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Evaluation of viscous force effects on rotor of squeeze film damper using newtonian and non-newtonian fluid

Kesar Singh
Department of Pharmacy, Dr. Bhimrao Ambedkar University, Chhalesar Campus, Uttar Pradesh, India

Abstract

Presents mainscript mainly deals with the evaluation of force effects on rotor of squeeze film damper. Rotor is eccentric placed and its motion is translate-circular. The amplitude of rotor motion is smaller than its initial eccentricity. The force effects are calculated from pressure and viscous forces which were gained by using computational modeling. Two types of fluid were considered as filling of damper. First type of fluid is Newtonian (has constant viscosity) and second type is magnetorheological fluid (does not have constant viscosity). Viscosity of non-Newtonian fluid is given using Bingham rheology model. Yield stress is a function of magnetic induction which is described by many variables. The most important variables of magnetic induction are electric current and gap width which is between rotor and stator. Comparison of application two given types of fluids is shown in results.

Keywords: Squeeze film damper, magnetorheological fluid, computational fluid dynamic

Introduction

Magnetorheological (MR) fluids are non-Newtonian liquids which show fast transition from a liquid to a nearly solid state under the presence of external magnetic fields. Generally, their viscosity depends on magnetic induction. This special property makes them very good candidates for applications in mechanical systems that require active control of vibrations. Typical examples are shock absorbers or vibration dampers. Vibrations of shaft are generated from the motion of rotor imbalance which can be caused by manufacturing or assembling inaccuracies. These effects can be significantly reduced if active or semi-active damping elements are inserted between the shaft and the stationary part of the rotating machine. Promising parameters of MR fluids in connection with conventional squeeze film dampers provide a possibility to design a semi-active damping element. Nowadays the MR dampers are a subject of an intensive experimental and theoretical research. Mathematical models of squeeze film damper were published in works [1, 4]. A computational simulation was done in article. An interaction between surface wettability and MR fluids was solved in works [5, 6]. The aim of this paper is to show advantages of use MR fluids in squeeze film damper. Recently the blood flow of newtonion and non-newtonion fluid flow blood vessels with flexible wall [7], quantification in effective viscosity of fluid in a porous medium by Brinkman equation [8] and the oscillatory blood flow by viscosity shearing dependent model have already been studied. [9]

Materials and Methods

The geometry of possible application of MR damper. The shaft is put in bearings which allow its rotational movement. There is a fixed connection between bearings and housing by a squirrel spring. Squeeze film damper is composed of an inner and an outer ring and magnetorheological oil. The main aim of damper is to eliminate undesirable vibrations. Magnitude of viscosity is controlled by the electric current in electric coil which generates magnetic induction. The domain for numerical simulation was just the place between inner and outer ring.

The outer ring is a stationary wall and its diameter is 152 mm. The inner ring is a moving wall with 150 mm diameter and is eccentric placed in relations to outer ring. Motion of inner ring is translate-circular and its amplitude of deviation is 0,05 mm. Mean value of eccentricity (center of movement) in direction of x axis is 0,5 mm.

The real length of the damper is 44 mm. The numerical solution was calculated by commercial CFD (computational fluid dynamics) software (ANSYS Fluent). Following boundary conditions were set up for numerical simulation. The outer ring was defined as a stationary wall. At the outlet from damper, a pressure outlet with magnitude of relative pressure 0 Pa was set. To obtain lower simulation time, the geometry was cut in the middle of damper length and symmetry condition was used. The inner ring of squeeze film damper was determined as a moving wall. Its motion was prescribed by velocities functions for every axis:

$$v_x = -e \cdot \omega \cdot \sin(\omega \cdot t) \qquad \text{......... (1)}$$

$$v_y = e \cdot \omega \cdot \cos(\omega \cdot t) \qquad \text{......... (2)}$$

where vx and vy are components of velocity in direction of x and y axis, e is amplitude of deviation and its value is 0,05 mm.

Frequency of inner ring motion is prescribed by its angular velocity ω = 60 · π $s-1$. The velocity in direction of z axis was equal to 0 $m \cdot s-1$.

Numerical simulation was solved by the dynamic mesh. Displacements were small in this solution, therefore the mesh of computational domain did not have to be remeshed (number of elements did not change during the simulation). Because the mesh was just deformed (stretched and pressed), Smoothnig method was applied, which is included in ANSYS Fluent. Diffusion parameter was defined as Cell-volume and its value was set equal to 0. Mesh of computational domain has 320 000 hexahedral elements (minimum orthogonal quality = 0,888; maximum ortho skew = 0,112; maximum aspect ratio = 18,928).

Fluid Properties: In case there is no electric current in the coil, the viscosity of magnetorheological fluids is constant and the fluid behavior is Newtonian. The viscosity for this case was defined as 0,1 $Pa \cdot s$. Electric current in coil generates a magnetic field and the magnetorheological fluid will change its properties. For the mixed viscosity the Bingham rheology model applies which was described in work [1]. The model is defined by equation:

$$\tau = \tau_y + \mu \cdot \gamma^{\cdot} \qquad \text{.......} (3)$$

where τ [Pa] is shear stress which acts upon the element of fluid,
τy [Pa] is shear yield stress,
μ [Pa·s] is dynamic viscosity,
$\gamma^{\cdot}$ [s-1] expresses shear rate.

Commonly, the shear yield stress is considered constant. However, in the resolved problem, it is a function of many variables and it is defined by the following equation:

$$\tau_y = k_y \cdot B^{n}y \qquad \text{.........} (4)$$

where B is magnetic induction, ky and ny are material constant of magnetorheological fluid. For this simulation following values were chosen ky = 10000 $Pa \cdot T{-}2$; ny = 2.

Beside other things, magnetic induction is dependent on the thickness of the lubricating film in radial direction. Definition of magnetic induction in squeeze film damper is described by the following relation:

$$B = k_B \cdot \mu 0 \cdot \mu r \cdot h(t) \qquad \text{..........} (5)$$

where kB is construction parameter of damper (100 threads and efficiency 60 % means its value is kB = 0,6),

$\mu 0$: expresses a permeability of vacuum (4π·10-7 Hm-1),
μr: is relative permeability of magnetorheological fluid which for our case has value 5,
I: is electric current which flows through coil.

Results and Discussion

Motion of inner ring is time dependent. Therefore, the solution was calculated as transient. The size of time step was 10−4 s. The viscosity of filling fluid in damper was relatively high, velocities and the size of gap width are small. Therefore, also the Reynolds number comes out small. And for this reason no turbulence model was used and laminar model was chosen.

The aim of the solution was to determine force effects on the moving wall. Final force in the direction and time given was calculated as a sum of pressure and viscous forces on the whole inner ring surface. Only the positive values of relative pressure were considered for simulation of the force effects during cavitation in fluid (p > 0 Pa).

Dependence of force components amplitudes is displayed. Amplitudes were taken from both direction, positive (pos) and negative (neg). In absolute values of amplitudes are presented. Force and current are related as polynomial function of second order. In direction of x axis, there are only small differences in force amplitudes. But in case of force amplitudes in y axis, the difference between the positive and the negative is rapidly increasing with rising current.

This phenomenon is probably caused by reversed flow in gap which is created due to motion of the inner ring. Significant difference of force amplitudes in y axis direction may be caused by different types of flow on the upper and lower side of damper. In the top region of damper the fluid flows through the diffuser against bottom part of the damper, where fluid flows in convergent nozzle.

Conclusion

There is a strong dependence of force effects on the size of electric current in coil. The force effects on both rings grow with increasing electric current. The positive and negative amplitudes of forces in x direction are almost the same. Substantial differences are between the positive and negative force amplitudes in direction of y axis. This phenomenon is probably caused by a different character of flow on the bottom and the top of damper. In future work, this problem will be investigated for different mean value of eccentricity and magnitude of eccentricity motion. Different frequency of inner ring motion will also be applied. Next aim is to continue in work of authors in articles [5, 6] and present numerical model will be extended by boundary conditions of different wettability of surface. Another possible innovation of numerical simulation is that this problem will be solved for variable value of magnetic induction in damper length.

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