A STUDY OF Al_2O_3 NANOPARTICLE EFFECT ON LUBRICANT TO HYDRODYNAMIC JOURNAL BEARING

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ABSTRACT

Adding adaptive in general and nanoparticles in detail to lubricated oil will result in changing lubricated properties of oil and hydrodynamic pressure profile, load capacity of hydrodynamic journal bearing. The Al_2O_3 nanopowder (particle size is about 80 nm in diameter) was dispersed into lubricated oil (BP Vistra 300 - supplied by Vietnam National Petroleum Corporation) with different Al_2O_3 nanoparticle concentrations. Hydrodynamic pressure profile of Al_2O_3 nanoparticle added lubricant in hydrodynamic journal bearing has been extensively studied. The experimental results indicated that Al_2O_3 nanoparticle has made significant changing in hydrodynamic pressure profile of hydrodynamic bearing, which results in significant increment in load capacity of the bearing. It also demonstrated that the changing is a function of Al_2O_3 nanoparticle concentration.

KEYWORDS: Nanoparticle, Aluminum Oxide Nanoparticle, Lubricated Properties of Oil, Hydrodynamic Pressure Profile & Nanoparticle Added Lubricant

Original Article

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1. INTRODUCTION

Hydrodynamic journal bearings are typical energy transmission components that carry high loads in large rotating machinery [1, 2]. Friction and wear are unavoidable in hydrodynamic journal bearing but can depend on hydrodynamic pressure profile. Adding nanoparticles to lubricated oil will result in changing lubricated properties of oil and hydrodynamic pressure profile, load capacity of hydrodynamic journal bearing [3-8]. The contribution made to the hydrodynamic pressure from the convergent wedge actions are based on solution of Reynolds equation in two-dimensions by [9, 10]:

$$\frac{\partial}{\partial x} \left\{ h^3 \frac{\partial p}{\partial x} \right\} + \frac{\partial}{\partial y} \left\{ h^3 \frac{\partial p}{\partial y} \right\} = 12\eta \bar{U} \frac{dh}{dx} \quad (1)$$

Where:

$\bar{U} = U/2$ - entraining velocity;

h -The film thickness;

p -the pressure of fluid;

η -The viscosity

If the bearing is very long in Y-direction, it can be considered as infinite length, then there is no axial flow q_y or pressure gradient $\frac{\partial p}{\partial y}$. In such a case equation (1) will become

$$\frac{\partial}{\partial x} \left\{ h^3 \frac{\partial p}{\partial x} \right\} = 12\eta \bar{U} \frac{dh}{dx} \quad (2)$$

Which can be integrated directly to give

$$\frac{dp}{dx} = 12\eta \bar{U} \frac{h - \bar{h}}{h^3} \quad (3)$$

Where

$\bar{h}$ – The value of the film thickness at which the pressure gradient become zero

The equation (3) is the well known Reynolds equation in simple one- dimension. The geometry of hydrodynamic journal bearing is shown in figure 1. C is the centre of journal and O the centre of bush or bearing; ε is the clearance or difference in radius between the journal and the bearing which is here shown very greatly exaggerated-in practice it is typically less than 1% of the bearing radius. The shaft carries a load W and rotates with speed ω . Bolt the bearing is supplied with a viscous lubricant η and the speed of the journal is sufficient for hydrodynamic activity to be initiated. The minimum gap between the solid surfaces $h_{\min}$ is then given by:

$$h_{\min} = c - e = c(1 - \varepsilon) \quad (4)$$

The gap h will be related to the circumferential position θ by the equation:

$$h = c(1 + \varepsilon \cos \theta) \quad (5)$$

Where θ is the angular position counted from the position of maximum film thickness to current position. The line OC and the load vector will not be collinear and the angle ψ between them is known as the attitude angle.

An important geometric parameter in the behaviour of journal bearings is ratio of the bearing length to its diameter, L/D. In practice this ratio varies from 1/4 in narrowest of journals to 2. If L/D=1 then Journal bearing is a “square” bearing.

Figure 1: Plain Journal Bearing with Hydrodynamic Load Support.

The axial position coordinate y , is measured the central section of bearing. We have parabolic pressure distribution, namely

$$p = \frac{12\eta}{h^3} \frac{dh}{dx} \bar{U} \left\{ y^2 - \frac{L^2}{4} \right\} \quad (6)$$

Provided that y , the axial position coordinate, is measured from the central section of the bearing.. Combining this equation with (2) we can write that the pressure distribution around the bearing is given by

$$p = \frac{3\pi\omega\epsilon \sin \theta}{c^2 (1 + \epsilon \cos \theta)^2} \left\{ \frac{L^2}{4} - y^2 \right\} \quad (7)$$

where:

$$\bar{U} = \frac{R\omega}{2},$$

$$x = R\theta,$$

$$\frac{dh}{dx} = -\frac{c\epsilon}{R \sin \theta},$$

The magnitude of load W on the journal is defined by adopting from the half-Sommerfeld boundary conditions, by setting the film pressure equal to zero at value of θ between π and 2π , the range over which they would otherwise be negative, in this case, by the expression [9, 10]

$$W = \frac{\eta R \omega L^3}{4c^2} \frac{\pi\epsilon}{(1 - \epsilon^2)^2} (1 + 0.62\epsilon^2)^{\frac{1}{2}} \quad (8)$$

Defining a non-dimensional load W^*

$$W^* = \frac{W/L}{\eta R \omega} \left(\frac{c}{R} \right)^2 \quad (9)$$

Nanoparticle has been widely used and those applications have gained significant benefits. Nanoparticle has been being studied to improve the application potential of nanoparticle such as increase strength of composite materials, reinforce materials etc. [4, 5, 7, 11]. Aluminium oxide is a light, hard and wear-resistant material; it also is a good thermal conductivity, high strength and stiffness material. Aluminium strongly resists acid and alkali attack at elevated temperatures. Nanoparticle has been believed that significant improves lubricative properties of nanoparticle added oil [4-7]. However, its application capability is strongly depended on how homogeneously that nanoparticle could be dispersed into oil. Many dispersing techniques had been proposed to get uniformly dispersion nanoparticle in substrate [8, 12-15]. The most common dispersing technique that often used is ultrasonic sonication bath, ultrasonic probe dispersing, ultrasonic cavitation and ultrasonic resonance vibration dispersal techniques [8, 16-19]. In which, ultrasonic resonance vibration dispersal technique is a powerful dispersing technique for uniformly dispersing nanopowder into colloid [17, 18].

In this study, Al_2O_3 nanoparticle in form of nanopowder with size of 80 nm in diameter has been dispersed homogeneously into lubricant oil by ultrasonic resonance vibration dispersal (URVD) [17]. Then hydrodynamic pressure profile of Al_2O_3 nanoparticle added lubricant in hydrodynamic journal bearing has been extensively studied and their performance was evaluated and compared with studies of non-nanoparticle added lubricant.

2. EXPERIMENTAL PROCEDURE

2.1 Experimental Setup

A typical hydrodynamic journal bearing system compensated with pressure distribution measurement connected PC is shown in Figure. 2. Hydrodynamic pressure profile of the journal bearing in this study was measured at the middle of bearing and step by step around the bearing (360°) for lubricated oil and Al_2O_3 nanopowder added to lubricated oil with changing speed ω and W . The cross section of this journal bearing is shown in figure 3.

1-DC motor, 2-Coupling, 3-Lead-worm, 4-Shaft, 5&8-Ball bearing, 6-Belt
7-AC Motor, 9-System base, 10&12- Encoder, 11-Pressure tachometer,
13- Controller, 14- Computer, 15- Oil tank

Figure 2: Schematic of Hydrodynamic Journal Bearing System.

Figure 3: Journal Bearing Configuration.

The bearing (figure 3) is supplied with a viscous lubricant and is supported an external load W as shown in figure 2. The journal (4) is rotated with angular speed ω by a motor (7). The bearing and worm can be rotated around its center with a small angular velocity by a DC motor. In order to measure pressure of lubricant in side the hydrodynamic journal bearing, a small hole is made on the bearing, which is connected to pressure measuring system. During the experiment procedure, the bearing is very slowly rotated around the shaft to take out the pressure signal around the circumference of the bearing. The pressure signal is recorded respectively to form the hydrodynamic pressure profile of hydrodynamic journal bearing.

2.2 Materials Preparation

The bearing in this system was made of copper alloy BpOC 6-6-3 and journal was made of steel 1045, with the dimension are 24mm in length, 24mm in diameter and central different is 0.036. Lubricated oil is a mixture of BP Vistra 300-supplied by Vietnam National Petroleum Corporation and Al_2O_3 nanopowder with the size is about 80 nm in diameter. The structure of nanoparticle is shown in figure 4.

Figure 4: Nanograph of Al_2O_3 Nanoparticle.

Figure 4 is SEM image of Al_2O_3 nanoparticle, the image indicates that the size of Al_2O_3 is around 80nm in diameter. The lubrication properties of oil BP Vistra 300-4T (Oil grade SAE 20W-50): Kinematics viscosity (cS):16.5-18.5 at 100°C , Viscosity index: 112, ASTM-D92: minimum 200°C , ASTM-D2896: minimum: 6.5, ASTM-D892maximum 50/0 ml/ml, ASTM-D4951minimum:0.25%w, ASTM-D95: maximum: 0.05%v.

3. RESULTS AND DISCUSSIONS

Testing machine is implemented under the load of 300,500 and 800 N, angular velocity is 94, 141 and 214 rad/s, lubrication oil is BP Vistra 300-4T and Al_2O_3 nanoparticle concentration is (1gram/litre) at temperature of $50^\circ\text{C} \sim 65^\circ\text{C}$. The hydrodynamic pressure at the middle length of hydrodynamic bearing using original BP Vistra 300-4T oil at different angle speeds and different loads are show in table 1. From these results, profiles of hydrodynamic pressures of the bearing have been drawn. The figure 5, figure 6 and figure 7 are hydrodynamic pressure of bearing with different loads (300, 500 and 800N) and different speed 94 rad/s, 141 rad/s and 241 rad/s respectively.

Table 1: Measurement Pressure around Bearing with non Nanopowder added Lubrication Oil (psi)

Angle (deg)	$\omega=94/\text{s}$			$\omega=141/\text{s}$			$\omega=214/\text{s}$		
	W=300N	W=500N	W=800N	W=300N	W=500N	W=800N	W=300N	W=500N	W=800N
120	0	0	0	0	7	8	0	0	0
130	2	3	5	6	12	14	8	12	13
140	8	8	11	11	18	23	13	20	25
150	16	18	21	22	32	35	25	35	40
160	25	30	33	36	45	50	42	52	60
170	48	50	60	56	77	82	62	85	90
180	50	55	62	71	90	96	87	110	115
185	21	33	40	80	100	111	104	128	140
190	14	18	20	50	80	100	80	105	140
195	7	13	13	30	52	70	40	45	95
200	0	2	2	8	15	16	2	3	3
210	0	0	0	3	3	4	0	0	0
220	0	0	0	0	7	8	0	0	0

Figure 5: Hydrodynamic Pressure of Bearing at Speed of 94 Rad/s.

Figure 6: Hydrodynamic Pressure of Bearing at Speed of 141 rad/s.

Figure 7: Hydrodynamic Pressure of Bearing at Speed of 241 rad/s.

When BP Vistra 300-4T oil was added Al_2O_3 nanopowder, hydrodynamic pressure of the bearing at those different speeds and loads are measured and shown on table 2

Table 2: Measurement Pressure around Bearing with Al_2O_3 Nanopowder added Oil (psi)

Angle α (deg)	$\omega=94/s$			$\omega=141/s$			$\omega=214/s$		
	W=300N	W=500N	W=800N	W=300N	W=500N	W=800N	W=300N	W=500N	W=800N
120	0	0	0	0	2	3	0	3	4
130	0	0	2	0	3	5	0	5	8
140	2	3	4	2	5	10	3	7	15
150	2	5	9	3	9	17	4	9	24
160	4	8	13	4	13	25	7	12	35
170	5	10	19	6	19	39	9	19	43
180	9	16	27	10	25	50	12	25	56
185	11	18	32	13	29	59	16	29	64
190	13	21	35	16	32	63	19	34	67
195	13	22	36	17	32	64	20	36	70
200	13	21	35	16	30	60	20	35	70
210	9	16	25	12	25	40	15	26	56
220	6	9	18	9	17	24	9	18	29
230	3	4	8	4	6	10	5	7	15
240	0	0	2	0	2	3	2	3	4

Then profile of hydrodynamic pressure of this hydrodynamic journal bearing has been carried out respectively and shown on the figure 8, figure 9 and figure 10 respectively.

Figure 8: Hydrodynamic Pressure of the Bearing with Al_2O_3 Nanoparticle added Oil at Speed of 94 Rad/s.

Figure 9: Hydrodynamic Pressure of the Bearing with Al_2O_3 Nanoparticle added Oil at Speed of 141 Rad/s.

Figure 10: Hydrodynamic Pressure of the Bearing with Al_2O_3 Nanoparticle added Oil at Speed of 241 Rad/s.

It is also clear from table 1, 2 and figures of hydrodynamic pressure profile that maximum pressure generally decreased about 40% to 50% but boundary angle of hydrodynamic pressure around bearing increased about 30% when BP Vistra 300-4T oil was added Al_2O_3 nanopowder. In this case, it was supposed that the journal can be supported by both hydrodynamic pressure of wedge oil and Al_2O_3 nanoparticles with size is about 80nm which rolling in the oil film. In other words, Al_2O_3 nanoparticle acting like nano-roller that share load with hydrodynamic pressure in hydrodynamic bearing (figure 11). This causes a lowering of hydrodynamic pressure in the case of Al_2O_3 added oil.

These results consistent with behavior of hydrodynamic pressure profile of the oil grade SAE 20W-50 especially oil added Al_2O_3 nanopowder. Because oil grade SAE 20W-50 added Al_2O_3 nanopowder has given lower hydrodynamic pressure profile for different speeds and load, therefore temperature of oil will be lower and life time of lubricant will be longer.

Figure 11: Nano-Roller in Contact Area of Hydrodynamic Bearing.

4. CONCLUSIONS

Based on the results of this study, the following conclusion could be drawn:

A direct proportionally was not found between hydrodynamic pressure profile and viscosity due to the complexity of Lubricated Oil added Al_2O_3 nanopowder.

Hydrodynamic pressure profile of hydrodynamic bearing changing depends on speed, load and added Al_2O_3 nanopowder.

Al_2O_3 played a role like a roller inside the bearing which shared the load of the shaft with hydrodynamic pressure.

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