Chapter I

INTRODUCTION

1.1 Fluid Film Lubrication

Lubrication is the art of reducing frictional resistance by means of some kind of substance introduced between two surfaces having relative motion. Such a substance is called a lubricant. The function of a lubricant is to hold the moving surfaces apart allowing them to slide on each other with minimum effort. Lubrication is indispensable in bearings which support moving members in a machine. Jet engines, rolling mills, wrist watches, grinding wheel spindles, electric motors, auto engines, electric generating equipment -- in all these and in many more examples of the machines that sustain our civilization some form of bearing is found as the vital and indispensable element. In nature also the frame work of animals comprises many joints which are so perfect mechanically and so well lubricated with a liquid lubricant that they operate for an entire life time.

The development and wide acceptance of the steam engine in the nineteenth century brought about a need for both thrust and journal bearings. Later on, with the rapid advancement of machines manufacturing processes and materials, there has been a revolution in the design of bearings and the method of lubrication. The lubricant employed may be almost anything. Bearings have been run successfully on water, oil, alcohol, acid, molten metal, liquid refrigerants, gasoline, grease or even air.

Though the use of lubricants to reduce wear and resistance to movement was known to man for quite a long time, it was not a subject of any theoretical analysis till the end of the nineteenth century. Petrov (1883) was apparently the first to make significant attempt to analyze theoretically the friction effect of fluid film lubrication. However, the systematic development of the theory of hydrodynamic lubrication stems directly from the experiments conducted by Tower (1883) and their interpretation by Reynolds (1886). In a classical paper Reynolds obtained a differential equation, which bears his name now, making use of hydrodynamical laws, and showed that the motion of a viscous fluid in narrow clearance of bearing surfaces develop such high pressures as to sustain a load. Kingsbury (1897) verified the hydrodynamic theory of lubrication by experiments on air-lubricated bearings.

Later on, many people contributed much to the theory of fluid film lubrication. Mention may be made of Sommerfield (1904) who provided elegant theoretical extensions to the journal bearing problem, Michell (1905) who extended Reynolds theory to include side leakage, Rayleigh (1918) who found that the optimum profile for the maximum load capacity of a slider bearing was a step function, Kingsbury (1931) who used electrical analogy method to obtain the solution of a bearing with side leakage and Christopherson (1942) who used numerical methods to solve bearing problems.

In recent years numerous engineers and applied mathematicians have contributed their full share in studying the theoretical and practical aspects of hydrodynamic lubrication. As a result, a huge amount of literature now exists in the form of books by Shaw and Macks (1949), Michell (1950), Fuller (1956), Pinkus and Sternlicht (1961), Tipei (1962), Gross (1962) and Cameron (1971).

1.2 Polar Fluid Theory

Classical continuum mechanics is based on the fundamental assumption that all material bodies possess continuous mass density, and that the laws of motion and axioms of constitution are valid for every part of the body regardless of its size. To treat the flow of fluids with microstructure like those containing some additives, suspensions or granular matter, the classical theory is inadequate and one has to look for a generalization of the classical concepts.

During the last decade various theories of microcontinuum have been developed. Eringen (1964 introduced the theory of simple microfluids which exhibit certain microscopic effects arising from local deformation and micromotions of the microconstituents. As a subclass of microfluids, Eringen (1966) introduced micropolar fluids in which the local fluid elements were allowed to undergo only rigid rotations without stretch. Physically micropolar fluids may represent fluids with rigid spherical substructure.

The basic equations of motion of fluids with rigid spherical substructure have also been obtained by various workers from different view points. Mention may be made of Aero, Bulygin and Kuvshinskii (1965), Allen and Kline (1968), Cowin (1968), and Erdogan (1972). Different names like asymmetric hydrodynamics, polar fluid theory etc. have been used to describe micropolar fluid theory. In this thesis we prefer the short name 'polar fluids' except in Chapter II. An excellent review of various theories of microcontinuum fluid mechanics and their applications has been made by Ariman, Turk and Sylvester (1973, 1974).

An elegant theory of fluid microcontinua was formulated by Stokes (1966). This theory is the simplest generalization of the classical theory which would allow for the polar effects like the presence of couple stresses and body couples. The microrotation vector, which is independent of fluid velocity vector in micropolar fluid theory, is assumed to be equal to vorticity vector (half curl velocity) in this theory. The antisymmetric part of stress tensor and the trace of couple stress tensor are left undetermined by the constitutive equations. Hence this theory is sometimes called indeterminate couple stress theory. Stokes (1966, 1968, 1971) has solved a number of boundary value problems to indicate the effect of couple stress over the flow field.

Boundary conditions

In polar fluid theory we have two independent vectors to describe the flow field. These are the velocity vector $\underset{\sim}{v}$ and microrotation vector $\underset{\sim}{\nu}$. For velocity vector the usual no-slip condition is almost always used. In this thesis we always use the no-slip boundary condition on velocity vector. However there is no unanimity over the correct set of boundary conditions for microrotation vector. In the literature on polar fluid theory various sorts of boundary conditions have been used. In our investigations we consider three types of boundary conditions : namely (i) no-spin boundary conditions (ii) no-couple stress boundary conditions and (iii) no-antisymmetric stress boundary conditions, called respectively, Eringen boundary conditions, Stokes boundary conditions and Cauchy boundary conditions, and discuss their relative merits. It is shown that Cauchy boundary conditions predict the classical results.