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Finite Element Analysis of a Journal Bearing Lubricated with Nano lubricants

The oil-film pressure is a key factor used to examine the performance of a journal bearing. The developed nano lubricant was used as an alternate lubricant for journal bearing system described in the present study. For this purpose, oil-film pressure of the journal bearing was analyzed by using COMSOL multi physics and developed the oil-film pressure of the journal bearing lubricated with various lubricants. The COMSOL results stated that, this model is suitable for analyzing the pressure of an oil-film of the journal bearing and these results were compared with experimental results.

Keywords: *Journal bearing, Hydrodynamic lubrication, Finite element analysis, Bio-lubricant, COMSOL multi physics approach.*

1. INTRODUCTION

In general, most of the mechanical systems possess hydrodynamic journal bearings. The performance of the hydrodynamic journal bearing depends on the high load, high speed and higher operating temperature [1]. The load and speed increased the dissipated energy in lubricant oil-film, which modifies the properties of lubricant and the bearing performance [2]. The existing analytical methods for bearing can be characterized by hard methods [3]. The analysis of bearing geometry using numerical method is expensive and requires technical skill. Time and accuracy lack in the fortitude of an overall recital of sliding bearings [4]. Usually, the experimental work carried out by one-factor-at-a-time was applied to estimate bearing characteristics by varying one variable with other parameter is a constant. These methods were difficult, time consuming and infrequently guarantees to determine the optimal conditions [5]. The existing literature considered that the journal bearing pressure was studied by using the one-factor-at-a-time method [6]. Sharma and Pandey [7] investigated pressure profile of finite slider bearing and showed that the experimental values are in good agreement with theoretical results. Ram et al. [8-9] analyzed the hybrid journal bearing with iterative method by using finite element method. Micro polar lubricant showed better performance than Newtonian lubricant as it influences the minimum film thickness effectively. Gertzos et al. [10] carried out the simulation analysis using CFD as a medium. Fluent software was used to solve the equations. Various dimensionless parameters with different L/D ratio resulted for a Bingham lubricant and concluded that Bingham lubricant showed better results than Newtonian lubricant as oil-film pressure, frictional force, and load carrying capacity increased effectively. Hou Yu et al. [11] examined the distribution of pressure in a journal bearing with protuberant foil structure from finite element method and the number of protuberances on the bearing were analyzed. In this sequence, most of the researchers performed experimental studies based on one factor method used to develop the distribution of pressure in a slide journal bearing [12-18]. Furthermore, the above statement led to inappropriate solutions.

The precincts of the above statement could be overpowered by the finite element model. Regarding this solution, the finite element analysis was successfully employed in the numerical modeling of the bearing [19-22]. The objective of the present work is to develop finite element model to envisage the pressure of an oil-film in a journal bearing. The key factors for the present investigation are: load, speed and lubricating oils. The experimental results are compared with the finite element based COMSOL approach.

2. EXPERIMENTAL WORK

2.1 Formulation of Nano lubricants

The bio-lubricant was derived from raw rapeseed oil through chemical modification techniques, in order to improve its oxidative stability and cold flow behavior. The chemical modification procedure was adopted from the research work of Arumugam and Sriram [12]. An anti-wear nano additives such as Copper oxide, Tungsten disulphide and Titanium dioxide of 0.5 wt. % supplied by M/S US Research Nanomaterials Inc., USA were included in chemically modified rapeseed oil to develop its anti-wear behavior. A preparation of the nano lubricant was made by ultrasonic sonicator and 1 wt% of ethylene glycol was used to confirm the homogeneity of mixture [23, 24]. The nano lubricating oil properties are presented in Table 1.

2.2 Journal Bearing Test Rig

Four identical bearings [27] of diameter and length 50 mm and 25 mm respectively were used and Fig.1

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displays the journal bearing test rig (JBTR) [27]. In this study, journal diameter is 49.992 mm and the bearing tolerance is ranges from 40 to 50 µm. A JBTR is used to conduct the experiment with a load range of 10 N to 10 kN. The test sample was fixed in ball bearing housing and the load cell was used to measure the frictional force. The lubricant pump was used to supply the lubricant with required temperature. The linear variable differential transducer (LVDT) sensor was used to measure oil-film pressure of the journal bearing. The experiments were conducted in standard conditions as presented in Table 2.

Table 1. Properties of nano lubricants [25, 26]

Properties	Standard	nano copper oxide in chemically modified rapeseed oil	nano tungsten disulphide in chemically modified rapeseed oil	nano titanium dioxide in chemically modified rapeseed oil
Viscosity @100°C (cSt)	ASTM D445	15.6	15.3	15.1
Viscosity index	ASTM D2270	185	179	170
Specific gravity @ 15°C	ASTM D287	0.89	0.88	0.88
Wear scar diameter (mm)	ASTM D4172	0.35	0.37	0.38
Thickness of an Oil-film (µm)	-	69	63	59

Table 2. Details of Experiments [26]

Parameter	Value
Load	10 kN
Journal speed	3000 rpm
Lubricating oil temperature	75◦C
L/D ratio	1/2
Test duration	5 hr

2.3 Development of a Finite element (COMSOL) Model

Many researchers were concerned with simulation of journal bearing using a one factor at a time method. However, the above said approach led to inappropriate solutions in the simulation of journal bearing. The limitations of the above said approach can be over-powered by finite element approach [28-29]. The solution of a hydrodynamic journal bearing was obtained by using numerical modelling of the finite element analysis (FEA). The developed model was accurate to some extent and required to be established further for nano based lubricants. In that sense, the support of FEA may be valuable for understanding the hydrodynamic journal bearing of any system. A bearing consists of two cylinders, the outer bearing wraps the inner journal. The journal axis is eccentric with the axis of bearing, whereas lubricating oil filled the gap between the bearing and journal. The lubricant is supplied to the journal bearing system through a groove. The journal eccentricity is based on the pressure of an oil-film developed in the bearing. The cavitation was induced in the bearing due to the gases dissolved in the lubricating oil at normal operating condition. This is due to the pressure drop of an oil-film in the lubricating oil below the saturation pressure. The developed model could not consider the cavitation and hence envisages sub-ambient pressures. The Somerfield boundary condition was induced due to the sub-ambient pressure developed by the bearing.

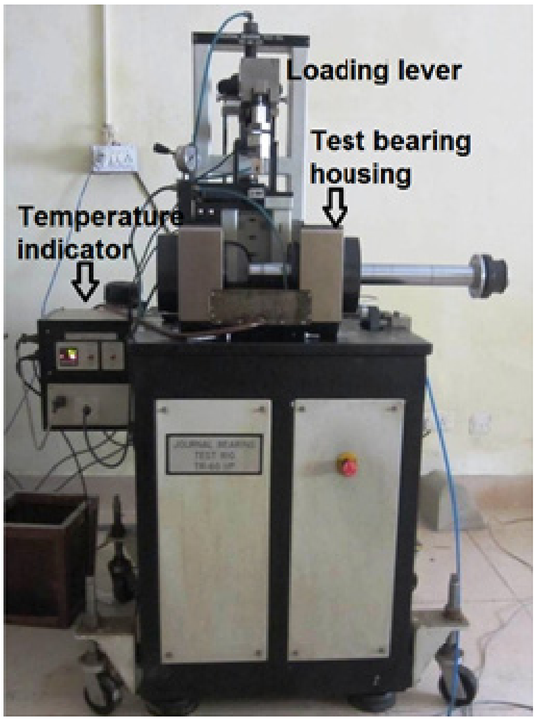


Figure 1. Experimental setup [26]

The FEA based model was developed by using COMSOL multiphysics v4.3b software and the thin film flow CFD model [30] of the journal bearing was used in the present work. The pressure of an oil-film developed in the journal bearing lubricated with nano lubricants, was governed by Reynolds equation. The FEA model was developed based on the following assumptions: a) Flow of lubricant is laminar, b) Lubricant flow is continuous, Newtonian and incompressible, c) In the boundary no traces of fluid slip, d) Considering the velocity components of the X and Z directions and neglecting the velocity component in the Y direction, e) velocity gradients along the thin fluid film in the X and Z directions are small, and velocity gradients across the film are negligible, f) Ignore the curvature effect, g) The variations of pressure in the Y direction are negligibly small, and h) The gravity force on the fluid is neglected. The equation of the hydrodynamic lubrication should be expressed mathematically in the form of the Reynolds equation. This equation is derived from the Navier-Stokes momentum equation and considering the equilibrium of the liquid element, corresponds to viscous shear and the continuity flow principle. For an incompressible fluid with no-slip condition, the Reynolds equation is:

$$\nabla_T\left(\frac{-\rho h^3}{12\eta}\nabla_T p+\frac{\rho h}{2}(V_a+V_b)\right)-\rho((\nabla_T b.V_b)-(\nabla_T a.V_a))=0 \quad (1)$$

The rotating journal is considered to be the solid wall. As the oil-film pressure is constant through the entire lubricant film, COMSOL uses the tangential projection of the gradient operator, ∇_T, to calculate the pressure distribution on the lubricant surface and the term $\rho((\nabla_{Tb} \cdot v_b) - (\nabla_{Ta} \cdot v_a))$ equates to zero, so the simplified governing equation is

$$\nabla_T\left(\frac{-\rho h^3}{12\eta}\nabla_T p+\frac{\rho h}{2}(V_a+V_b)\right)=0 \quad (2)$$

The lubricating oil-film thickness (h) is described in (3),

$$h = c\,\left(1 + \varepsilon\, cos\theta\right) \quad (3)$$

where, radial $c \equiv R_B - R_J$ is the difference between the radius of the bearing and the journal

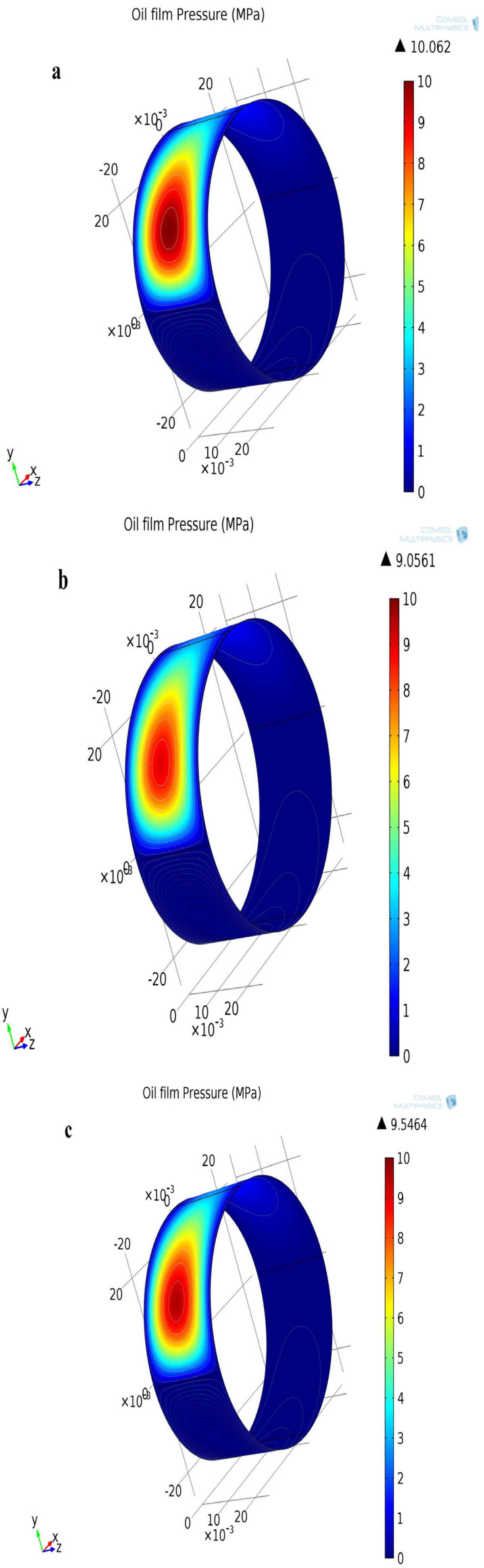
ε = eccentricity

θ = Polar angular coordinate of a point on lubricating oil.

3. RESULTS AND DISCUSSION

3.1 Oil-film pressure analysis

For better performance of a hydrodynamic journal bearing, it is essential to produce minimum oil-film pressure by any lubricant. The pressure of an oil-film of various lubricants at a load of 10 kN and speed of 3000 rpm was analysed by a COMSOL model displayed in Figure 2 (a-d). From Fig. 2 (b) exposed that the minimum pressure of 9.056 MPa was exerted in bearing lubricated with the nano CuO in CMRO. The pressure of an oil-film was 10.062 MPa, 9.546 MPa and 9.804 MPa for SAE20W40, CMRO with nano WS_2 & nano TiO_2 respectively, as shown in Fig. 2 (a, c, & d) for similar working conditions, Table 3 shows the experimental values of oil-film pressure for various lubricants at specified experimental conditions. It is confirmed that the minimum pressure of 9.165 MPa is observed in CMRO with nano CuO. The oil-film pressure was 10.122 MPa, 9.662 MPa and 9.893 MPa for SAE20W40, CMRO with nano WS_2, and nano TiO_2 respectively for similar working conditions. The viscosity of CMRO increases due to the inclusion of nano additives. The viscosity of nano lubricants increases the oil-film thickness and reduces the contact between journal and bearing. The lubricant viscosity was higher, oil-film pressure of lubricant was reduced considerably [31]. The tribo film was formed due to the thin film, which decreases the contact [32-34]. From the experiments, it is confirmed that the oil=film pressure of the nano CuO in CMRO offers the minimum oil-film pressure. The viscosity of nano CuO in CMRO is higher than the SAE20W40, nano WS_2 and nano TiO_2 in CMRO respectively as listed in Table 1. From Table 1, nano CuO in CMRO possessess the high viscosity index (VI) of 185 among the nano WS_2 and nano TiO_2 in CMRO respectively. Further the experimental results were compared with the developed COMSOL multi physics model and indicated that the experimental result is in good agreement with the COMSOL multi physics finite element model.



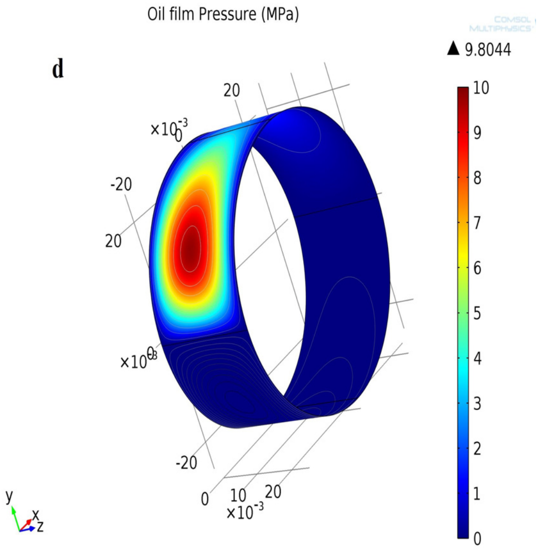


Figure 2. Oil-film pressure from COMSOL model a) SAE 20W40, b) nano copper oxide in CMRO, c) nano tungsten disulphide in CMRO & d) nano titanium dioxide in CMRO.

Table 2. Experimental results

Lubricants	Oil-film Pressure (MPa)
SAE20W40	10.122
CMRO + nano CuO	9.165
CMRO + nano WS2	9.662
CMRO + nano TiO2	9.893

4. CONCLUSIONS

A COMSOL model was used to develop pressure of an oil-film of a bearing with various nano lubricants and the result is:

1. A FEA model results and experimental values are fairly closer and expressed that the COMSOL approach can be successfully utilized to develop oil-film pressure of the bearing lubricated with the nano lubricants.
2. The FEA results of an oil-film pressure are 10.062, 9.056, 9.546 and 9.804 MPa of the journal bearing lubricated with SAE20W40, CMRO with nano CuO, nano WS_2, and nano TiO_2 respectively. The experimental results of an oil-film pressure are 10.122, 9.165, 9.662 and 9.893 MPa respectively of the journal bearing lubricated with SAE20W40, CMRO with nano CuO, nano WS_2, and nano TiO_2 respectively.
3. Out of all lubricants considered, oil-film pressure is minimum and VI is maximum in CMRO with nano CuO.

Overall, this study provides the suitable method to identify the proper lubricant for the journal bearing system without conducting the experiments. The present study is used to suggest this method and minimizing the experimental cost for a journal bearing system.

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NOMENCLATURE

ρ	density in kg/m^3
h	oil-film thickness in m
η	viscosity in Pa• S
p	pressure of an oil-film in Pa
a	channel base location in m
V_a	tangential velocity of the channel base in m/s
b	solid wall location in m
V_b	tangential velocity of the solid wall (journal) in m/s

ПРИМЕНА АНАЛИЗЕ КОНАЧНИХ ЕЛЕМЕНАТА КОД РАДИЈАЛНОГ ЛЕЖАЈА ПОДМАЗИВАНОГ НАНО МАЗИВИМА

Рамаганеш Р, Баскар С., Срирам Г., Арумугам С., Рамачандран М.

Притисак уљаног филма је кључни фактор у испитивању перформанси радијалног лежаја. Развили смо нано мазиво које је коришћено као алтернативно мазиво за подмазивање система радијалног лежаја приказаног у овом раду. Анализа притиска уљаног филма је извршена помоћу софтвера COMSOL. Такође је анализиран притисак уљаног филма код радијалног лежаја подмазиваног другим врстама мазива. Резултати примене наведеног

софтвера показују да је овај модел погодан за анализу притиска уљаног филма код радијалног лежаја. Добијени резултати су упоређени са експерименталним резултатима.