PREFACE

The investigation presented here, in the form of a thesis, is an analytical and numerical study of problems in hydrodynamic lubrication of bearings. Mathematical models have been developed for understanding the lubrication characteristics of various isotropic, porous and poroelastic squeeze film bearings. Squeeze film behaviors are widely used in rolling elements, automotive engines, and hydraulic systems and also in skeletal joints. Squeeze film phenomenon arises when upper plate approaches lower plate with nominal velocity. When the viscous lubricant is present in between the two lubricating surfaces, it cannot be squeezed out instantaneously. Hence, a certain time period is required for the two bearing surfaces to come in contact. Since the viscous lubricant has the resistance to extrusion, a pressure is thus built-up in the squeezed film, which supports the load.

Self-lubricating porous bearings have been widely used in industry due to their self-contained oil reservoir in addition to their low cost. The porous oil bearings also simplify certain problems of machine design since they do not need continuous lubrication. Motivated by these practical aspects, there have been numerous analytical studies of these bearings with Newtonian lubricants. However, the Newtonian constitutive approximation is not a satisfactory approach for many of the practical lubrication applications. Experimental results show that, the addition of small amount of a long chain polymer solution to a Newtonian lubricant gives the most desirable lubricant. Hence, in the present thesis, the effect
of lubricant additives on the performance characteristics of various bearing systems is studied. The lubricants with additives have been modeled as Stokes couple-stress fluid, which is the simplest generalization of the classical theory of fluids, which allows for the polar effects such as the presence of couple stresses and body couples. The couple stresses might be expected to be significant in lubricant containing long-chain molecules when the fluid is confined to narrow passages. Hence it is important to study the effect of couple stresses on the performance characteristics of various porous and poroelastic bearings. In large number of bearings, nowadays, conducting fluids are used. Salient features of such bearings are also investigated based on modified Reynolds equation derived using MHD equations.

The study of the effect of surface roughness on the hydrodynamic lubrication of bearing surface has attracted the attention of many researchers in recent years due to the fact that, all bearing surfaces are rough to some extent. In general, the roughness asperities are of the same order as the mean separation in the lubricated contacts. Under these conditions, the influence of surface roughness on the performance characteristics of the bearings should be considered. The study of surface roughness has a greater importance in the analysis of porous bearings, since the surface roughness is inherent to the process used in their manufacture. Several researchers have studied the effect of surface roughness on the characteristics of porous bearings with Newtonian lubricants. Hence a part of the thesis is also devoted for the study of effect of surface roughness in the
characteristics of porous squeeze film bearings with couple stress fluid as lubricant. Christensen developed a stochastic model for the study of hydrodynamic lubrication of rough surfaces. Several investigators employed this approach for the study of surface roughness on the performance of various bearing systems. All these studies are based on the assumption that the probability density function for the random variable characterizing the surface roughness is symmetric with zero mean. However in practice, due to non-uniform rubbing of surfaces the distribution of surface roughness may be asymmetrical. Andharia et al. used a random variable characterizing the surface roughness whose probability density function is asymmetrical with non-zero mean, variance and skewness. The thesis is organized into eight chapters.

Chapter-I is of introductory nature and contains the basic equations of fluid dynamics. An introduction to non-Newtonian fluids and their classification is given. The basic assumption of hydrodynamic lubrication and their use in the derivation of modified Reynolds equation are also presented in this chapter. A brief history of the study of the effect of surface roughness on the performance of various bearing systems is given. Briefly Equations of poroelasticity are also given here. This will be an ideal investigation of broad category of EHL bearings.

In Chapter-II, the combined effects of couple-stress and surface roughness patterns on the characteristics of squeeze film lubrication between a curved circular plate and a flat plate is presented. The Stokes couple-stress fluid model is included to account for the couple stresses arising due to the presence of microstructure
additives in the lubricant. In the context of Christensen stochastic theory, for the lubrication of rough surfaces, two types of one-dimensional roughness patterns are considered. The modified stochastic Reynolds type equations are derived for the two types of roughness patterns. Expressions for the mean squeeze film characteristics are obtained. It is found that the effect of couple stresses is to increase the load carrying capacity and the squeeze film time as compared to the corresponding Newtonian case. These results are more pronounced for concave pads. From the above observation we find that roughness effects are marginal for radial roughness pattern whereas they are more pronounced for those with circumferential roughness pattern.

Chapter-III deals with the effect of surface roughness on the characteristics of squeeze film lubrication between curved annular plates using Christensen's stochastic theory. The stochastic Reynolds equation governing the mean squeeze film pressure is derived for the two types of circumferential and radial roughness patterns. The closed form expressions for the squeeze film pressure are obtained. Numerical computations of the results show that, the circumferential roughness pattern on the curved annular plate improves the squeeze film characteristics whereas the performance of the squeeze film suffers due to the one-dimensional radial roughness pattern for both concave and convex pad geometries.

In Chapter-IV the combined effects of couple stresses and surface roughness patterns on the squeeze film characteristics of curved annular plates are studied. The Stokes couple-stress fluid model is considered. In the context of Christensen
stochastic theory, for the lubrication of rough surfaces, two types of one-dimensional roughness patterns (circumferential and radial) are considered. The governing modified stochastic Reynolds type equations are derived for these roughness patterns. Expressions for the mean squeeze film characteristics are obtained. The results show that, the circumferential roughness pattern on the curved annular plate results in more pressure build up whereas performance of the squeeze film suffers due to the radial roughness pattern for both concave and convex pads. Further, improvement in performance of the bearings with couple-stress lubricant is predicted.

In Chapter-V the effect of surface roughness on squeeze film behavior between two circular disks with couple-stress lubricant is analyzed when the upper disk has porous facing which approaches the lower disk with uniform velocity. Modified Reynolds equation of the film region is derived. The modified Reynolds equation is solved in closed form and expressions for mean squeeze-film pressure, mean load carrying capacity and the squeeze film time for the disks in terms of Fourier-Bessel series are obtained using Christensen Stochastic theory for hydrodynamic lubrication of rough surfaces. We also study four types of distribution roughness functions, Pseudo-normal distribution, Rectangular distribution and Inverse square root distribution. The importance of roughness and couple stress on bearing characteristics are presented in terms of relative percentage increase in load for all these types of roughness patterns.
In Chapter-VI it is attempted to analyse the effect of poroelasticity of the bearing surface on lubrication characteristics. This is an idealized form of EHL problems in tribology. The role of elasticity is to enhance the performance of bearings. The finite difference based multigrid method is used for the solution of modified Reynolds equation. A major advantage of this approach is that errors are minimized, as the grid size tends to zero. Also multigrid method has significant savings in computation and achieves results which have higher accuracy compared to traditional methods. Lubrication characteristics, which are functions of poroelastic and couple stress parameters are obtained.

Chapter-VII contains the theoretical study of non-Newtonian effects of an isothermal incompressible laminar flow of lubricant on the dynamic stiffness and damping characteristics of one-dimensional hyperbolic slider bearings. In the derivation of modified Reynolds type equation considering transient motion of the slider, the bearing squeeze action is taken in to account, and the Rabinowitsch fluid model is used as a lubricant. The modified Reynolds equation of the one-dimensional slider bearings is solved using the perturbation technique. Both the steady state and dynamic performances are obtained. The results show the influence of the non-Newtonian parameter on the performance of hyperbolic slider bearings. The non-Newtonian effects of lubricants, bearing characteristics including the steady film pressure, load carrying capacity, the dynamic stiffness and damping coefficients are presented and compared with the classical case.
In Chapter-VIII the effect of surface roughness on the magneto hydrodynamic squeeze film behavior between two rectangular plates is analyzed. A generalized form of surface roughness pattern is considered. A stochastic random variable with non-zero mean, variance and skewness is used to mathematically model the surface roughness and analyze of the squeeze film bearings. The modified averaged Reynolds equation governing the squeeze film pressure is derived using magneto hydrodynamic (MHD) equations of motion. The expressions for the squeeze film pressure, load carrying capacity and squeeze film time are obtained. Numerical computations of the results show that the negatively skewed surface roughness pattern increases the load carrying capacity and squeeze film time. On the contrary the performance of squeeze film suffers due to positively skewed surface roughness pattern. Further the magnetic effect characterized by the Hartmann number influences the performance of the squeeze film lubrication as compared to the classical non-conducting lubricant case.