磁性流體與外部磁場之總和效應對於正弦膜厚推力軸承承載性能之影響

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摘要

推力軸承之機制常用於支持旋轉機械在旋轉時所產生軸向推力，進而可避免轉動件之軸向位移。因此，推力軸承之承載性能的探討，於工程應用上便顯得相當重要。本文之目的主要是在探討，正弦膜厚推力軸承使用磁性流體潤滑劑並施加外部磁場之作用時，兩者之總和效應對於軸承承載性能之影響。藉由磁性流體之體積濃度參數與外部磁場參數之變化，探討正弦推力軸承之流體膜壓力與承載性能。本研究所得之成果，可提供薄膜潤滑與工程實務上在設計推力軸承時之有用參考訊息。

關鍵詞：正弦膜厚，推力軸承，承載性能，磁性流體，外部磁場

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COMBINED EFFECTS OF FERROFLUIDS AND EXTERNAL MAGNETIC FIELDS ON THE LOAD PERFORMANCE OF A SINE FILM THRUST BEARING

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Abstract

Thrust bearings are generally designed to support the axial thrust force generated from rotating machinery. Therefore, the study of the load performances of thrust bearings is important in engineering applications. The aim of the present paper is to investigate the combined effects of ferrofluids and external magnetic fields on the load performance of a sine film thrust bearing. The results of the film pressure and the load capacity are discussed through the variation of the volume concentration parameter and the magnetic parameter. The results of the present study provide useful references for bearing design and engineering applications.

Key Words: sine film, thrust bearings, load performances, ferrofluids, magnetic fields

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1. INTRODUCTION

A thrust bearing is usually designed to support the axial thrust force generated from rotating machinery. The pressure distribution and the load performance of thrust bearings lubricated with a non-ferrofluid have been investigated in the literature, such the works by Hamrock [1] and Williams [2]. Owing to the evolution of recent engineering, the applications of ferrofluids have been emphasized. A ferrofluid is a colloidal suspension, which is composed of nano-size magnetic particles dispersing stably in a carrier liquid [3]. Due to their specific features, ferrofluids are widely used in many applied engineerings such as the drug targeting [4], the magnetic actuators by Olaru et al. [5], the optical devices [6], the servo-valve torque motors [7], the flow sensors [8], the squeeze films [9], and the journal bearings [10]. In order to provide more information for the application of ferrofluids on lubrication fields, the study of combined effects of ferrofluids and external magnetic fields on the load performance of a sine film thrust bearing is motivated in the present paper. According to the ferrofluid flow model, a lubrication equation for the thrust bearing with ferrofluid in the presence of external magnetic fields will be derived and then applied to calculate the bearing characteristics. The results of the film pressure and the load capacity are discussed through the variation of the volume concentration parameter and the magnetic parameter. The results of the present study provide useful references for bearing design and engineering applications.

2. ANALYSIS

Figure 1 shows the physical configuration of a sine film thrust bearing lubricated with a ferrofluid in the presence of an external magnetic field. The bearing length in the x-direction is B_L and the bearing width perpendicular to the xz-plane is B_W. We consider the bearing is infinitely wide, i.e., $B_W >> B_L$. In addition, h_A is the inlet film height, h_B is the outlet film height, and U denotes the sliding velocity. The local film height h for the sine film bearing can be represented as:

$$h(x) = h_B + h_s(x) \tag{1}$$

where the sine curve $h_s(x)$ can be expressed as:

$$h_s(x) = (h_A - h_B) - (h_A - h_B) \cdot \sin\left(\frac{\pi}{2} \cdot \frac{x}{B_L}\right) \tag{2}$$

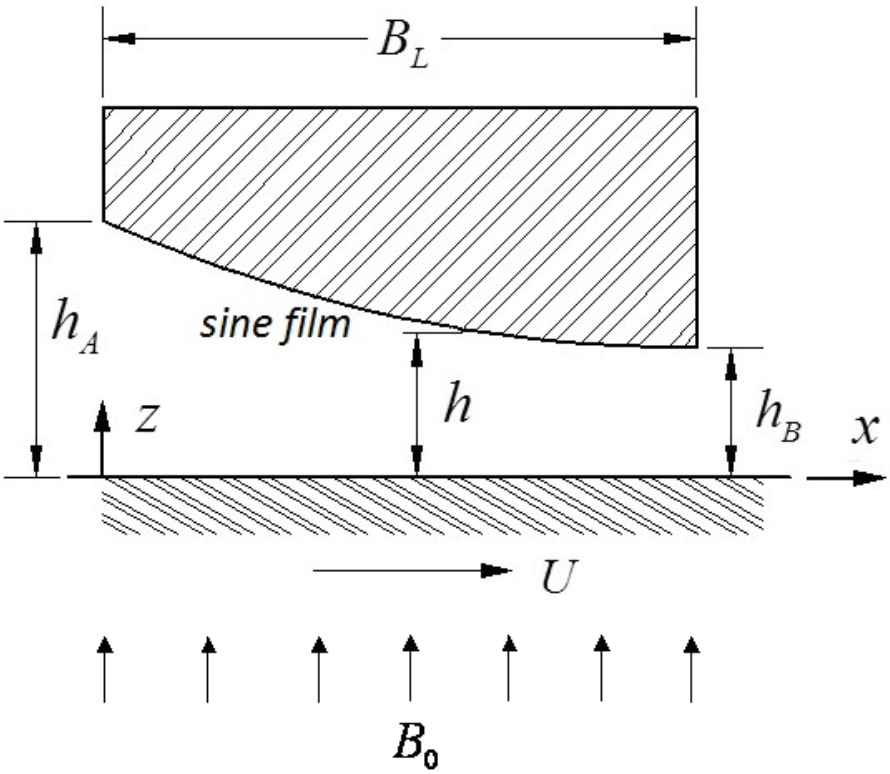

Figure 1 Physical configuration of a sine film thrust bearing lubricated with a ferrofluid

According to the ferrofluid flow model proposed by Shliomis [11], the momentum equations and the continuity equation for a thin film bearing with ferrofluids in the presence of a magnetic field B_0 can be written as:

$$\frac{\partial p}{\partial x} = \eta(1+\tau)\frac{\partial^2 u}{\partial z^2} \tag{3}$$

$$\frac{\partial p}{\partial z} = 0 \tag{4}$$

$$\frac{\partial u}{\partial x} + \frac{\partial w}{\partial z} = 0 \tag{5}$$

where p is the pressure, η is the ferrofluid viscosity, u and v is the velocity components in the $x-$ and $z-$directions, respectively. In addition,

$$\tau = \frac{3}{2} V \frac{L - \tanh L}{L + \tanh L} \tag{6}$$

where V is the volume concentration of particles and L the magnetic Langevin parameter defined by

$$L = \frac{m B_0 \mu_0}{B_c T} \tag{7}$$

In this equation, m is the magnetic moment of a particle, μ_0 is the free space permeability, B_c is the Boltzmann constant, and T is the temperature. Applying the no-slip velocity boundary conditions $u|_{z=0} = U$ and $u|_{z=h} = 0$ to equation (3), one can obtain the velocity component.

$$u = \frac{z^2 - hz}{2\eta(1+\tau)} \frac{\partial p}{\partial x} + (1 - \frac{z}{h})U \tag{8}$$

Integrating the continuity equation (5) by using the expression of the velocity component u and the boundary conditions $w|_{z=0} = 0$ and $w|_{z=h} = 0$, one can derive the lubrication equation for the sine film thrust bearing lubricated with a ferrofluid under the action an external magnetic field.

$$\frac{\partial}{\partial x}\left\{ h^3 \frac{\partial p}{\partial x} \right\} = 6\eta(1+\tau) U \frac{\partial h}{\partial x} \tag{9}$$

This lubrication can be used to determine the pressure distribution and thereafter the load capacity of a sine film thrust bearing.

3. PRESSURE DISTRIBUTION AND LOAD CAPACITY

From the research of Batchelor [12], the viscosity of ferrofluds increases with the volume concentration of particles. $\eta = \Phi \cdot \eta_0$,

$$\Phi = 1 + 2.5V + 6.2V^2 \tag{10}$$

where η_0 is the viscosity of the main liquid. Introduce the non-dimensional quantities.

$$X = \frac{x}{B_L},\ H = \frac{h}{h_B},\ \alpha = \frac{h_A}{h_B},\ P = \frac{p h_B{}^2}{\eta_0 U B_L},\ H_s = \frac{h_s}{h_B} = (\alpha - 1)\left[1 - \sin\left(\frac{\pi}{2} \cdot X\right)\right] \tag{11}$$

Then the non-dimensional lubrication equation can be expressed as:

$$\frac{\partial}{\partial X}\left\{H^3 \cdot \frac{\partial P}{\partial X}\right\} = 6\Phi(1+\tau)\cdot\frac{\partial H_s}{\partial X} \tag{12}$$

The film pressure conditions at the inlet and outlet positions $X=0$ and $X=1$ are: $P=0$. Integrating the lubrication equation, one can obtain the solution of the non-dimensional film pressure.

$$P = 6\Phi(1+\tau)\cdot g_A - 6\Phi(1+\tau)\cdot\frac{g_A\big|_{X=1}}{g_C\big|_{X=1}}\cdot g_C \tag{13}$$

where

$$g_A = g_A(X) = \int_0^X \frac{H_s}{H^3}dX \tag{14}$$

$$g_C = g_C(X) = \int_0^X \frac{1}{H^3}dX \tag{15}$$

Integrating the film pressure, one can obtain the load carrying capacity, l_c.

$$l_c = \int_{x=0}^{B_L} pB_W dx \tag{16}$$

Using the non-dimensional form and performing the integration, one can obtain the non-dimensional load carrying capacity, $W = l_c h_B{}^2 / \eta_0 U B_L{}^2 B_W$.

$$W = 6\Phi(1+\tau)\cdot\int_{X=0}^{1} g_A dX - 6\Phi(1+\tau)\cdot\frac{g_A\big|_{X=1}}{g_C\big|_{X=1}}\cdot\int_{X=0}^{1} g_C dX \tag{17}$$

4. RESULTS AND DISCUSSION

In order to present the results, the non-dimensional film pressure and the non-dimensional load capacity are illustrated for the bearing operating at the inlet to outlet film ratio, $\alpha = h_A / h_B$ =2.

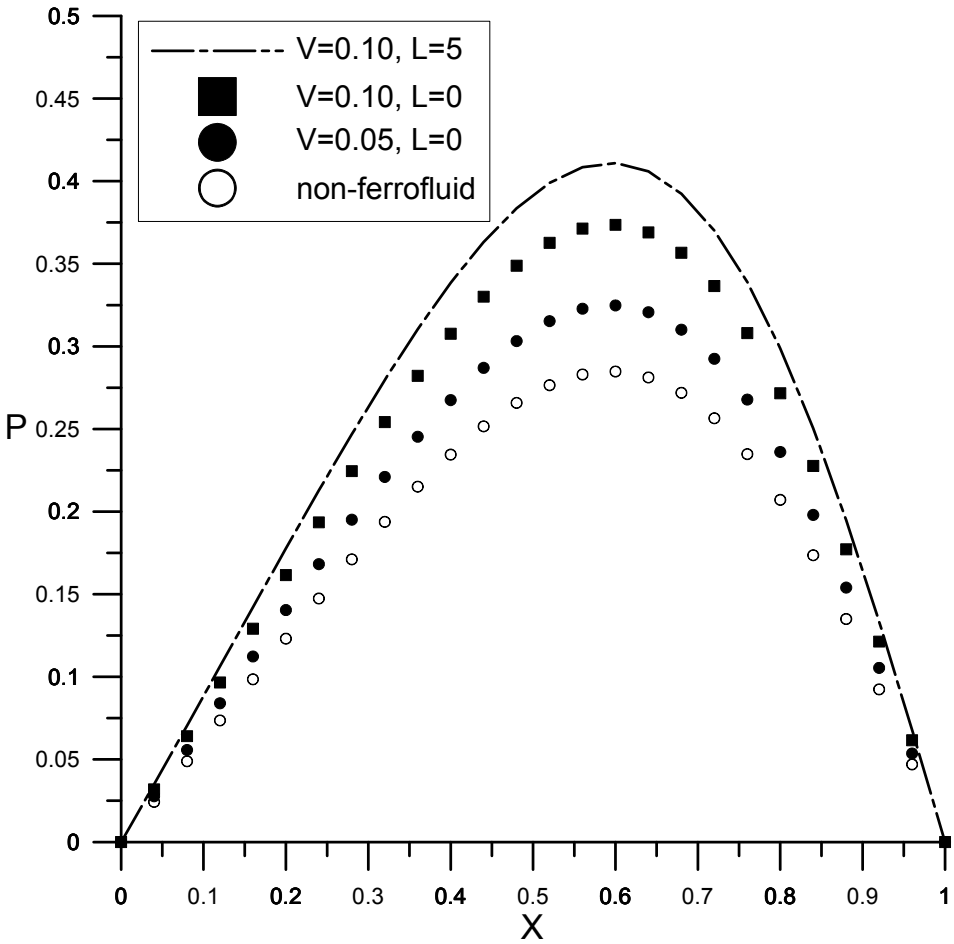

Figure 2 Film pressure P as a function the coordinate X for different V and L

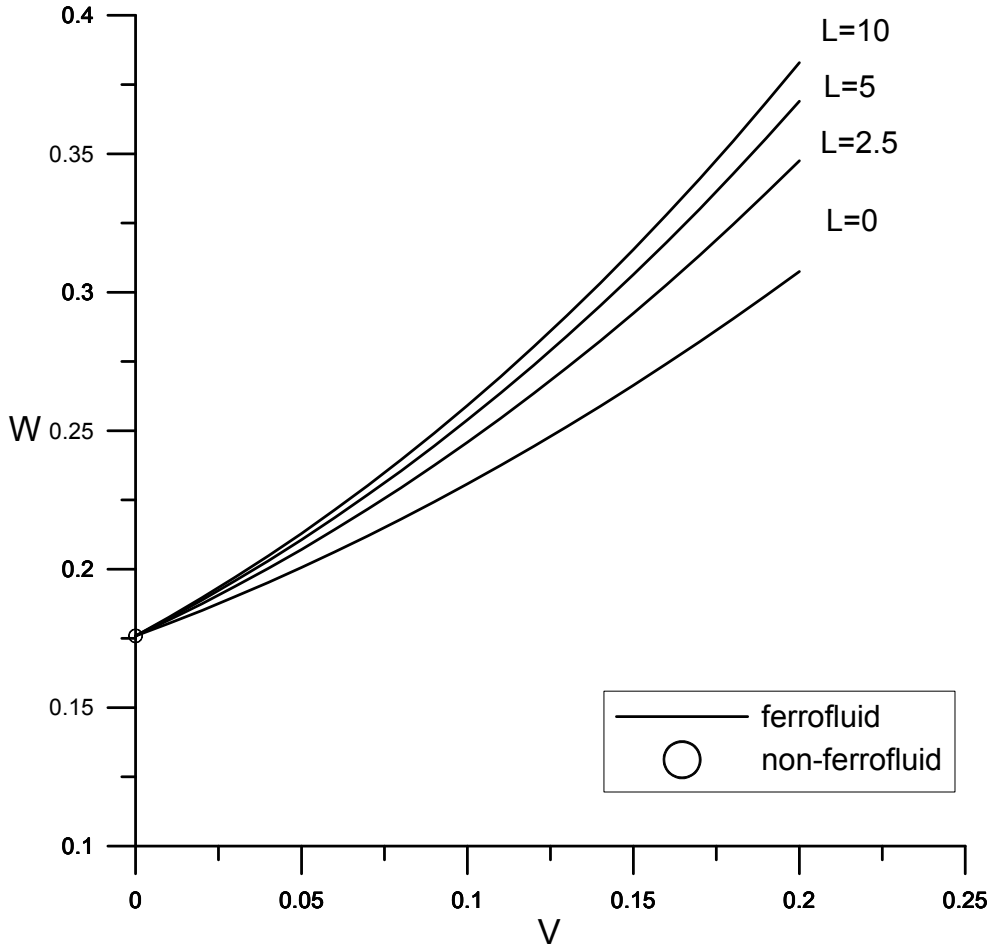

Figure 3 Load capacity W as a function of the volume concentration V for different L

Figure 2 presents the non-dimensional film pressure P as a function the non-dimensional coordinate X for different values of the volume concentration parameter V and the magnetic Langevin parameter L. Comparing with the case of non-ferrofluid lubricant, the use of ferrofluids as the lubricant without magnetic fields ($V=0.05,\ L=0;\ V=0.1,\ L=0$) yields higher values of the film pressure. When a magnetic field is applied ($V=0.1,\ L=5$), further increments of the film pressure are obtained. Figure 3 shows the non-dimensional load capacity W as a function of the volume concentration V for different values of the magnetic Langevin parameter L. Comparing with the case of non-ferrofluid lubricant, the load capacity of the bearing lubricated with ferrofluids in the absence of magnetic fields ($L=0$) increases with increasing values of the volume concentration parameter. It is observed that when the

external magnetic fields are applied ($L = 2.5$; $L = 5$; $L = 10$), the ferrofluid lubricated sine film thrust bearing provides further higher values of the load capacity.

5. CONCLUSION

In this paper, we have investigated the combined effects of ferrofluids and external magnetic fields on the load performance of a sine film thrust bearing. From the results discussed, conclusions can be drawn as follows.

Based on the ferrofluid flow model, a lubrication equation for the thrust bearing lubricated with ferrofluid in the presence of external magnetic fields have been derived for calculateing the bearing characteristics. Comparing with those of the non-ferrofluid lubricated case, the sine film thrust bearing lubricated with a ferrofluid in the presence of external magnetic fields provide higher values of the film pressure and the load-carrying capacity. The combined effects of ferroflids and magnetic fields on the sine film bearing performances are more emphasized for the bearing operating at larger values of the volume concentration parameter and the magnetic Langevin parameter. This useful information can provide engineers for bearing design and engineering applications.

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