STATIC AND DYNAMIC CHARACTERSTICS OF E.R. FLUID JOURNAL BEARING AND E.R. FLUID SQUEEZE FILM DAMPERS: A COMPARATIVE STUDY.

Dr.B.Rajanesh Kumar
Associate: Professor, Dept: of Mechanical Engineering B.M.S Evening College Of Engineering , Bangalore-19

ABSTRACT

Heavy rotating machinery such as power generator, compressor and pump are generally supported by journal bearings on the basis of rigid foundation support. The journal bearings are used to support radial loads in rotor dynamic machinery. On the other hand, squeeze film damper (SFD) is installed to support the bearing to reduce the vibration amplitude of rotor system by adding damping externally. The present paper investigates the static and dynamic characteristics of a ER fluid squeeze film damper in comparison with ER fluid journal bearing. The comparative study is carried out for various parameters like load capacity, stiffness and damping characteristics of ER fluid journal bearing and ER fluid squeeze film damper. The investigation focuses only on low eccentricity up to 0.2, since most of the lightly loaded bearings run at eccentricity less than 0.2. The type of control scheme required and its effectiveness was used for comparing the dampers in this paper as the control of rotor vibration is essential in rotating machine design.

Keywords: Journal bearing, squeeze film bearing, vibration amplitude, static and dynamic characteristics, Stiffness and damping characteristics.

INTRODUCTION

In many industrial applications, mechanisms such as turbines or pumps are increasingly used under more and more severe conditions, including higher operating speeds, pressures and loads, and as a result, bearing associated problems have become more frequently in high speed rotating machines. This has necessitated the crossing over of the system's critical speed at least once during its operation. In order to limit the amplitudes of the rotor, damping has to be provided externally to the system. This reduces the amplitude considerably and helps in safe operation. **[1, 2, 3]** Thus study of damping characteristics of external dampers becomes an essential part of analysis. Electro-rheological fluid (ERF) is currently used throughout industry as well as being studied in research. The result will lead to improvements and explain why it is significant to devote effort to its study, and how these advancements will make ER fluids more useful in the future.

ELECTRO-RHEOLOGICAL FLUID

Electro-rheological (ER) Fluids are such smart materials whose rheological properties (viscosity, yield stress, shear modulus etc) can be readily controlled using an external electric field. E.R. fluids are the suspensions of fine particles in liquids such as non-conducting oils. When subjected to an electric field, these fluids become a gel-like solid, due to the suspended particles becoming polarized and aligned into chains along the direction of field. Because these chains resist shear along the direction vertical to the field, the liquid reacts like a solid. When the field is removed, the material reverts back to a liquid state within milliseconds. Moreover the degree of gelling is proportional to the strength of the electric field **[4]**. By varying the voltage, any state between liquid and the solid can be quickly selected. In absence of electric field the ER fluid exhibits Newtonian flow where the shear stress is proportional to shear rate. When an electric field is applied a yield stress phenomenon appears and no shearing takes place until the shear exceeds a minimum yield value that increases with the field strength, i.e., the fluid appears to behave like Bingham plastic **[5]** The ER effect was first described by Mr. Willis Winslow in 1949; previously this phenomenon was referred to as the electro-viscous effect. ER fluids require electric field strength in the range tens of kilovolts per millimeter expressed as kV/mm. In Mr. Winslow's initial experimentation he found that 3kV/mm field strength was a sufficient. **[6]** With the advent of new technology namely Nano technology, ER fluids will continue to be explored and implemented.

RESPONSE OF ELECTRO-RHEOLOGICAL FLUID- DIMENSIONAL ANALYSIS MODEL:

The literature review on performance of bearing lubricated with electro-rheological fluid indicated that the strain rate $\dot{\gamma}$ and applied electric field E were the main important parameters which control the response of electro-rheological fluids which in turn affect the performance of bearings. A dimensional approach in the present study was made use for obtaining modeling of electro-rheological fluids. In addition a phenomenon of shear thinning and thickening was also found to influence the behavior of the electro-rheological fluids. The Herschel and Bulkley model which modelled shear thinning was also incorporated in the final model of the theoretical model developed **[7].** Assuming μ_e is largely depends on $\dot{\gamma}$ and E, it is possible to obtain a relation between the viscosity, shear strain rate and the intensity of the applied electric field using Rayleigh's method of dimensional analysis.
Using the equation of the form;

$$\mu_e(E) = K|\dot{\gamma}|^p (E)^q \qquad \text{------ } 1$$

Introducing the corresponding MLT units,

$$ML^{-1}T^{-1} = K\left(T^{-1}\right)^{p}\left(M^{\frac{1}{2}}L^{-\frac{1}{2}}T^{-1}\right)^{q} \quad \text{------ 2}$$

Equating the coefficients of M, L, and T on both sides and simplifying, the values of p and q are;

p = -1, q = 2.

Introducing these values of p and q in equation (1) which simplified to;

$$\mu_e(E) = K|\dot{\gamma}|^{-1}(E)^2 \quad \text{------ 3}$$

This is the change in viscosity due to the applied electric field. In practice the electro-rheological fluids were found to exhibit shear thinning. The shear thinning of electro-rheological fluids was modelled by Herschel-Bulkley and is given as;

$$\mu_e = K|\dot{\gamma}|^{\frac{1}{m}-1} \quad \text{------ 4}$$

Taking into the effect of shear thinning as modelled by Herschel-Bulkley and incorporating in the model developed by the dimensional analysis, the total viscosity μt is given below;

$$\mu_t = K|\dot{\gamma}|^{-1}E^2 + K|\dot{\gamma}|^{\frac{1}{m}-1} \quad \text{------5}$$

Where 'm' in the equation (5) takes the value which is larger compared to unity when shear thinning occurs. When 'm' is large i.e., a case of shear thinning which is practically observed in electro-rheological fluids, then equation (5) can be written as;

$$\mu_t = K|\dot{\gamma}|^{\frac{1}{m}-1}E^2 + K|\dot{\gamma}|^{\frac{1}{m}-1} \quad \text{------6}$$

$$\mu_t = \left[K|\dot{\gamma}|^{\frac{1}{m}-1}\right](1+E^2) \quad - \quad \text{-----7}$$

Equation (7) is applicable for electro-rheological fluids which undergo large degree of shear thinning.

μ_t = μ (E) (1+E2)

where μ (E) = $\left[K|\dot{\gamma}|^{\frac{1}{m}-1}\right]$ -----8

The equation (8) represents the total viscosity estimated by the dimensional analysis and taking into effect of shear thinning of the electro-rheological fluid under the action of the electric field. Total viscosity predicted in (8) is proportional to the square of the electric field intensity and hence the yield stress τy is proportional to E2. .

The numerical values of μ_t can be estimated using μ(0), where μ(0) co –efficient of friction for zero viscosity. Literature review indicated authors quoting the values of μ(0). Sharana Basavaraja etal **[8]** are one such authors who had taken as 1.100x10-7 Pa-s for μ(0) and 0 to 4 Kv/mm as range for applied electric field 'E'. Equation (8) is used to estimate μt taking the values of μ(0) and E. The estimated value of μt (E) is plotted as a function of E and is shown in the figure 1.

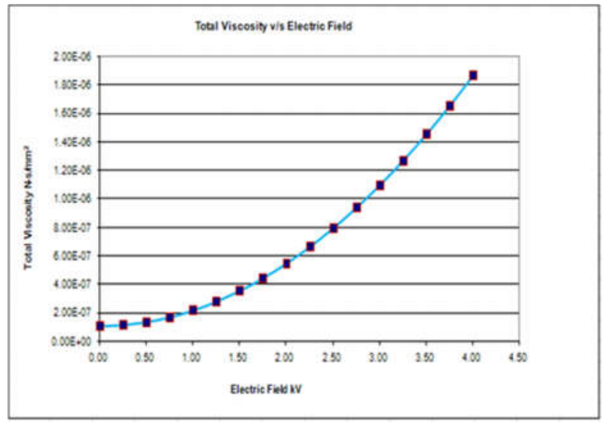

Fig:1. Dependency of total viscosity with electric field

The plot shows that μt is exponential function of applied electric field E. the μt start with a value μ(0) which is 1.100x10-7 Pa-s in the absence of applied electric field. The exponent of E in the function of μt is 2.

JOURNAL BEARINGS:

The performance of a journal bearing lubricated with electro-rheological fluids which was modeled using dimensional analysis is presented. The typical part of a journal bearing is shown in figure (2). The modeling and analysis of rotor-dynamic system using journal bearings, where the dynamic co-efficient (stiffness and damping co-efficient) for the lubricant film were obtained from the Reynolds's equation **[9]**

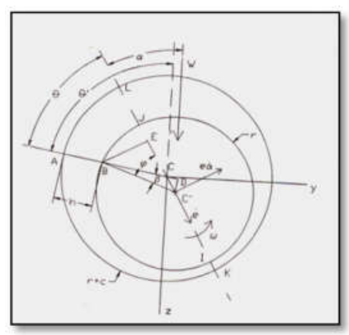

Fig: 2

Static Characteristics of Journal Bearing-Load Carrying Capacity:

The journal bearing configuration and the co-ordinate system used is depicted in Figure 2

Reynolds equation for the fluid flow in the journal bearing is

$$\frac{1}{r^2}\frac{\partial}{\partial\theta'}\left[h^3\frac{\partial p}{\partial\theta'}\right] + h^3\frac{\partial^2 p}{\partial x^2} = 6\mu\omega\frac{\partial h}{\partial\theta'} + 12\mu\frac{\partial h}{\partial t} \quad \text{----- 9}$$

Where h is the film thickness and expressed as a function of c, n, θ, θ', α in the form;

h = c (1 + n cosθ) = c [1 + n cos (θ' -α)]

Rao **[10]** simplified the above equation neglecting $\frac{\partial h}{\partial t}$ comparing with $\frac{\partial h}{\partial \theta'}$ and the modified equation is;

$$\frac{1}{r^2}\frac{\partial}{\partial\theta'}\left[h^3\frac{\partial p}{\partial\theta'}\right]+h^3\frac{\partial^2 p}{\partial x^2}=6\mu\omega\frac{\partial h}{\partial\theta'} \quad \text{------ 10}$$

The static characteristics, load capacity W, for the short bearing approximation for half – Summerfield condition is;

$$W = \frac{\mu(E)(1+E^2)\omega n L^3}{4c^2(1-n^2)}\sqrt{16n^2+\pi^2(1-n^2)} \quad \text{---- 11}$$

Dynamic Characteristics of Journal Bearing:

Stiffness and damping coefficient:

The non-dimensional stiffness and damping characteristics for journal bearing are;

$$\bar{K}_{zz} = f_1(no)\left[9.8696+41.8696\,n_0^2+12.2608\,n_0^4\right]$$

$$\bar{K}_{yz} = f_2(no)\left[-7.75157+15.50314\,n_0^2+4.8148\,n_0^4\right]$$

$$\bar{K}_{zy} = f_2(no)\left[7.75157+32.884314\,n_0^2+9.6296\,n_0^4\right]$$

$$\bar{K}_{yy} = f_3(no)\left[19.7392+6.1304\,n_0^2\right] \quad \text{--12}$$

$$\bar{C}_{zz} = f_2(no)\left[15.50314+44.39195\,n_0^2+15.50314\,n_0^4\right]$$

$$\bar{C}_{yz} = \bar{C}_{zy} = f_3(no)\left[19.7392+7.47842\,n_0^2\right]$$

$$C_{yy} = f_2(n_0)\left[15.50314-9.6296n_0^2-5.87354n_0^4\right] \quad \text{-13}$$

$$f_1(no) = \frac{4}{\left(1-n_0^2\right)\left[16n_0^2+\pi^2\left(1-n_0^2\right)\right]^{.5}}$$

$$f_2(no) = \frac{4}{n_0\sqrt{1-n_0^2}\left[16n_0^2+\pi^2\left(1-n_0^2\right)\right]^{.5}}$$

$$f_3(no) = \frac{4}{\left[16n_0^2+\pi^2\left(1-n_0^2\right)\right]^{.5}}$$

Using these non-dimensional parameters, stiffness and damping coefficient are estimated as follows;

$$K_{zz} = \frac{W}{c}\bar{K}_{zz} \quad \text{------14}$$

$$C_{zz} = \frac{W}{c\omega}\bar{C}_{zz} \quad \text{-----15}$$

RESULT AND DISCUSSION:

The numerical values of load capacity 'w', direct stiffness co-efficient K_{yy}, direct stiffness co-efficient K_{zz}, cross coupled stiffness co-efficient K_{yz}, cross coupled stiffness co-efficient K_{zy}, direct damping co-efficient C_{yy}, direct damping co-efficient C_{zz} and cross coupled damping co-efficient $C_{zy}= C_{yz}$., are estimated using equations 11,14 and 15. The geometrical dimensions used for estimating load capacity, stiffness and damping coefficient of journal bearing are tabulated in table 1.The physical properties of electro-rheological are tabulated in table.2 .The estimated values are plotted as function of applied electric field and shown in figures 3a, 3b, 3c, 3d , 3e , 3f ,3g and 3h .

Table 1
JOURNAL BEARING SPECIFICATIONS:

Description		
Clearence c,mm	0.1	0.2
Length L, mm	30	40
Diameter D, mm	86	86
L/D ratio	0.35	0.46
Excitation Frequency, (ω,rad/s)	105	105
Eccentricity ratio,(n)	0.25,0.5	0.25,0.5

TABLE 2
ELECTRO-RHEOLOGICAL FLUID SPECIFICATIONS:

Type	Manufacturer	Density, Kg/m3	Viscosity Pa-s
Lid 3354	Lord Corporation	1.46X103	1.100x10-7

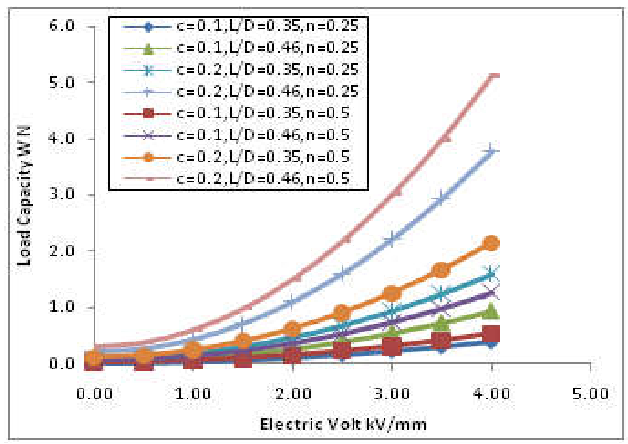

Fig.3a Dependency of load capacity (W) with Electric field (E)

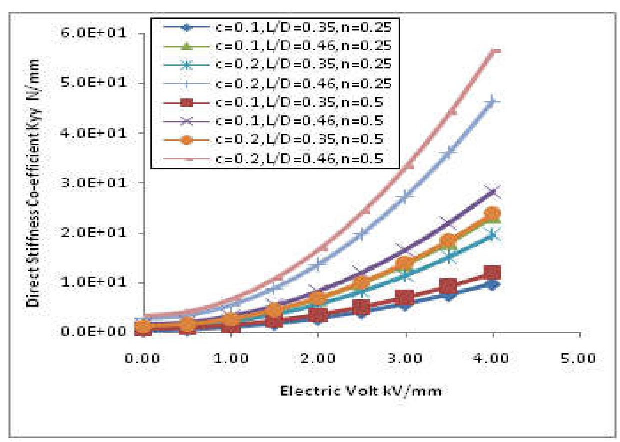

Fig.3b Dependency of direct stiffness co-efficient (K_{yy}) with Electric field

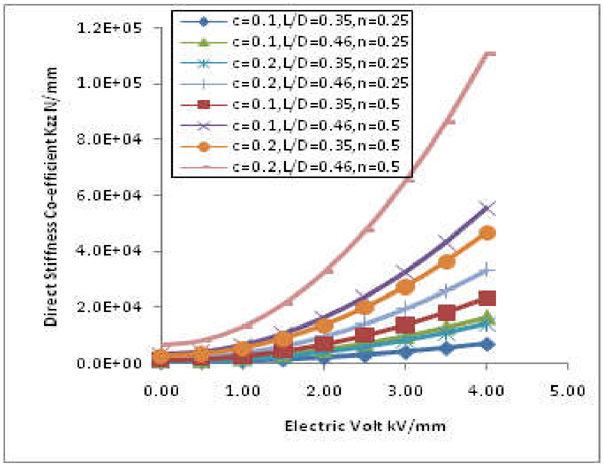

Fig.3c Dependency of direct stiffness co-efficient (K_{zz}) with Electric field (E)

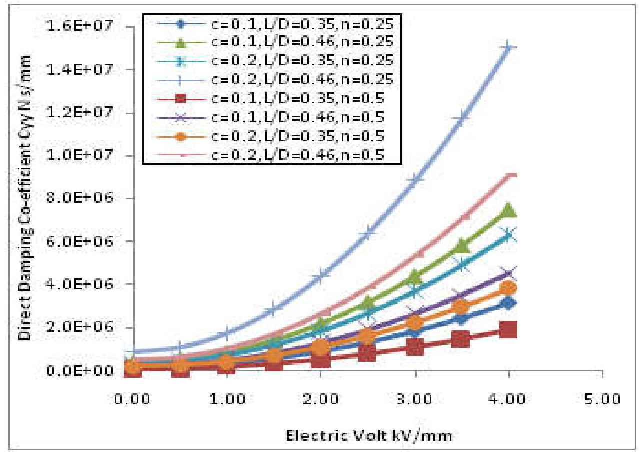

Fig.3f Dependency of Direct Damping Coefficient C_{yy} with Electric field (E)

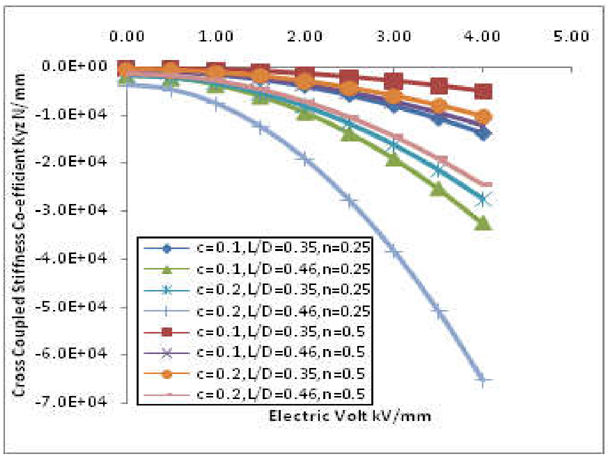

Fig.3d Dependency of Cross Coupled Stiffness Co-efficient K_{yz}. with Electric field (E)

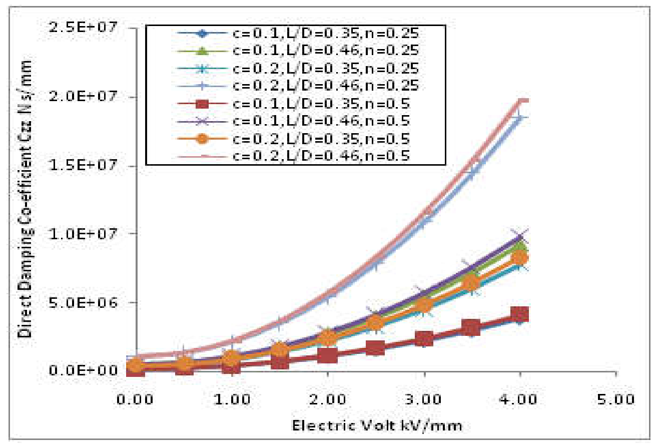

Fig.3g Dependency of Direct Damping Coefficient C_{zz} with Electric field (E)

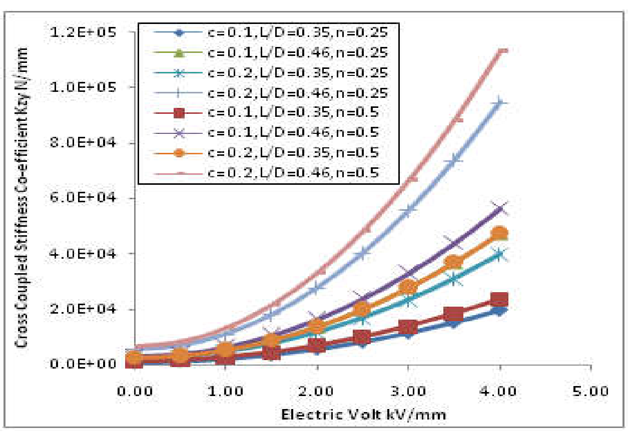

Fig.3e Dependency of Cross Coupled Stiffness Co-efficient K_{zy}. with Electric field (E)

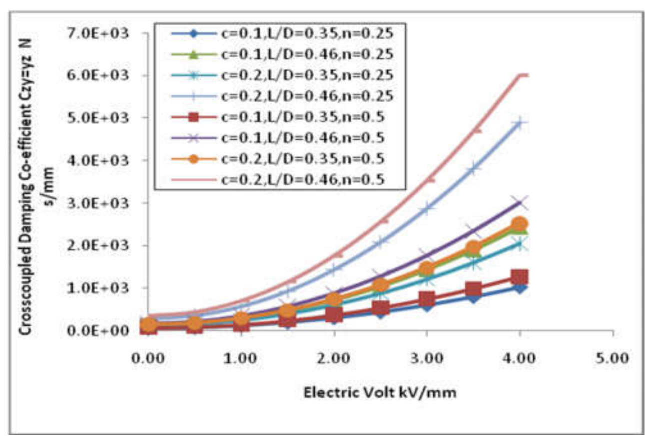

Fig.3h Dependency of Cross Coupled Damping Coefficient $C_{zy}=C_{yz}$ with Electric field (E)

CONCLUSIONS:

The influence of electro-rheological effects, caused by the electric field, on the static characteristics (load capacity), and dynamic characteristics (stiffness and damping) of the journal bearing were studied. The influence of electro-rheological effects, caused by the electric field are not negligible, but they provide enhancement in the load capacity, stiffness and damping co-efficient. The quantitative effects on the load capacity, stiffness and damping co-efficient are more pronounced for journal bearing operating at higher values of eccentricity ratio. The result from this investigations indicate that the cross-coupled stiffness exhibit high asymmetry (one positive and other negative with the same magnitude) under similar clearance, L/D ratio and eccentricity ratio.

REFERENCES

1. Thomsen, K. K., and Andersen, H., 1974 'Experimental Investigation of a Simple Squeeze film Damper' ASME. J. Eng. Ind., 96 No. 2, pp.427-430
2. Satio, S., and Kobayashi, M., 1982, ''On the Vibration of a Rotor Supported by Squeeze Film Damper,'' Trans. Jpn. Soc. Mech. Eng., Ser. C, **48**, No. 436, pp. 1883–1888.
3. Nikolajsen, J. L., and Hoque, M. S., 1988, ''An Electroviscous Damper for Rotor Applications,'' ASME J. Vibr. Acoust., **112**, No. 3, pp. 440–443.
4. Hao, Tian. "Electrorheological Suspensions." Advances in Colloid and Interface Science, v97, n1-3, Mar 29, 2002, p 1-35.
5. Christopher,D And Tichy, J.A. Behavior of Bingham-Like Viscous Fluid In Lubrication Flows, Journal Of Non-Newtonian Fluid Mechanics, 1992, Vol.45, No.2, Pp.291.6
6. Winslow W.M., " Induced Vibration of suspension", Journal of Applied Physics, Vol 20(12), pp.1137-1140, 1949
7. E.Switonski, A.Mezyk, W.Klein, "Application of smart materials in vibration control systems, Journal of achievements in materials and manufacturing engineering ,2007, vol.24, issue 1, pp.291-296 .
8. J Sharana Basavaraja, S.C. Jain and Satish. C.Sharma "A study of smart fluid Lubricated Non- Recessed Hybrid lournal Bearing". International conference on smart materials structure and systems, pp 24-26 july 2008.
9. Majumdar B.C, Introduction to Tribology of Bearings, Wheeler Publishing,NewDelhi,1996.
10. J.S. Rao, Rotor dynamics, New Age International (p) Ltd., III Edition,2006.