a radially rough plate using FF lubricant. It is shown that better performance of the dimensionless load-carrying capacity is obtained with respect to various parameters. Laghrabli *et. al.* [27] studied finite journal bearings. The results show that pressure, load capacity, attitude angle and side leakage increases while friction factor decreases. Bhat *et. al.* [28] analyzed comparative study of journal bearing with the use of conventional engine oil, FF and MR fluid as lubricant.

1.3 Motivation of the Present Work

While referring the literature on lubrication theory, I motivated by observing its many applications in different areas – in mechanical engineering (tribology), chemical engineering for property of lubricants, etc.

From Industry view points, lubrication theory is useful in different machine components like machine tools, teeth of gears, rolling elements, hydraulic systems, engines, clutch plates, etc.

From bio-tribology view points, it is especially useful in skeletal joints .

Moreover, the theory is also useful to move heavy object on the floor, memory device technology, space engineering, bioengineering, conservation of energy and resources, etc.

1.4 Investigated Problems of the Thesis

Chapters 3-6 are author's own contributions, which mainly deals with the use of Shliomis model for FF flow using transverse or oblique radially variable magnetic fields (VMFs). The Shliomis model is important because it includes the effects of rotations of the carrier liquid as well as magnetic particles. Also, the variable magnetic field is important because of its advantage of generating maximum field at the required active contact zone in the bearing design systems. Using Shliomis model different bearing designs are discussed from different viewpoints, where in some designs effect of porosity is also considered. The validity of the Darcy's law is assumed in the porous region. In all problems equation of continuity is also considered while deriving the mathematical model in both film as well as porous region.

Chapter 3 derived modified Reynolds equation for the study of lubrication of different slider bearings by considering the effects of oblique radially variable magnetic field and squeeze velocity. Using Reynolds equation, expressions for dimensionless load-carrying capacity, frictional force, coefficient of friction and center of pressure are obtained. Using these expressions, results for different slider bearings are computed for different parameters and compared.

In Chapter 4 modified Reynolds equation for lubrication of circular squeeze film-bearings is derived by considering the effects of oblique radially variable magnetic field, slip velocity at the film-porous interface and rotations of both the discs. The squeeze film-bearings are made up of circular porous upper disc of different shapes (exponential, secant, mirror image of secant and parallel) and circular impermeable flat lower disc. Using Reynolds equation, general form of pressure equation is derived and expression for dimensionless load-carrying capacity is obtained. Using this expression, results for different bearing design systems (due to different shapes of the upper disc) are computed and compared for variation of different parameters.

In Chapter 5 the case of porous journal bearing is studied. The modified Reynolds-Darcy equation for PJB is derived by considering the effects of squeeze velocity, anisotropic permeability and slip velocity. Using Reynolds equation dimensionless form of load-carrying capacity is obtained and computed. The results are also compared with the behavior of different types of journal bearing designs discussed by different authors.

In Chapter 6 static and dynamic performance of FF lubricated long journal bearing is studied. Here, FF is controlled by transverse uniform magnetic field. The dimensionless expressions different bearing characteristics are studied for static case, while the dimensionless expressions for stiffness coefficients and damping coefficients are studied for dynamic case.

1.5 Scope of the Present Work

The present study opens up for various direction of development in different disciplines as shown in figure 1.1 from lubrication view points.

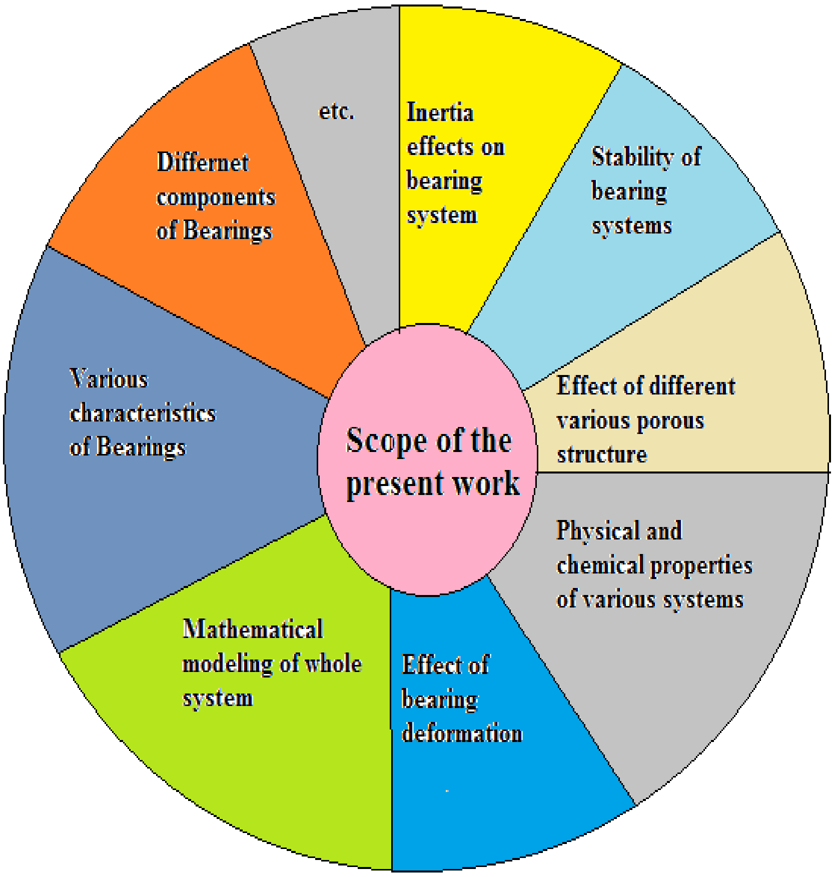

Figure 1.1 Scope of the present work

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