Stability Analysis of Journal Bearing Using Electro Rheological Fluid by Finite Element Analysis-Review

Mr. Chintan Vasani[1] Prof. A. T. Thacker[2]
[1]P.G. Student [2]Assistant professor
[1,2]Veerayatan Group of Institute F.O.E &F.O.M, Haripar, Ta-Mandvi

Abstract— in rotating machinery, the damping of structure which supports the rotating shaft has significant effect in machine vibration. Therefore by controlling the lubricant properties, the dynamic behavior of the system can be controlled. The objective of this paper is to study the dynamic behavior of a rotor supported by a journal bearing and fed with Electro-rheological (ER) fluid. ER fluids can be used to create 'smart' journal bearings & vibration controllers can be constructed to control the Stability of the ER fluid lubricated bearings. The ER fluid behaves like a Bingham fluid with a higher viscosity when electric field is applied, and restores its property when the field is removed. A reversible change in viscosity occurs in milliseconds with the electric field applied.

Key words: Journal bearing, Electro-Rheological fluid, Stability Analysis.

I. INTRODUCTION

Rotating machinery, such as machining spindles, industrial turbo machinery, and aircraft gas turbine engines are very commonly used in industry. One major problem faced by these machineries is harmful, imbalance-induced vibration due to imbalance of masses. These vibrations are somehow depends on the damping of structure, which supports the rotating shaft. These vibrations induced in the system can be controlled by controlling the lubricant properties.

The behaviour of many grease lubricants, as well as electro-rheological (ER) and magneto-rheological (MR) fluids [1] proposed as ‘‘smart’’ lubricants, is well described by the Bingham model of non-Newtonian fluid flow. A major difference from the Newtonian fluid flow is that the Bingham model is characterized by two parameters: (a) yield stress and (b) viscosity. When the stress on the lubricant is less than the yield stress, the material is rigid and a region called the ‘‘core’’ is formed; exceeding the yield stress leads to a quasi-Newtonian flow.

Milne [2] examined a journal-bearing model both experimentally and theoretically and concluded that cores are formed near the bearing at the region of maximum film thickness and near the moving shaft at the region of the minimum film thickness. The extent of this core formation depends only on the geometrical condition at the bearing and the dimensionless yield stress. Batra [3] studied only the case of attached cores in a journal bearing, but showed that both floating and attached cores may occur. He found that the load capacity and the moment of friction of the bearing with a Bingham material are larger than that with a Newtonian material.

Wada et al. [4] developed the general theory of a Bingham solid in hydrodynamic lubrication, establishing the core formation and also applied their theory to a step bearing [5]. Their theory finds both a floating rigid core and cores that adhere to surfaces. Hayashi and Wada [6] developed a more general modified Reynolds equation that includes the effects of correlation of shear stresses with the velocity gradients in the circumferential and axial directions. Finally, they applied their theory to a journal bearing and obtained the theoretical core profile formed in the bearing as well as the bearing performance [7]. They also observed the core formation on a bearing made of a transparent material and measured both the pressure distribution and the journal displacements. The experimental results of these works are used in this paper to validate the obtained numerical results for a Bingham material. Experimental results from various types of greases are presented more recently by Mutuli et al. [8].

Tichy [9] obtained different modified Reynolds equations which are dependent on the possible local formation of a rigid core, which may be either attached to the surface or floating between the surfaces. Results are presented for a squeeze film damper and journal bearing. He also mentions that the analysis may be useful to those studying lubrication issues and trying to predict the behavior of electro-rheological fluids (ERFs). Peng [10] studied the hydrodynamic characteristics of a journal bearing with an ER fluid and also used the modified Bingham plastic model to describe the behaviour of the ER fluid.

All of the above investigations are applied to lubricants which behave like a Bingham fluid. However, many commercial lubricants, due to the presence of different types of additives, behave like non-Newtonian fluids which are different from Bingham fluids. The relationship between shear stress and shear strain rate seems to follow the cubic shear stress law [11–13], the power law [14, 15], or the Eyring model [16].

Recently, following the progress in computer technology, many researchers began to use commercial computational fluid dynamics (CFD) programs in their investigations. The main advantage of CFD code is that it uses the full Naiver–Stokes equations and provides a solution to the flow problem, whereas finite difference codes are based on the Reynolds equation. The results obtained by the two approaches are therefore likely to differ. Moreover, the CFD packages are applicable in very complex geometries.

Chen et al. [17] studied the influence of end seal clearance and flow path length on the performance of a circular orbiting squeeze film damper with a central circumferential feed groove, using the CFD package CFX4.2. Ranjan et al. [18] presented a CFD approach, using FLUENT, to model fluid flow in a journal bearing with three equally spaced axial grooves which was supplied with water from one end. They also calculated the stiffness and damping coefficients.

A. Geometrical model

For the present work, the bearing is considered to be rigid, and the flow steady and isothermal. The geometry of the bearing follows the model that is shown in Fig. 1; here, O_b is the bearing centre, O_j the journal centre, R_b the bearing radius, R_j the journal radius, e the bearing eccentricity, φ the attitude angle, and L the bearing length. The external load W is assumed vertical (i.e. along the y-axis) and constant and an Electric field E is applied between rotor and the bearing.

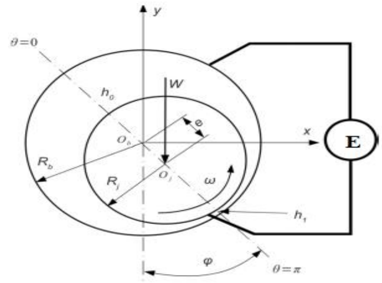

Fig. 1 General geometry and characteristics.

II. GOVERNING EQUATIONS

The viscosity of electro-rheological fluids can be approximated with the Bingham law (Fig. 2a) for yield stress:

$$\tau = \tau_0(E) + \mu\dot{\gamma} \qquad 1.1$$

Where, τ is the shear stress of the material, τ_0 the critical shear stress or yield stress and $\dot{\gamma}$ the shear rate. The relation of the critical shear stress τ_0 with the Electric field intensity E can be estimated by experimental data. For certain electro-rheological fluids this relation is available through manufacturer's literature. It is possible to obtain an equivalent or apparent viscosity:

$$\mu_a = \mu_f + {\tau_0(E)}\Big/\left|\frac{\partial \vec{U}}{\partial y}\right| \qquad 1.2$$

where, μ_a is the apparent viscosity of the material and μ_f is the Newtonian viscosity of the material when the shear stress overcomes the yield stress, in which case the material is flowing. During the electrostatic simulation in ANSYS the Bingham model is defined somewhat differently by a bi-zone viscosity model (Fig. 2b). So for the purposes of the simulation the apparent viscosity is a function of two separate viscosity regions. The first region is the plastic viscosity region where the material exhibits the Bingham solid behaviour. In this region the viscosity takes a high value. This is the Plastic viscosity or μ_p. When the shear stress overcomes the yield threshold, the behaviour of the Bingham material is described with the viscosity of flow or

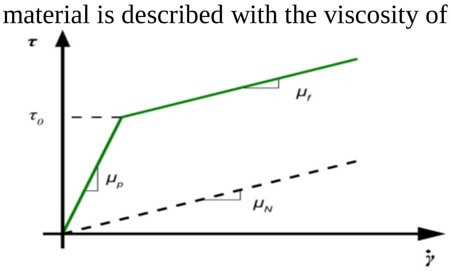

Fig. 2a: The Bingham model.

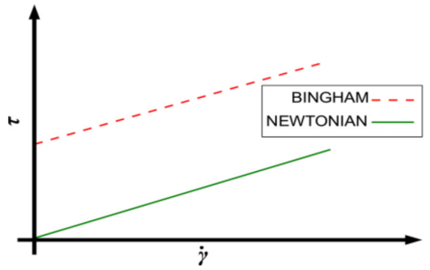

Fig. 2b: The ANSYS bi-zone Bingham model.

Thus the apparent viscosity of the Bingham model in the ANSYS simulation environment is mathematically defined as:

$$\mu = \begin{cases} \mu_f + {\tau_0(E)}/{\dot{\gamma}}, & \dot{\gamma} > \frac{\tau_0(E)}{\mu-\mu_f} \\ \mu_p, & \dot{\gamma} \le \frac{\tau_0(E)}{\mu-\mu_f} \end{cases} \qquad 1.3$$

This work in hand is only the first step in obtaining solution to different problems in the field of electro-rheological fluid lubricated journal bearings, where the Reynolds equation has certain limitations. One of the main assumptions included in Reynolds equation is that the influence of the inertial force is omitted. Thus the use of Reynolds equation is limited when the clearance to diameter ratio becomes larger than a specific threshold. Moreover Naiver–Stokes should be more suitable for high density materials, such as the Bingham Fluids. For example, the density of typical SAE-30 oil is approximately $890 kg/m^3$ whereas the MRF-132DG has a density of $2980 kg/m^3$. Given the magnitude of density for the specific application, Naiver–Stokes equations have been chosen, giving a safe and generic tool for the stability of an electro-rheological bearing.

III. CONCLUSION

In this review article, the governing equations of Bingham fluid for the shear stress as a function of shear rate and viscosity have been studied and the following conclusions were made:

- Reynolds equation has certain limitations for ER fluid lubricated Journal Bearing due to the varying viscosity of fluid.
- Naiver-Stokes equations are more suitable for such a type of lubricant.
- Computational Fluid Dynamics (CFD) code uses the full Naiver-Stokes equations and provides a solution to a flow problems.
- The tribological properties of the Journal bearing, lubricated with ER fluid, can be derived as a function of L/D ratios and varying Electric field using CFD simulation.

REFERENCES

[1] Lord Corporation. Designing with MR fluids, Engineering note <www.lord.com> Rev 12/99.
[2] Milne AA. A theory of rheo-dynamic lubrication. Kolloid Z 1954; 139:96–100.
[3] Batra RL. Rheo-dynamic lubrication of a journal bearing. App. Sci Res 1965; Sec A 15:331–44.
[4] Wada S, Hayashi H, Haga K. Behavior of Bingham solid in hydrodynamic lubrication. Part 1, General theory. Bull JSME 1973; 92(16):422–31.

[5] Wada S, Hayashi H, Haga K. Behavior of Bingham solid in hydrodynamic lubrication. Part 2, application to step bearing. Bull JSME 1973; 92(16):432–40.
[6] Hayashi H, Wada S. Hydrodynamic lubrication of journal bearings by pseudo plastic lubricants considering effects of correlation. Part 3, theoretical analysis. Bull JSME 1974; 109(17):432–40.
[7] Wada S, Hayashi H, Haga K. Behavior of Bingham solid in hydrodynamic lubrication. Part 3, application to journal bearing. Bull JSME 1974; 111(17):1182–91.
[8] Mutuli S, Bonneau D, Frene J. Velocity measurements in the grease lubricating film of a sliding contact. ASLE Trans 1985;29(4):515–22.
[9] Tichy JA. Hydrodynamic lubrication theory for the Bingham plastic flow model. J Rheol 1991; 35(4):477–96.
[10] Peng J, Zhu KQ. Hydrodynamic characteristics of ER journal bearing with external electric field imposed on the contractive part. J Intell Mater Systems Struct 2005(16):493–9.
[11] Swamy STN, Brabhu BS, Rao BVA. Steady state and stability characteristics of a hydrodynamic journal bearing with a non-Newtonian lubricant. Wear 1977;2(42):229–44.
[12] Tayal SP, Sinhasan R, Singh DV. Analysis of hydrodynamic journal bearings with skewed axes using non-Newtonian lubricants. Wear 1982; 3(82): 291–307.
[13] Sharma SC, Jain SC, Sah PL. Effect of non-Newtonian behavior of lubricant and bearing flexibility on the performance of slot entry journal bearings. Tribol Int 2000; 7(33):179–84.
[14] Tayal SP, Sinhasan R, Singh V. Analysis of hydrodynamic journal bearings having non-Newtonian power law lubricants by the finite element method. Wear 1981;1(71):15–27.
[15] Ranghunandana K, Majumdar BC. Stability of journal bearing systems using non-Newtonian lubricants: a non linear transient analysis. Tribol Int 1999; 4(32):179–84.
[16] Tayal SP, Sinhasan R, Singh DV. Analysis of hydrodynamic journal bearings having non-Newtonian lubricants. Tribol Int 1982; 3(25):17–21.
[17] Chen PYP, Hahn EJ. Side clearance effects on squeeze film damper performance. Tribol Int 2000; 3–4(33):161–5.
[18] Ranjan V, Pai R, Hargreaves DJ. Stiffness and damping coefficients of 3-axial grooved water lubricated bearing using perturbation technique. In: Proceedings of fifth EDF & LMS poitiers workshop: bearing behavior under unusual operating conditions. Futuroscope 5 October 2006. p. Q.1–6.