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Evaluation of Load Carrying Capacity of Hydrodynamic Journal Bearing with Nanolubricants

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Abstract

In this work, influence of nanolubricants on the load carrying capacity of hydrodynamic journal bearing is studied. Increase in viscosity of lubricant oil with nanopartical as lubricant additives is modeled using different classical model and compared with Kriger-Doughetry viscosity model. This Kriger-Doughetry viscosity model for simulating viscosity of nanolubricant is validated by Experimental verification using reheometer. The pressure distribution and load carrying capacity are theoretically analyzed using Reynolds Equation for Reynolds boundary condition for different concentration of nanoparticles volume fraction. Result reveal increase in pressure and load carrying capacity of Journal bearing withnanolubricants in comparison to base oil.

Keywords—Journal Bearing; Nanolubricants; Pressure Distribution; Load Carrying Capacity

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1. INTRODUICTION

About one third of world's energy resources appear as friction in one form or other and most of these results in waste. It is estimated that about 70% of failures in mechanical components are due to tribological aspects. This shows the importance of tribological study and tribological treatment in industries result in considerable savings.Journal bearings are used as indispensable bearing in many rotating machine such as steam turbine, generator, blowers, compressor, internal combustion engine, Rolling mills and ship propulsion shafts etc. A journal bearing consist of a shaft rotating within a stationary bush. In hydrodynamic lubrication, the load is supported by fluid film pressure which is created due to relative motion of the journal and bearing surfaces [14]. There is quest for improvement in performance of journal bearings [3].Nanotechnology is considered as the revolutionary technology of the 21st century [11]. Recently nanotribology has shown property of reducing friction and wear and better load carrying capacity using nanoparticles as lubricant additives [12].Effect of nanoparticles in Boundary lubrication regime to reduce friction and wear have been found as: first is Primary effect where the nanoparticles in lubricating oil act as ball bearings between the interacting surfaces. Furthermore they also form a protective film over rough interacting surfaces by providing coating over it. The other is the secondary effect where the nanoparticles deposit on the friction surface and loss of mass is filled up by nanoparticles knownas mending effect.

NOMENCLATURE

C	Radial clearance (m)
e	Eccentricity (m)
h	Fluid film thickness (m)
$\bar{h}$	Fluid film thickness in Non Dimensional form $\bar{h} = c(1+\varepsilon\cos\theta)$
L	Bearing length (m)
p	Lubricant fluid film pressure (N/m^2)
$\bar{p}$	Fluid film Pressure in Non Dimensional form $\bar{p} = \frac{pC^2}{\mu_{bl} UR}$
R	Journal Radius (m)
U	Surface Velocity of Journal (m/s)
W	Total Load (N)
$\bar{W}$	Non Dimensional Load Carrying Capacity, $\bar{W} = \frac{WC^2}{\mu_{bl}\omega R^3 L}$
μ_{bl}	Viscosity of base oil (Pa-s)
μ_{nl}	Viscosity of the nanolubricant (Pa-s)
$\bar{\mu}$	Relative Viscosity in Non Dimensional form $\bar{\mu} = \frac{\mu_{nl}}{\mu_{bl}}$
ϕ	Volume fraction of Nanoparticles
ϕ_m	Maximum particle packing fraction
θ	Angular Coordinates (rad)
ω	Angular Velocity of Journal
θ_m	Starting of Cavitations Zone
$[\eta]$	Intrinsic viscosity

Also nanoparticles will act as abrasive and the roughness of the interacting surface is reduced by abrasive effect called a polishing effect [1]. In addition to reducing the friction and wear, nanolubricants also increase the load carrying capacity of lubrication fluid [10].The influence of nanolubricants on boundary lubrication regime is studied well; there is shortage of published work and enough scope of research on hydrodynamic lubrication regime. In this work various classical theoretical models to find viscosity of nanolubricants for various nanoparticle concentrations are evaluated. In this study experimentation is carried out to find the change in lubricant viscosity with various concentrations of TiO_2 nanoparticle as additives. Out of different nanofluid viscosity classical models used, the one which closely resemble the experimental values of viscosities, measured using shear rheometer is considered for evaluation of load carrying capacity of journal bearing. Pressureincrease andimprovement in load carrying capacity of journal bearing considering various volume fraction of TiO_2 nanoparticle is theoretically calculated and compared with the results for base oil.

2. THEORETICAL ANALYSIS

A. Govering Equation

The well known Reynolds equation is used for finding the Pressure distribution in Journal Bearing. Reynolds equation for journal bearing considering Newtonian, laminar, incompressible fluid flow with no slip at boundaries and neglecting fluid inertia and curvature of bearing surfaces with pressure and viscosity assumed to be constant throughout the thickness of the film is expressed as

$$\frac{\partial}{\partial x}\left[h^3\frac{\partial p}{\partial x}\right]+\frac{\partial}{\partial z}\left[h^3\frac{\partial p}{\partial z}\right]=6\mu U\frac{dh}{dx}$$

The nondimensional form of the Reynolds equation is expressed as

$$\frac{\partial}{\partial\theta}\left[\bar{h}^3\frac{\partial\bar{p}}{\partial\theta}\right]+\left(\frac{R^2}{L^2}\right)\frac{\partial}{\partial\bar{z}}\left[\bar{h}^3\frac{\partial\bar{p}}{\partial\bar{z}}\right]=6\bar{\mu}\frac{\partial\bar{h}}{\partial\theta}$$

Where $\bar{\mu}=\frac{\mu_{nl}}{\mu_{bl}}$ is Relative Viscosity in Non Dimensional form, μ_{nl} is the nanolubricant viscosity and μ_{bl} is the viscosity of the oil without nanoparticles additives.

B. Pressure Boundary conditions

Pressure at bearing ends are taken as zero. Positive pressure during calculation is identified and negative pressure is taken as zero. So the following boundary conditions are taken.

$\bar{p}=0$ at $\bar{z}=0,1$

$\bar{p}=0$ at $\theta=0$

$\bar{p}=\frac{\partial\bar{p}}{\partial\theta}=0$ at $\theta=\theta_m$

$\bar{p}=0$ at $\theta_m\le\theta\le 2\pi$

C. Pressure distribution

The pressure around the Journal in Bearing considering long bearing approximation is expressed as

$$p = \frac{6\mu_{bl} R^2 \omega \overline{p}}{C^2},$$

Where, Fluid film Pressure in Non Dimensional form $\overline{p}$ is given by

$$\overline{p} = \frac{\varepsilon \sin\theta \left(2 + \varepsilon \cos\theta\right)^2}{\left(2+\varepsilon^2\right)\left(1+\varepsilon\cos\theta\right)^2}$$

D. Load Carrying capacity

The load carrying capacity of journal bearing is given by

$$W = \frac{12\mu_{bl} R^3 \omega L \overline{W}}{C^2},$$

Where, Load carrying capacity in Non dimensional form $\overline{W}$ is given by

$$\overline{W} = \frac{\pi \varepsilon}{\left(1-\varepsilon^2\right)^{1/2}\left(2+\varepsilon^2\right)}$$

E. Estimation of nanofluid Viscosities

There are certain theoretical formulas used to find the viscosities of nanofluid. Most of such formulas arefound from Einstein model

$$\mu_{nl} = \mu_{bl}(1 + 2.5\phi)$$

Where ϕ is the volumetric concentration of Nanoparticles. Einstein's formula was used up to $\phi \le 0.02$. Brinkman has extended formula for moderate particle concentration as

$$\mu_{nl} = \mu_{bl}\left[\frac{1}{(1-\phi)^{2.5}}\right]$$

Batchelor has extended this formula considering Brownian motion of particles of the fluid

$$\mu_{nl} = \mu_{bl}(1 + 2.5\phi + 6.5\phi^2)$$

Cheng-Law proposed the following model for nanofluid considering spherical shape of nanoparticles

$$\mu_{nl} = \mu_{bl}(1 + 2.5\phi + (2.5\phi)^2 + (2.5\phi)^3 + ...)$$

Kole and Dey (2011) studied the viscosity variation with CuO nanopartical in gear oil. Study found modified version of Kriger-Dougherty model to find viscosities of nanofluid which were in close agreement with experimental result.

$$\bar{\mu} = \left(1 - \frac{\phi}{\phi_m}\right)^{-[\eta]\phi_m}$$

Where, ϕ_m is the maximum partical packing fraction, which is approximately 0.605. $[\eta]$ is the intrinsic viscosity whose typical value specified by Kole and Dey is 2.5.

F. Solution procedure:

Solution of Reynolds equation is carried out using finite difference method to find the distribution of pressure around the journal. The methodology to obtain the pressure distribution was iterative, where first of all; the pressures at all the points were taken as zero. Then obtained pressure from first iteration was taken for calculation of new pressure rather than zero. This cycle continues till the increment in the pressure was the thousandth part of last pressure (i.e. the value of epsilon is taken 1/1000) also that we can obtain the pressure with sufficient accuracy as the computational time is constraint. When the increment in the new pressure is less than thousandth part of the last pressure that procedure stops.

II. EXPERIMENTAL DETAIL

TiO_2 nanoparticles are purchased from Nano Labs, Jharkhand –india. The particles have size of 10-20 nm. Particles are of purity of 99.5% with spherical Crystallographic structure and White color. SAE30 engine oil purchased from local supplier and is used for making the nanolubricant samples for each concentration of nanoparticles. These nanoparticles are mixed in SAE30 engine oil with Mechanical agitation for four hour to breakdown aggregate particles and dispersed them uniformaly. As a surfactant Oleic acid is used in the mixing process to reduce sedimentation. Now Different volume fraction ranging from 0.5 to 2.5 in step of 0.5 is taken to prepare nanofluid sample and tested on Anton par rotational rheometer. Viscosity change is measured from 27 ˚C to 80 ˚C at a shear rate of 10 s^{-1}.

Fig.1 Mechanical Stirring

Fig.2 Anton Paar Reheometer

3. Results and discussion

A. Authors and Affiliations

Fig.3 represents comparison of simulated viscosities of nanofluid with different volume fraction using various viscosity models and compared with experimental viscosity measured by rotational rheometer. Observation from the figure shows that viscosity predicted by Krieger –Dougherty model of viscosity is in close agreement to experimental measured values. Fig 1 also shows that classical model other than Krieger –Dougherty viscosity model has considerably under predicted viscosity variation. So viscosity variation obtained from Krieger –Dougherty viscosity model is used for finding variation in pressure distribution and load carrying capacity.

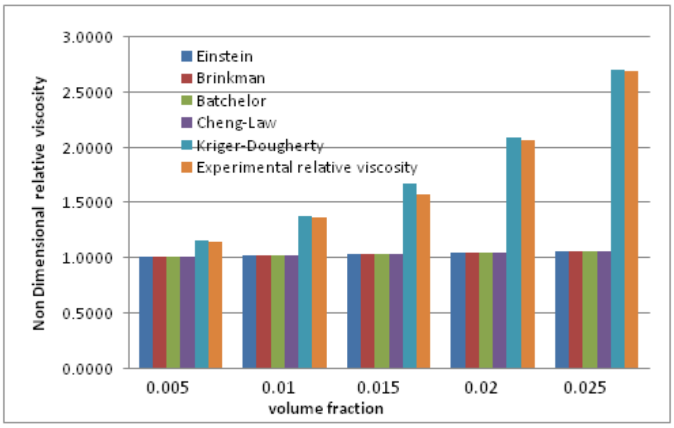

Fig.3 Non Dimensional Relative viscosity for various Volume fraction.

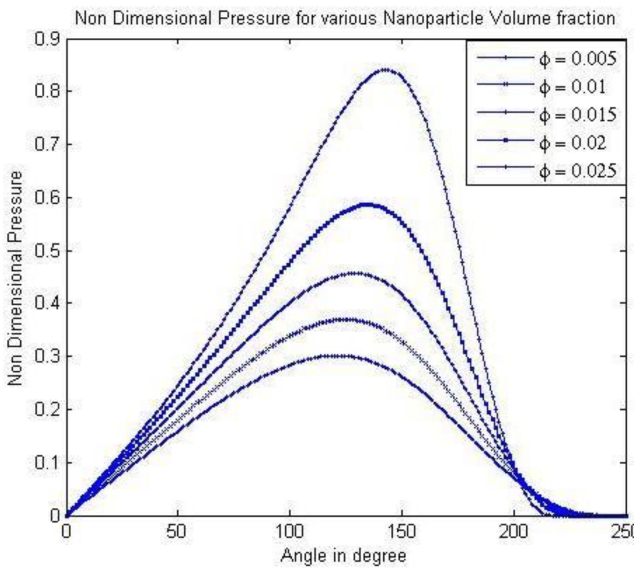

Fig.4 Non Dimensional Pressure Distribution

Fig.4 represents Pressure variation in Non dimensional form with respect to bearing angle for various volume fraction of nanoparticles ranging from 0.5 to 2.5 vol%. Fig.2 reveals fluid film pressure is increasing due to addition of nanoparticle and increment is found more significant at higher volume fraction.

Fig. 5 represents change in load carrying capacity for different eccentricity ratio for various nanoparticleconcentrations. Observation has been made from the figure that addition of nanoparticles as additives increase the load carrying capacity of journal bearing.

Fig.6 represents percentage increase in load carrying capacity for different nanoparticle volume fraction as compared to base oil. Analysis shows that 0.5vol% nanoparticle addition increase load carrying capacity by 18%. Similarly for 1vol% addition shows increment in load carrying capacity by 38% and 1.5 vol% increase it by 65%. A still higher value observed at high volume fraction of nanoparticles.

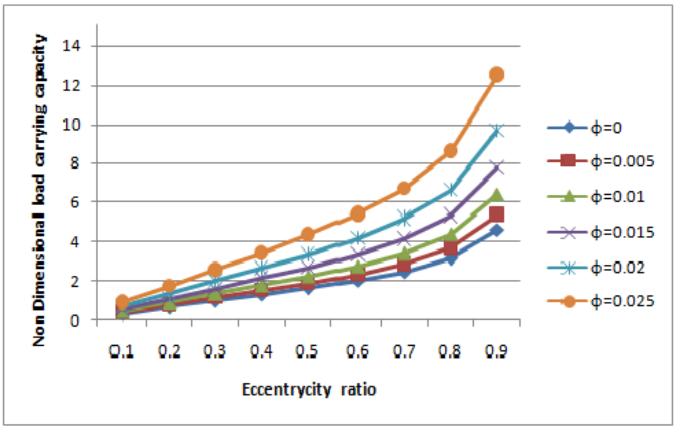

Fig.5 Non Dimensional Load Carrying Capacity

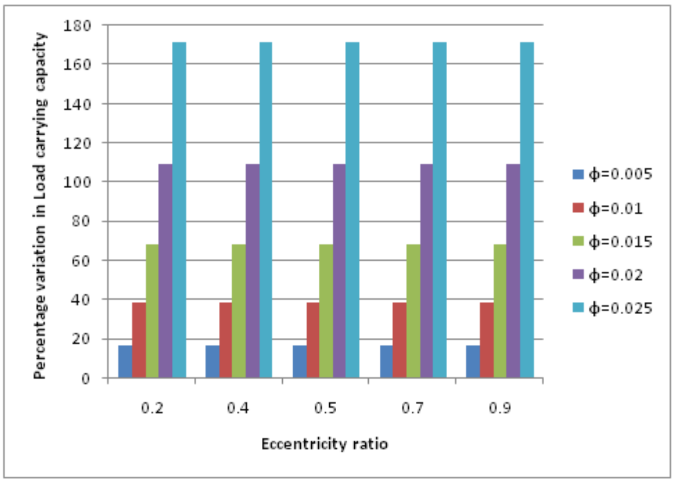

Fig.6 Percentage Variation in Load Carrying Capacity

4. Conclusions

A unique method for finding load carrying capacity of journal bearing with nanolubricants is proposed here. The study
shows the increase in lubricant viscosity due to nanoparticles addition is very accurate by Krieger –Dougherty viscosity model by comparing with experimental results. The effect of change in viscosity due to nanoparticle addition in various concentrations in the range from 0.5 to 2.5vol% on load carrying capacity is evaluated. It has been found that addition of even low volume fraction 1vol% is increases the load carrying capacity by 38%.

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