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EFFECT OF ADDITIVE VOLUME FRACTION ON A FLUID FILM PRESSURE AND LOAD OF HYDRODYNAMIC JOURNAL BEARING USING FERROMAGNETIC FLUID

M. A. Omer and T. V. V. L. N. Rao
Department of Mechanical Engineering, Universiti Teknologi Petronas, Bandar Seri Iskandar Darul Ridzuan, Malaysia
E-Mail: elifdrar10708@gmail.com

ABSTRACT

The fundamental objective of this work is to investigate the performance of Ferrolubricants under a combined effect of magnetization and fluid behaviours. Two types of fluid models were investigated for further improvement of hydrodynamic journal bearing performance. Lubrication of finite hydrodynamic journal bearing lubricated by ferromagnetic fluids under the influence of Power-law and Couple-stress fluid models. By taking into account additives' volume fraction, magnetization effect by the magnetic coefficient and fluid models (Power-law and Couple-stress) due to the microstructure additives. The fundamental approach involves a general modified form of Reynolds equation. The results showed an increase of pressure distribution within the fluid film whereby load carrying capacity of the hydrodynamic journal bearing improved.

Keywords: journal bearings, lubricant additives, volume fraction, ferromagnetic fluids, power-law and couple-stress fluid models.

INTRODUCTION

All Ferrofluids categorized as non-Newtonian fluid with high magnetic character that mainly comprises of three elements such as, main carrier fluid, ferromagnetic suspensions and a coating in each particle. Ferrolubricants can be adjusted and placed precisely where wear would be anticipated, such unique controllability can be carried out remotely by imposed magnetic field or external magnetic forces. Application of Ferrofluids are seen in medicine, whereby locating a cancer gland by magnetic resonance.

Ferrofluid does not exist as simple fluid, however, the science of Ferrofluids explains it as a blend of stable colloidal suspension of micro or nanoparticles of ferromagnetic additives to the main lubricant such as water or oil, usually, the blend stability achieved by adding certain surfactant polymers in the standard base fluid example Oleic Acid [1-3]. At time of magnetic field induction to the ferromagnetic fluid, each Ferrofluid particle experiences a force which dependent on the magnetization of the magnetic materials of the tiny particles and on the intensity and position of the imposed magnetic field [4]. Recently a numerous researches have been carried out on the field of ferrolubricants, and many of them [5], have presented Ferrofluids as having extraordinary lubricating behaviour that highly contributes to the improvement of load carrying capacity of journal bearing and minimizes friction generation.

Osman *et al.* [3, 6-9] have examined the effectiveness of Ferrofluid lubricants on the journal bearing operational characteristics. They have obtained a generalized modified form of Reynolds equation. They have concluded that increasing the Power-law index (n) and the Couple-stress parameter (ℓ) together with the magnetic field, leads to improved performance of journal bearing operational characteristics. It also showed an increase on the load carrying capacity of journal bearing and reduction on the coefficient of friction.

However, all above discussed works have not mention about the quantity of volume of additives used, nor the viscosity ratio between the main lubricant and the additives. Hence, the present work fundamental objective is to investigate the influence of ferromagnetic fluid additives blended within the base lubricant for the improvement of the hydrodynamic journal bearing performance taking in account of the volume fraction of additives and viscosity ratio in respect of the main fluid lubricant. The fundamental approach involves a general modified form of Reynolds equation. The modified Reynolds equation accounts for the volume fraction and viscosity effects of ferromagnetic fluid additive and base lubricant considering the Power-law and Couple-stress fluid models, used to simulate the Non-Newtonian behaviour by blending the base lubricant with ferromagnetic fluid additives. A modified Reynolds equation generated and presented for the Power-law and Couple-stress model. The effects of the non-Newtonian fluid behaviour of Ferrofluids on bearing performance characteristics such as pressure distribution and load-carrying capacity are analysed.

METHODOLOGY

To modify the base lubricant's viscosity, additive volume fraction v_2 is added. Therefore, the viscosity of the mixture lubricant expressed as [10];

$$\mu = \mu_1 v_1 + \mu_2 v_2 \tag{1}$$

- Where μ_1 and μ_2 are the viscosities of the base lubricant and the additive respectively, v_1 and v_2 are the corresponding volume fraction. ($v_1 + v_2 = 1$).
- $$\mu = (1 - v_2) * \mu_1 + \mu_2 v_2 \tag{2}$$
- The dimensionless form of equation (3) represented as,

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- $$\frac{\mu}{\mu_1} = 1 + \nu_2\left(\frac{\mu_2}{\mu_1} - 1\right) \tag{3}$$
- The dimensionless mean film pressure p,

$$P = \frac{p}{\mu_1 \omega^n}\left(\frac{C}{R}\right)^{n+1} \tag{4}$$

- The non-dimensional modified Reynolds equation with an approximation of a short journal bearing purpose, $\lambda < 1$ while emitting the circumferential variation in pressure,
- $$\frac{\partial}{\partial z}\left(G\frac{\partial p}{\partial z}\right) = 24\lambda^2\frac{\partial H}{\partial \theta} \tag{5}$$
- $$H = 1 + \varepsilon\cos\theta \tag{6}$$

Boundary conditions for P and Z

$$P = 0 \text{ At } Z = \pm 0.5 \tag{7}$$

$$\frac{dP}{dZ} = 0 \text{ At } Z = 0 \tag{8}$$

Integrating equation (5) at the boundary conditions of equation (7) and (8), the modified non-dimensional mean film pressure expressed as;

$$P = -12 * \lambda^2 * \varepsilon * \left(1 + v_2\left(\frac{\mu_2}{\mu_1} - 1\right)\right) * \sin(\theta)$$
$$* \frac{1}{G} * \left(Z^2 - \frac{1}{4}\right) + \frac{\gamma K}{2} \tag{9}$$

Power-law fluid model

The Power-law rheological model is used to simulate the non-Newtonian behavior of the lubricant. The term G in equation (9) is expressed as;

$$G = \frac{1}{H^{n+2}} \tag{10}$$

The non-Newtonian characteristics based on the Power-law model are mainly affected by the flow behaviour index (n). At n = 1, the fluid shows Newtonian behaviour.

Couple-stress fluid model

Couple-stresses could be expected to appear in noticeable magnitudes in lubricants containing additives with large molecules. The continuity and momentum equations governing the motion of Couple-stress fluids. Hence, the modified form of Reynolds equation based on a Couple-stress fluid model would include the following Couple-stress parameter:

$$G(\ell, h) = h^3 - 12\ell^2 h + 24\ell^3 \tanh\left(h/2\ell\right) \tag{11}$$

Where, the Couple-stress parameter ℓ is expressed as;

$$\ell = \left(\eta/\mu\right)^{\frac{1}{2}} \tag{12}$$

RESULTS AND DISCUSSION

This work was mainly carried out to study the dimensionless pressure distribution P and load carrying capacity W in hydrodynamic journal bearing for two different lubricant fluid models. Power-law lubricant fluid model and Couple-stress model. Both fluid models were investigated under two different ferromagnetism effect. The non-ferromagnetism lubricant case γ=0 and the ferromagnetism lubricant case γ=0.5 [11]. Besides the lubricant fluid models and ferromagnetism cases, a further investigation was introduced as lubricant additive volume fraction. The volume fraction v_2 is the ratio of lubricant additive mixed to the main lubricant binder.

In the first case, Power-law lubricant fluid model, with a Power-law index n of 0.7, 1.0 and 1.3 were utilized and generated the following first four figures.

Figure-1 presents the relationship between dimensionless pressure distributions P and Z-coordinate of hydrodynamic journal bearing under a combined effect of lubricant additive volume fraction v_2 and ferromagnetic coefficient γ were generated.

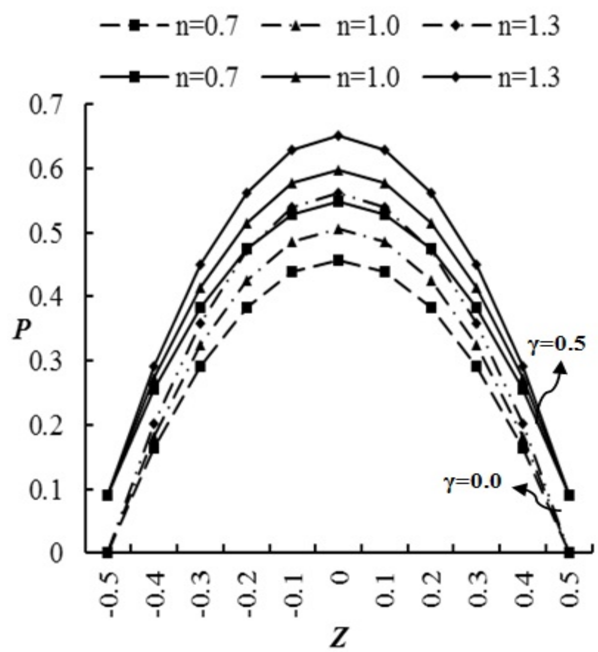

Figure-1. Relationship between dimensionless pressure P and Z-coordinate under various Power-law index n and ferromagnetic parameter γ=0 and γ=0.5, v_2=0.1, ε= 0.6, λ = 0.25.

Looking into the Power-law index n, the dimensionless pressure P distribution increases with the increase of the Power-law index n=0.7, 1.0 and 1.3. During the non-ferromagnetic lubrication case γ=0, the graphs showed lower pressure distribution compared to the same parameters but at ferromagnetic coefficient effect of γ=0.5.

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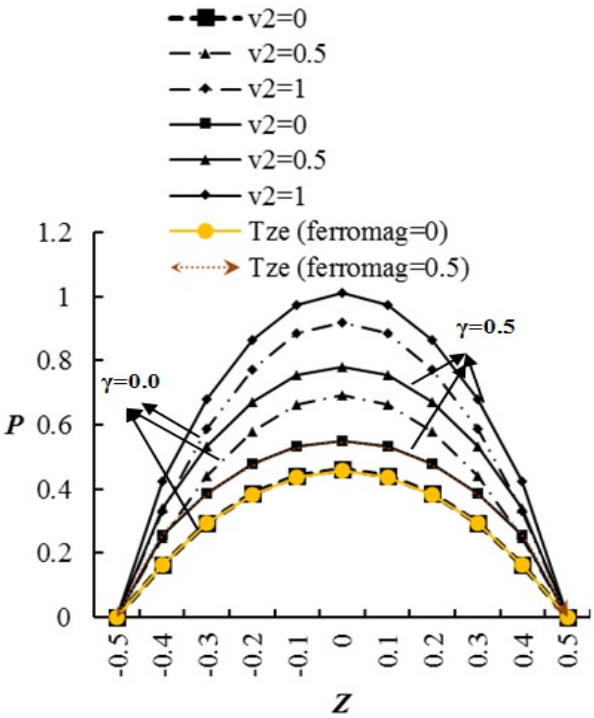

Figure-2. Relationship between dimensionless pressure P and Z coordinate under various volume fraction and ferromagnetic parameter γ=0 and γ=0.5, n=1, ε= 0.6, λ = 0.25.

Figure-2 shows the relationship between dimensionless pressure P and Z coordinate under various volume fraction (v_2) and effect of ferromagnetism (γ), when the lubricant additive volume fraction increased v_2=0, 0.5 and 1.0 the dimensionless pressure in the lubricant fluid film increases accordingly. The increase of dimensionless pressure is more pronounced with the effect of ferromagnetism γ=0.5 compared to the non-ferromagnetism γ=0. The results in figure-2 correspond to that of Tze *et al*. [11] at lubricant additive volume fraction zero in both cases of ferromagnetism γ=0.5 and non-ferromagnetism γ=0.

In Figure-3 the relationship between dimensionless load W and eccentricity ε of journal bearing under various Power-law index n and ferromagnetic parameter γ are showed. The load carrying capacity increasing directly proportional to the increase of eccentricity where the hydrodynamic effect becomes high, and Power-law index n. Again the increase is more when the effect of ferromagnetism is introduced to the lubricant.

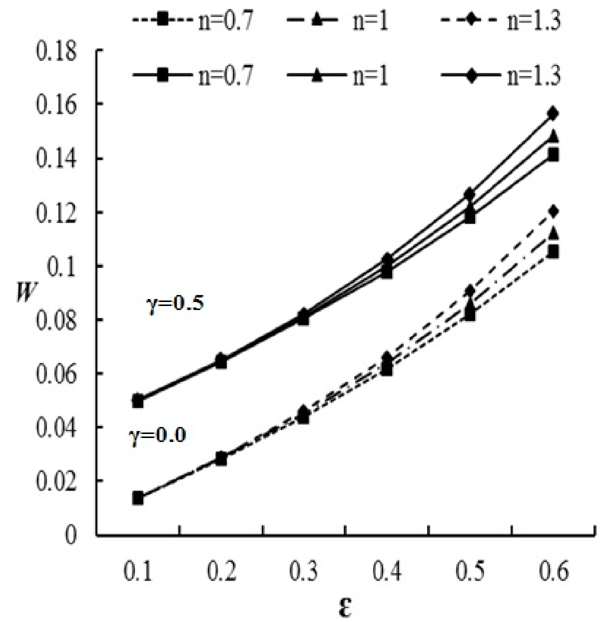

Figure-3. Relationship between dimensionless load W and eccentricity of journal bearing under various Power-law index n and ferromagnetic parameter γ=0 and γ=0.5, v_2=0.1, λ = 0.25.

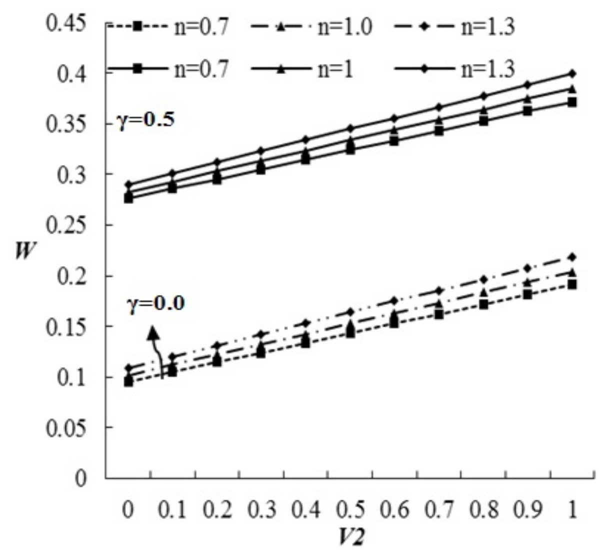

Figure-4. Relationship between dimensionless load W and lubricant additive volume fraction v_2 under various Power-law index n and ferromagnetic parameter γ=0 and γ=0.5, v_2=0.1, λ = 0.25.

Figure-4 on the other hand, represents the relationship between dimensionless load W and lubricant additive volume fraction v_2 under various Power-law index n =0.7, 1.0 and 1.3 and ferromagnetic coefficients γ=0 and 0.5. As the Power-law indices increase, the load carrying capacity of the fluid film increases. Also a further contribution of the lubricant additive volume fraction v_2

shows higher load carrying capacity. The increase of load carrying capacity in the lubricant fluid film is more pronounced in the case of ferromagnetic parameter compared to the non-ferromagnetic case.

In the second case, Couple-stress lubricant fluid model was studied. The Couple-stress parameter investigated were ℓ=0, 0.4 and 0.8. With this consideration, and using the modified Reynolds equation for lubrication, the following below figures were generated considering same situation as the Power-law lubricant fluid model.

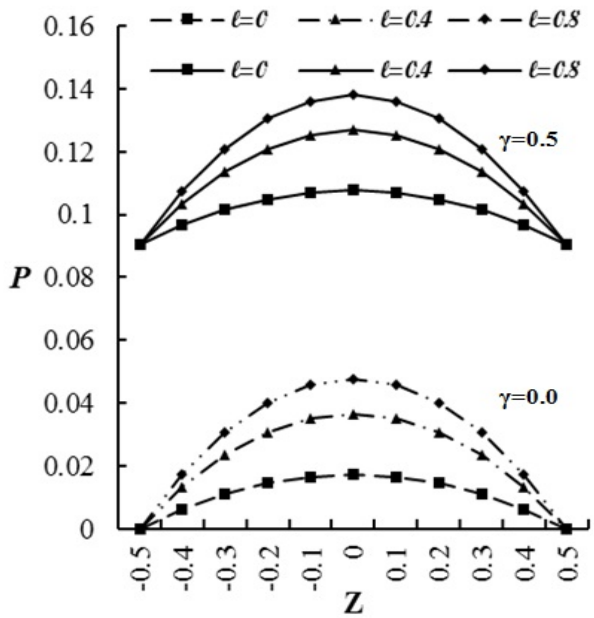

Figure-5. Relationship between dimensionless pressure P and Z-coordinate under various Couple-stress parameter ℓ and ferromagnetic parameter γ=0 and γ=0.5, v_2=0.1, ε= 0.6, λ = 0.25.

Figure-5, shows the relationship between dimensionless pressure P and Z-coordinate of hydrodynamic journal bearing. An increase on the couple stress parameter of journal bearing contributes to a higher dimensionless pressure in the lubricant fluid film. The consideration of the ferromagnetic parameter γ=0.5 with this model has yielded a much higher effect than with non-ferromagnetism property γ=0 in the lubrication.

Same increases for the dimensionless pressure was recorded considering an increase in lubricant additive volume fraction. The contribution of ferromagnetism was also highly noticeable as seen in Figure-6. The effect of Couple-stress parameter (ℓ), ferromagnetic coefficient (γ) and hydrodynamic journal bearing eccentricity (ε) on the load carrying capacity of hydrodynamic journal bearing is presented in Figure-7. As expected the combined effect of these parameters has yield increase of load carrying capacity on the hydrodynamic fluid film.

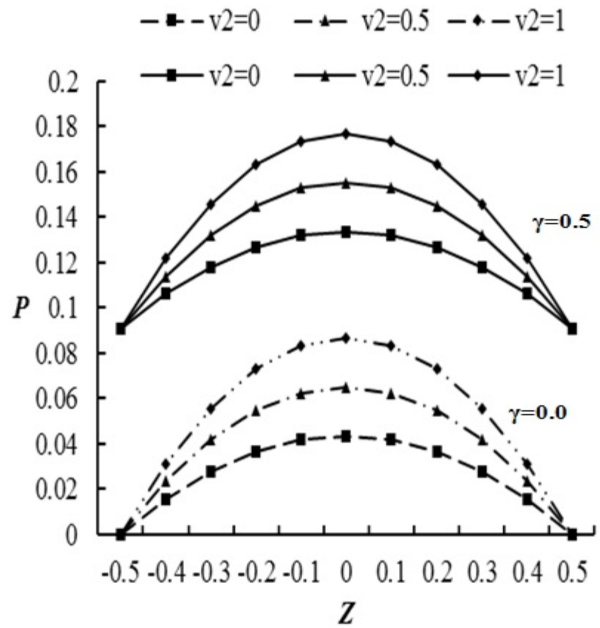

Figure-6. Relationship between dimensionless pressure P and Z-coordinate of journal bearing under various volume fraction of additive and ferromagnetic parameter γ=0 and γ=0.5, ε= 0.6, λ = 0.25.

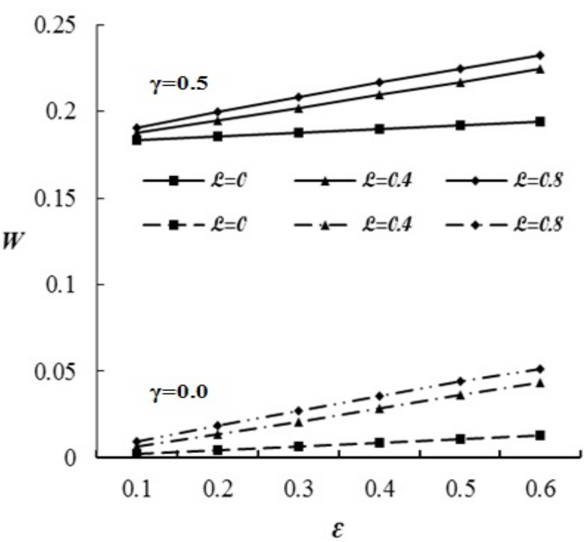

Figure-7. Relationship between dimensionless load W and eccentricity ε of journal bearing under various Couple-stress parameter ℓ and ferromagnetic parameter γ=0 and γ=0.5, v_2=0.1, λ = 0.25.

CONCLUSIONS

- Usage of ferromagnetic fluids as lubricant additives yields a higher dimensionless pressure and load carrying capacity in hydrodynamic journal bearing.
- The increase in the Power-law index n and Couple-stress parameter (ℓ) leads to increasing dimensionless pressure as well as improves the load carrying capacity by the fluid film lubricant.

- The fraction addition of additive volume fraction to the base lubricants, contributes to the increase of dimensionless pressure and load carrying capacity in hydrodynamic journal bearing systems.
- Further studies are highly recommended to investigate the frictional force and coefficient of friction trends.

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NOMENCLATURE

C	Radial clearance
e	Eccentricity, $e = \varepsilon C$
h	Thickness of lubricant film
h, H	Nominal smooth part of the film thickness, $H = h / C = 1 + \varepsilon \cos \theta$
L	Length of the bearing
ℓ	Couple-stress parameter
m_o	Flow consistency
n	Flow behaviour index/ Power-law index
μ	Viscosity parameter
P	Mean film pressure
R	Radius of the journal
x, y, z	Rectangular coordinates
Z	Dimensionless coordinate in the z-direction, $Z = z/L$
ε	Eccentricity ratio, $\varepsilon = e/C$
θ	Circumferential coordinate, $x = R/\theta$
λ	Length-to-diameter, $\lambda = L/2R$
Λ	Roughness parameter
ω	Angular speed
γ	Magnetic field coefficient

REFERENCES

[1] S K Guha, “On the Steady-State Performance of Hydrodynamic Flexible Journal Bearings of Finite Width Lubricated by Ferrofluids with Micro-Polar Effect”, International Journal of Mechanical Engineering and Robotics Research; July 2012, vol. 1, No. 2.

[2] J R Lin, P J Li and T C Hung, “Effects of Non-Newtonian Ferrofluids on the Performance Characteristics of Long Journal Bearings”, FDMP, 2013, Vol.9, no.4, pp.419-434.

[3] G S Nada, T A Osman, “Static Performance of Finite Hydrodynamic Journal Bearings Lubricated by Magnetic Fluids with Couple-stresses”, Tribology Letter, 2007, 27:261–8.

[4] Rosensweig R E, “Ferrohydrodynamic”, Cambridge Monographs on Mechanics and Applied Mathematics, Cambridge University Press, 1985, New York.

[5] Lin JR, Liang LJ, Chu LM. “Effects of non-Newtonian micro-polar fluids on the squeeze-film characteristics between a sphere and a plate surface”. Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology 2010; 224:825–32.

[6] Osman TA, Nada GS, Safar ZS. “Effect of using current-carrying-wire models in the design of hydrodynamic journal bearings lubricates with Ferrofluid”. Tribology Letters 2004; 11:61–70.

[7] Osman TA, Nada GS, Safar ZS. “Static and dynamic characteristics of magnetized journal bearings lubricated with Ferrofluid. Tribology International”. 2001; 34:369–80.

[8] Osman TA, Nada GS, Safar ZS. “Different Magnetic models in the design of hydrodynamic journal bearings lubricated with non-Newtonian Ferrofluid”. Tribology Letters 2003; 14:211–23.

[9] Osman TA. “Effect of lubricant non-Newtonian behavior and elastic deformation on the dynamic performance of finite journal plastic bearings”. Tribology Letters 2001; 17:31–40.

[10] T I Zohdi, “On the reduction of heat generation in lubricants using microscale additives”, International Journal of Engineering, 2013; 62:84–89.

[11] Tze-Chi Hsu, Jing-Hong Chen, Hsin-Lu Chiang Tsu-Liang Chou. “Lubrication performance of short journal bearings considering the effects of surface roughness and magnetic field”. Tribology International, 2013; 61: 169–175.