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Investigation of flow between deformed disks in hydro-viscous drive

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A R T I C L E I N F O

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A B S T R A C T

In order to investigate the dynamic behavior of oil film between deformed disks in hydro-viscous drive, revised mathematical models based on steady-state and axisymmetric flow conditions are developed. The models consist of two forms of thermal deformation that are caused by the combined effect of frictional heat and radial constraint. An approximate solution to the theoretical model is obtained assuming that the fluid viscosity remains constant. And the model considering the effect of variable viscosity is solved by means of computation fluid dynamics code FLUENT. Then the analytical and numerical solution profiles are compared. The results show that peak velocity at the outlet, pressure gap and temperature rise between the inlet and outlet of the film increase with increasing axial deformation size. The effect of radial deformation on the increase of friction area of the disks leads to the increase of the flow rate. The friction pairs should be kept in reasonable deformation size in case of turbulent flow. It is also found that both axial deformation and radial deformation significantly contribute to the increase of viscous torque on condition that the deformation size is controllable. Based on the comparison with the experimental results, the performance of the theoretical model is found satisfactory.

1. Introduction

As high-power mechanical equipment develops to high speed and heavy load, there has been an increasing demand for safer and more stable fluid transmission systems. The key component of the transmission device is controlled hydro-viscous drive (HVD) that provides smooth transfer of power under lubricated conditions. The long-term, satisfactory performance of HVD largely depends on the durability of the friction material. However, large amounts of frictional heat generated within a relatively short period of time cause a considerable and non-uniform temperature rise. Overheating of materials can lead to thermal deformation and even material degradation of the disks, which effectively exert an impact on the dynamic behavior of the oil film between the disks.

Since HVD is similar to wet clutch in structure except some working mechanism, the achievements of former scholars about the wet clutch can be used for reference. On one hand, numerous researches have been conducted on the relationship between the thermal failure of the disks and the transmission performance during the soft-start. Mansouri et al. [1] created a theoretical FE model to provide a very accurate way to describe the dynamic and thermal behavior of a wet clutch engagement. Marklund et al. [2] studied the wet clutches operating under low velocity and high load with the aim of obtaining reliable models for the torque transfer during boundary lubrication conditions. Jang et al. [3–8] developed comprehensive models for analyzing the onset of thermoelastic instability in a wet clutch. Their models took into account surface roughness, lubricant film, and permeability of the friction material with grooves. The effects of symmetry of the established model and the pattern and number of disturbances on thermoelastic instability are analyzed. Li et al. [9] performed the analysis of a wet clutch that covered the entire cycle of engagement. They presented a model for analyzing the wear characteristics of a paper-based friction material [10]. Also the results of a computerized wear prediction model in the wet clutch are examined using the Monte Carlo (MC) method [11]. Awrejcewicz et al. [12] presented a mathematical model describing the process of heat generation and its propagation in the mechanical friction clutch. Cui et al. [13] considered the influence of fluid-inertia item on temperature distribution of multidisc friction pairs in hydro-viscous drive. They also derived transient temperature models and thermal deformation model with the aim of revealing the effect of several parameters on temperature distribution. Thermal distribution and thermo-elastic-plastic deformation of friction pairs in hydro-viscous drive was obtained [14,15]. Liu et al. [16] investigated thermo-elastic dynamics in the stability of the homogeneous material coated half-plane sliding against a homogeneous half-plane. With consideration of the thermal effects, the stability of the thermo-elastic wave caused by a small perturbation was examined.

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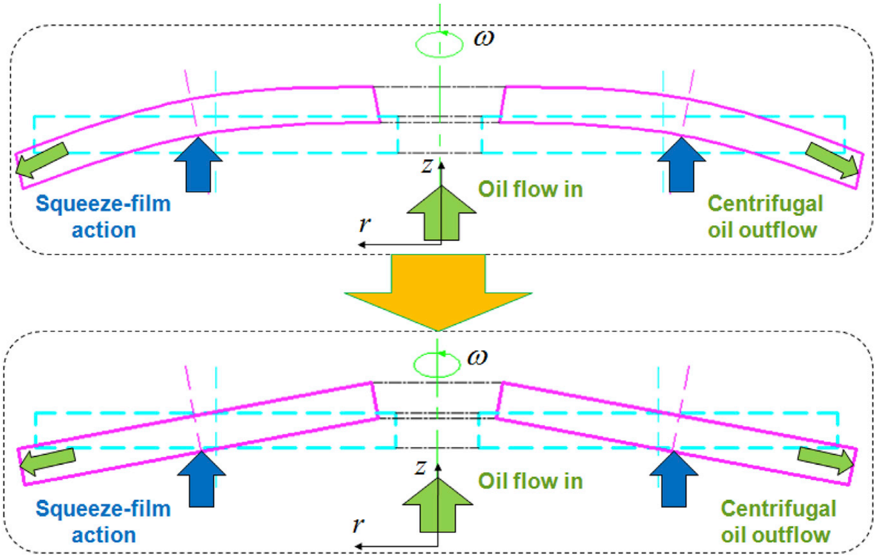

Fig. 1. Simplified schematic diagram of HVD, showing oil entering axially from the center of disks and exiting radially due to squeeze-film action and centrifugal action.

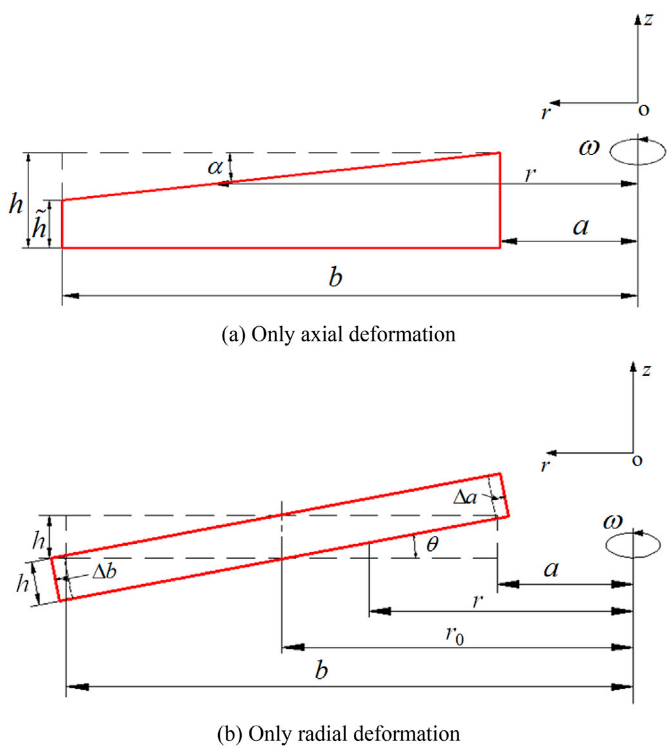

Fig. 2. Schematic for oil film between deformed disks.
(a) Only axial deformation.
(b) Only radial deformation.

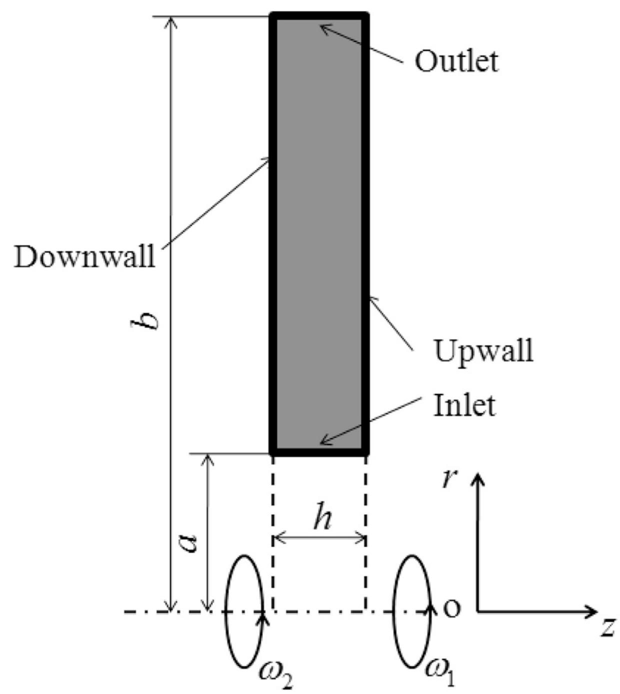

Fig. 3. Simulation model of oil film between the disks of HVD.

On the other hand, the modeling and experimental investigations on the HVD engagement dynamics have been widely performed. Kitabayashi et al. [17] presented a theoretical model based on laminar flow in the gap between the disks and studied the effects of design factors of clutch packs on drag torque. Nyman et al. [18] explored the influence of the surface topography and fluid on the friction characteristics during engagement. Yuan et al. [19] proposed an improved model for open, wet-clutch behavior. The theoretical model includes the effects of surface tension and wall adhesion. Mäki et al. [20] investigated the influence of different additives on the friction characteristics of the transmission fluid. The new transmission fluid with the desired frictional properties was formulated. Huang et al. [21] investigated the flow field of the oil film between frictional pairs in Hydro-viscous drive. The Navier-Stokes equation considering viscous force and inertial force rather than Reynolds equation or modified Reynolds equation was presented. Fei et al. [22] studied the influence of the composition of friction materials on the dynamic friction torque during engagement. Xie et al. [23] investigated the effect of deformed interface on the hydro-viscous drive characteristics through a three-dimensional fluid simulation in FLUENT software. Ompusunggu et al. [24] integrated a friction model appropriate for wet friction clutches based on the extension of the Generalized Maxwell Slip (GMS) friction model. Iqbal et al. [25] presented a mathematical model based on continuity and Navier-Stokes equations to estimate the drag in open multidisc wet clutches when considering laminar flow in the gap between the disks. Yao et al. [26] studied the speed stability of a HVD in mixed lubrication to improve the rotational speed stability of HVD in