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Non-Newtonian inertial magnetohydrodynamic porous squeeze film lubrication between circular discs

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ABSTRACT

This paper presents a numerical investigation of porous squeeze film between two circular discs of couple stress conducting lubricant in the presence of externally applied magnetic fields taking into account fluid inertia forces. The latter are considered using the reduced Navier–Stokes equations. The fluid flow within the porous disc is modeled by the modified Darcy law. The governing equations are resolved by successive over relaxation method in a sequential coupling algorithm. From the results obtained, the influence of transverse magnetic field, inertia forces and couple stress are to improve the porous squeeze film characteristics.

1. Introduction

With the development of modern machine elements, the use of electrically conducting fluids as lubricants, such as liquid metals, in the presence of externally applied magnetic field to avoid the viscosity variation with temperature has been emphasized. The study of magnetic field effects on squeeze lubrication fluid films finds applications in hydromagnetic lubrication of braking devices, hydraulic shock absorbers, astronautical vehicles, slider bearings, etc. Using Newtonian lubricants blended with solid particle additives has also become of great interest due to their benefits on bearings characteristics. The rheological flow behavior of these kinds of non-Newtonian fluids cannot be described accurately by the classical continuum theory. This theory neglects size of additives and thus couple stress. The Stokes micro-continuum theory has been proposed and applied to investigate this kind of lubricant flow behavior. Based upon the use of this theory, studies of magnetohydrodynamic squeezing films are found for a sphere and a plane surface by Naduvinamani and Rajashekar [1], for one dimensional parallel rectangular plates by Lin et al. [2], circular plates by Lin et al. [3], curved circular plates by Lin et al. [4], circular stepped plates by Naduvinamani et al. [5]. The effects of couple stresses and external magnetic fields provide an increase in the load capacity and the response time as compared to the classical Newtonian hydrodynamic case. Further studies of the effects of couple-stress fluids were presented on the squeeze film circular stepped plates by Naduvinamani et al. [6], rectangular finite plates by Kudenatti et al. [7], circular plates by Fathima et al. [8]. Magnetohydrodynamic porous squeeze film bearings have been studied in the last few decades because of their industrial applications and machine manufacturing. The effects of MHD on the couple stresses squeeze film lubrication were studied by Naduvinamani et al. [9] between porous circular stepped plates, by Rajashekar and Kashinath [10] between a sphere and a porous plane surface, by Kudenatti et al. [11] between two rectangular plates where the lower plate is a porous material, by Fathima et al. [12] between anisotropic porous rectangular plates. The effect of roughness parameter that the load-carrying capacity and squeeze-film time increase for azimuthal and decrease for radial roughness patterns as compared to the smooth case. Also, the effect of porous parameter is to decrease the load-carrying capacity and increase the squeeze-film time as compared to the no porous case.

All the above studies, however, focus upon on the assumption of negligible inertia forces. In situations where the machine speed is increased or when using low-viscosity and high-density lubricants such liquid metals, the effects of fluid inertia forces may become relatively significant. All of these effects contribute to an increased Reynolds number and therefore result in conditions for which the inertia effect may no longer be negligible. Inertia effects are no longer negligible in comparison to viscous forces when this Reynolds number is equal or greater than unity. The transition from laminar to turbulent flow in hydrodynamic lubrication initiates at about $Re = 1000$, and the flow becomes completely turbulent at about $Re = 1600$ [13]. The maximum Reynolds number used in this analysis is $Re = 1$, so the flow

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Nomenclature

$\vec{b}$	induced magnetic field (Wb/m^2)
B_0	magnetic field (Wb/m^2)
D_{ij}	deformation rate tensor (1/s)
d_p	average size of the solid particles (m)
F_0	upper disc weight (N)
f	friction coefficient
$\vec{J}$	current density (A/m3)
h	fluid film thickness (m)
$\overline{h}$	dimensionless fluid film thickness
h_0	initial fluid film thickness (m)
H	porous disc thickness (m)
$\frac{dh}{dt}$	squeeze veleocity (m/s)
$\frac{\overline{dh}}{dt}$	dimensionless squeeze veleocity
k	porous disc permeability (m^2)
l	characteristic length of the size of solid particles suspended in fluid (m), $l=\sqrt{\frac{\eta}{\mu}}$
M	Hartmann number, $M=B_0h_0\sqrt{\frac{\sigma}{\mu}}$
m	upper disc mass (kg)
p	pressure in the fluid film (Pa)
$\overline{p}$	dimensionless pressure in the fluid film
p^*	pressure in the porous disc (Pa)
$\overline{p^*}$	dimensionless pressure in the porous disc
P_0	reference pressure (Pa), $P_0=\frac{F_0}{\pi R^2}$
r	radial coordinate (m)
$\overline{r}$	dimensionless radial coordinate
R	radius of the two discs (m)
Re	Reynolds number in the fluid film, $\mathrm{Re}=\frac{\rho V_0 h_0}{\mu}$
R_m	Reynolds magnetic number, $V_0L^2\sigma\mu_m/h_0$
t	time (s)
$\overline{t}$	dimensionless time
u	radial component of velocity in the fluid film (m/s)
$\overline{u}$	radial component of dimensionless velocity in the fluid film
u^*	velocity radial component in the porous disc (m/s)
$\overline{u^*}$	radial component of dimensionless velocity in the porous disc
V_0	reference velocity (m/s), $V_0=\frac{F_0{h_0}^3}{\mu\pi R^4}$
w	velocity axial component in the fluid film (m/s)
$\overline{w}$	axial component of dimensionless velocity in the fluid film
w^*	velocity axial component in the porous disc (m/s)
$\overline{w^*}$	axial component of dimensionless velocity in the porous disc
W	load capacity (N)
$\overline{W}$	dimensionless load capacity
W_{ij}	vorticity tensor (1/s)
z	axial coordinate (m)
$\overline{z}$	dimensionless axial coordinate
α	dimensionless slip parameter
λ	couple stress parameter, $\lambda=\frac{l}{h_0}$
μ	fluid dynamic viscosity (Pa s)
μ_m	magnetic permeability (N/A_2)
$\overline{\tau}$	dimensionless friction force
ρ	fluid density (kg/m3)
ψ	permeability parameter, $\psi=\frac{kH}{h_0^3}$
η	property parameter (constant) of the couple stress fluid (Pa s m^2)
σ	electrical conductivity of the fluid (mho/m)
σ_{ij}	stress tensor (N/m^2)
$\sigma_{(ij)}$	symmetric part of stress tensor (N/m^2)
$\sigma_{[ij]}$	antisymmetric part of stress tensor (N/m^2)
ϕ	porosity

may be considered laminar. Therefore it is important to understand the combined effects of fluid inertia forces and the MHD effects of lubricants on squeeze film characteristics. Daliri et al. [14] extended the classical theory of magnetohydrodynamic lubrication to include convective fluid-inertia effects approximating the inertia terms by the average value across the film for the non porous case. The author presented an analytical solution of squeeze film in wide parallel rectangular plates under constant load with electrically conducting couple stress fluids. Here, it is shown that, both couple stress fluids and convective inertia significantly improves the load carrying capacity. Nevertheless, it is of paramount importance to also study the dynamics of the upper squeezing surface coupled with the transient forces generated by the film motion in the porous case.

In the present paper, the influence of the nonlinear inertia terms is investigated in a more exact way considering the local variation of the inertia terms across the film in the presence of a porous facing. The combined effects of magnetic field, inertial forces, and the permeability of the porous medium on the squeeze film characteristics between two parallel permeable discs have been studied. Acceleration forces acting on the upper disc are also included in the analysis. Fluid inertia forces are considered using reduced Navier–Stokes (RNSP) equations for couple stress electrically conducting fluid. The fluid flow within the porous disc is described using the modified Darcy model suing the Beavers and Joseph [15] slip condition. The governing equations are discretised by finite difference method and solved iteratively by Gauss–Seidel technique in a sequential coupling algorithm. The finding of this study provides useful information for engineers and designing of inertial MHD non-Newtonian porous squeeze film systems and understanding their behaviors.

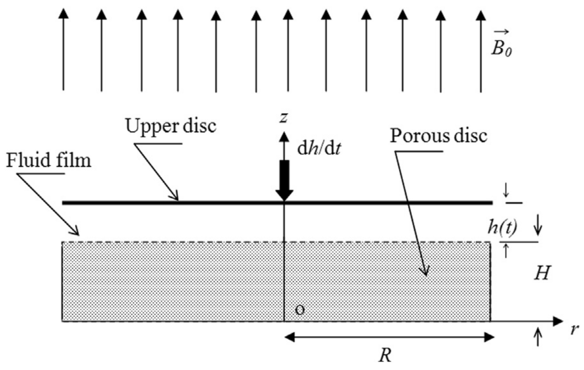

Fig. 1. Geometrical configuration.

2. Governing equations and numerical solution

The MHD porous squeeze film is generated between two parallel circular discs of radius R separated by a fluid film lubricant of thickness h (Fig. 1). The upper disc is in motion under a constant load capacity W along the z-axis with squeezing velocity dh/dt towards the lower porous disc, which remains at a fixed position $z=0$. We assume that a uniform magnetic field of strength B_0 created by a magnet is applied in the z-direction and the magnetic Reynolds number.

MHD is the study of the interaction of conducting fluids with electromagnetic phenomena. If the liquid moves in the presence of a magnetic field, a body force is experienced by the liquid. Most known liquid metals are essentially nonmagnetic, so that this body