INTRODUCTION

The ever growing demands of bearings with precision even in adverse working conditions, have led to innovative developments in their design and operations in the specialized fields like space technology, nuclear engineering, electronics, cryogenic engineering and computer technology. In most of the industrial applications, liquid lubricated bearings are used. However, in some cases, solid lubricants such as graphite or molybdenum disulphide are used. Now-a-days air or gas is also being used as a stable lubricant in bearings.

A gas bearing has inferior load carrying capacity compared to an oil bearing of identical size because of reduced viscosity of lubricant. But these bearings can operate over much wider range of speed due to less frictional characteristics. The heat produced by friction is, in most of the cases negligible. A unique feature of gas lubrication is its capacity to operate satisfactorily over wide range of temperature. Due to these advantages, the aerostatic bearings are now employed in precision grinding, micro-hole drilling and in other measuring instruments. They are also being used in machine tools, textile spindles and turbo-machinery successfully. Gas-lubricated bearings have some disadvantages too. Besides having limited load carrying capacity, they are prone to instability. High precision is also required in manufacturing these bearings.

In conventional externally pressurized gas bearings, compressed gas is admitted into the bearing clearance through a number of discrete holes vis restrictors. But these bearings possess low load carrying capacity and stiffness relative to supply pressure and flow required. The use of large recesses ensure effective distribution of flow in case of bearings with incompressible lubricant, resulting an increase in load carrying capacity. But for the bearings with compressible lubricant, a large recess volume leads to bearing instability due to pneumatic hammer. This led to researchers to replace the feed orifices by bearings with porous material. However, complete elimination of pneumatic instability is these bearings is not possible, because of porosity (per cent void) present in the porous bush.

These bearings have been found suitable for application in textile industries[1] and in miniature turbomachinery for cryogenics[2]. They have been successfully applied in computer tape handling systems and machine tools[3]. Motor head bearings of different sizes and high temperature ceramic bearings were reported to be commercially available even more than 18 years ago[4]. The first experimental work on externally pressurized porous gas bearings was reported in the year 1955, the theoretical investigation on such bearings were taken up at a comparatively later stage. However, in the last 25 years quite a good deal of theoretical and experimental investigations have been carried out on porous gas bearings of different configurations. The theoretical studies are mainly concerned with the prediction of static and dynamic performance characteristics of journal and thrust bearings with different shapes.

Till the recent past, while analysing such bearings, it was customery to assume that the lubricating fluid enters the clearance space with zero tangential velocity at the porous interface. Since the fluid migrates tangent to the boundary with the porous medium, it is only approximate to assume that there is no tangential flow at the immediate neighbourhood of the outside boundary. So it is obvious that there is some net tangential drag due to the transfer of the forward momentum across this permeable boundary. Therefore the fluid enters the clearance space with a positive tangential velocity, the so-called slip velocity or velocity slip.

Beavers and Joseph[5] proposed an empirical boundary condition to predict the velocity slip. The validity of this boundary condition has been subsequently established by many investigators both theoretically and experimentally for both incompressible and compressible lubricants. The importance of slip velocity in the analysis and design of porous bearings has been emphasized by the International Research Committee on Lubrication[6]. They have suggested the necessity of recomputing all the earlier data of porous bearings on the basis of velocity slip boundary condition. But there are only a few work available concerning such studies in gas bearings. In most of the available cases, the flow through porous medium has been assumed to be one dimensional, whereas, it is essential to consider the three dimensional flow if the effect of slip is to be incorporated.

The Beavers-Joseph model has been subsequently modified. The modified model neglects the Darcy's velocity component. Another slip model, that considers the velocity slip to be same as Darcy's, is sometimes adopted. Solutions for infinitely long and short and finite self-acting journal bearings, based on modified slip model are available. Theoretical studies on externally pressurized porous gas bearings with slip velocity are mainly concerned with the prediction of static performance characteristics.

ABOUT THE THESIS

The aim of the thesis is to determine theoretically stability of externally pressurized porous gas bearings considering velocity slip at the bearing film interface. Externally pressurized gas bearings exhibit two types of instability, one of pneumatic, self-excited nature called pneumatic hammer or pneumatic instability which is independent of system resonance and one induced by the rotation of the journal is known as whirl instability. Pneumatic instability is encountered even if the runner/journal does not have sliding/rotating velocity. The bearing configurations considered are journal bearings and thrust bearings of rectangular and circular shapes. The pneumatic instability of these bearings have been investigated. Also, for journal bearings the studies have been made to obtain whirl instability by linear and non-linear transient method. The non-linear transient analysis gives the journal centre locus and from this one can know the system stability. In case of thrust bearings, uniform film thickness is very difficult to maintain during actual operation due to off centre loading and/or misalignment during assembly/running. Under such conditions, the runner pad experiences a tilt. Hence in the analysis of thrust bearings the effect of tilt has been taken into account. Pneumatic instability of these bearings has been identified considering three-dimensional flow in the porous matrix. However, the whirl instability has been studied based on conventional adherence velocity condition. Theoretical analysis of pneumatic instability has been carried out through simultaneous solution of flow continuity equation for porous medium and modified Reynolds equation for bearing clearance by applying Gauss-Seidel iteration method using successive over-relaxation (SOR) scheme. But while analysing whirl instability of a porous journal bearing, the pressure distribution has been found out by Newton-Raphson iteration (NRI) method.

In the analysis of pneumatic instability, stiffness and damping coefficients have been calculated from the dynamic pressure distribution. At the threshold of instability, the damping force is zero. This condition is fulfilled by varying the squeeze number. The threshold mass parameter has been obtained from the equation of motion of the rotor/runner using this squeeze number and the corresponding stiffness coefficient.

In linearized approach, a small perturbation of the journal centre (in case of rotating journal) about the line of centres and its perpendicular direction from the equilibrium position is given. Stiffness and damping coefficients are calculated from the resulting differential equations and these coefficients are used to find out the mass parameter (a measure of stability) with the help of the equations of motion of the rotor.

But in case of non-linear transient method, the dynamical equations of motion of the rotor are solved numerically by fourth-order Runge-Kutta method for eccentricity ratio and attitude angle and also for their derivatives. These derivatives are then used in the time dependent Reynolds equation for the calculation of hydrodynamic force components for the next time step. This analysis gives the journal centre locus and from this one can know about the system stability. A bearing is said to be operating under stable condition if the journal locus does not grow with time, whereas a bearing is considered to be unstable if the journal locus grows with time and tends to meet the clearance circle.

The thesis has been divided into seven chapters. Chapter 1 deals with the review of the relevant literature on porous gas bearings. The basic governing equations have been derived in generalized form in Chapter 2.

In Chapter 3, analysis of pneumatic instability of a porous annular thrust bearing was considered. The results for no slip condition, derived as a special case from the present analysis are compared with similar available solutions. Chapter 4 also deals with a similar analysis of a rectangular porous bearing with tilt.

Chapter 5 deals with the study of pneumatic instability of a porous journal bearing. The effect of elastic deformation of the bush on stability parameter has also been studied. It has been observed that this effect is very marginal. The results of no slip condition, derived as a special case from the present analysis, are compared with the existing data.

In Chapter 6, whirl instability of a porous journal bearing was considered. Theoretical analysis has been performed by both linear analysis and non-linear transient method. The present results are compared with the available experimental results.

For the bearing types considered in Chapters 3-6, the effects of bearing design and operating parameters, on the stability parameter have been discussed.

Finally, some important conclusions based on the work presented in the various chapters of the thesis are summarized in Chapter 7. Scope for further work in this area of research is also indicated.

A list of references, computer programmes and appendices are given at the end of the thesis.