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STABILITY OF SYNCHRONOUS VIBRATION OF RIGID ROTORS MOUNTED IN MAGNETICALLY SENSITIVE SUPPORT ELEMENTS

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Abstract: *The optimum design and function of some rotating machines may require to mount the rotors in hydrodynamic bearings. To prevent excitation of non-synchronous vibration of large amplitude, the bearings are inserted in squeeze film dampers. To achieve their optimum performance in a wide range of running speeds their damping effect shoud be controllable. This is offered by dampers lubricated by magnetically sensitive oils. The needs of control the damping lead to the proposal and study of a new support element consisting of a hydrodynamic bearing and a magnetorheological squeeze film damper. The results of computational simulations show that from the point of view of vibration mitigation, minimization of the force transmitted to the stationary part and stability of synchronous oscillation of rigid rotors application of the studied support element provides better technological parameters in comparsion with the design variant when the rotors are mounted only in hydrodynamic bearings.*

Keywords: **Controllable rotor support element, Magnetically sensitive fluids, Vibration attenuation, Force reduction, Vibration stability extension**

1. Introduction

The hydrodynamic bearings are often used to support rotors of rotating machines. It is because of their high loading capacity, simple design, and quite running. Their drawback is the possibility of inducing non-synchronous vibration of large amplitude if the angular speed exeeds a critical value. The solution consists in increase of damping in the rotor supports.

This is offered by inserting the bearings in squeeze film dampers. The presence of damping has effect on the vibration amplitude, the vibration stability, and transmission of the force between the rotor and the stationary part in dependence of angular speed of the rotor rotation. If realization of the technological process requires the rotating machine to operate in a large extent of angular velocities, then the amount of damping must be adaptable to the current working conditions to achieve optimum performance of the damping devices. This is offered by a squeeze film damper lubricated by magnetically sensitive fluid.

This paper deals with the study and properties of a new rotor support element that consists of a hydrodynamic bearing placed in a magnetorheological squeeze film damper and on its effect on the stability of synchronous vibration of a rigid rotor.

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2. The studied support element

The studied support element consists of a hydrodynamic bearing inserted in a magnetorheological squeeze film damper. The bearing is lubricated by normal oil and the damper by magnetorheological fluid. In the damper body there are embedded electric coils that generate magnetic flux passing through the layer of magnetorheological oil. As resistance against its flow depends of magnetic induction, the change of the applied current feeding the coils can be used to control the damping force.

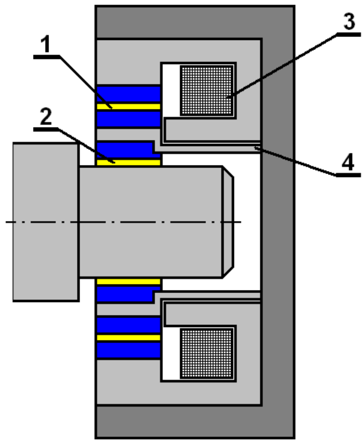

Fig. 1: The studied support element (1 - normal oil layer, 2 - magnetorheological oil layer, 3 - electric coil, 4 - cage spring)

The development of mathematical model of the studied support element is based on assumptions of the classical theory of lubrication. Only the magnetorheological oil is represented by bilinear material the yielding shear stress of which depends of magnetic induction. The pressure distribution in the layer of normal oil is governed by the Reynolds equation (Szeri, 1980) and in the layer of magnetorheological oil by the Reynolds equation adapted to bilinear material (Zapoměl, 2017). In cavitated areas it is assumed that the pressure remains constant. The dependence of the yielding shear stress on magnetic induction is approximated by a power function. Magnetic induction in the damper gap is proportional to the applied current and inverse proportional to the thickness of the oil film.

3. The investigated rotor system

The investigated rotor is rigid. It consists of a shaft and of one disc. At both its ends it is connected to the rigid stationary part. The rotor turns at constant angular speed, is loaded by its weight and is excited by the disc imbalance. The whole system can be considered as symmetric relative to the disc middle plane.

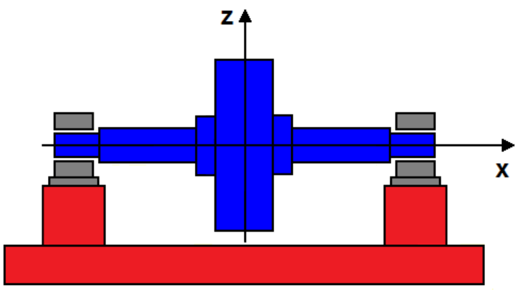

Fig. 2: Scheme of the studied rotor system and the introduced coordinate system.

Vibration of the rotor system is governed by a set of two nonlinear motion equations and two equations of equilibrium of the elastic and hydraulic forces (Zapoměl, 2019). The trigonometric collocation method was applied to get the steady state solution. Its stability was evaluated by imploying the Floquet theorem. This requires to construct the transition matrix related to the time history of deviation of kinematic parametres of slightly disturbed rotor system over the span of time of one period (of one rotor revolution). The steady state vibration is stable if magnitudes of all its eigenvalues are less than 1 (Nataraj, 1989).

4. Results of the simulations

The principal technological and operation parametres of the investigated rotor system are: the rotor mass 450 kg, the coefficient of the rotor linear damping caused by the environment 10 Ns/m, the stiffness of one damper cage spring 4.0 MN/m, the eccentricity of the rotor disc centre of gravity 40 μm, the hydrodynamic bearing length/diameter 60/110 mm, the width of the bearing gap 0.1 mm, the oil dynamic viscosity (hydrodynamic bearing) 0.008 Pas, the magnetorheological squeeze film damper length/diameter 40/150 mm, the width of the damper gap 0.8 mm, the magnetorheological oil dynamic viscosity not effected by a magnetic field 0.3 Pas and the oil relative permeability 5.

In the interval of low angular velocities application of sufficient amout of damping (applied current 4.0 A) leads to reduction of the rotor vibration amplitude (Fig. 3 left). The size of the orbit goes down from 102 × 52 to 6 × 4 μm and its dimensions are comparable with the size of the orbit related to the design variant when the rotor is supported only by hydrodynamic bearings (Fig. 3 right, the orbit size 6 × 6 μm).

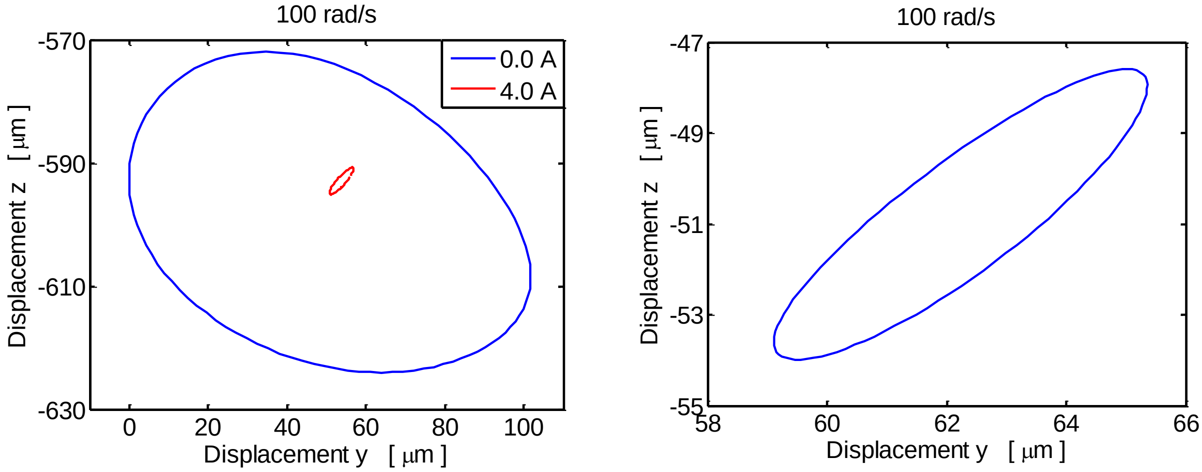

Fig. 3: Orbits of the rotor centre (speed of rotation 100 rad/s).

In the interval of high angular velocities the damping in the rotor supports has only little influence on the oscillation amplitude but its decrease reduces the force transmitted to the stationary part. The transmitted force is than lower than that when the rotor is mounted only in hydrodynamic bearings (Fig. 4).

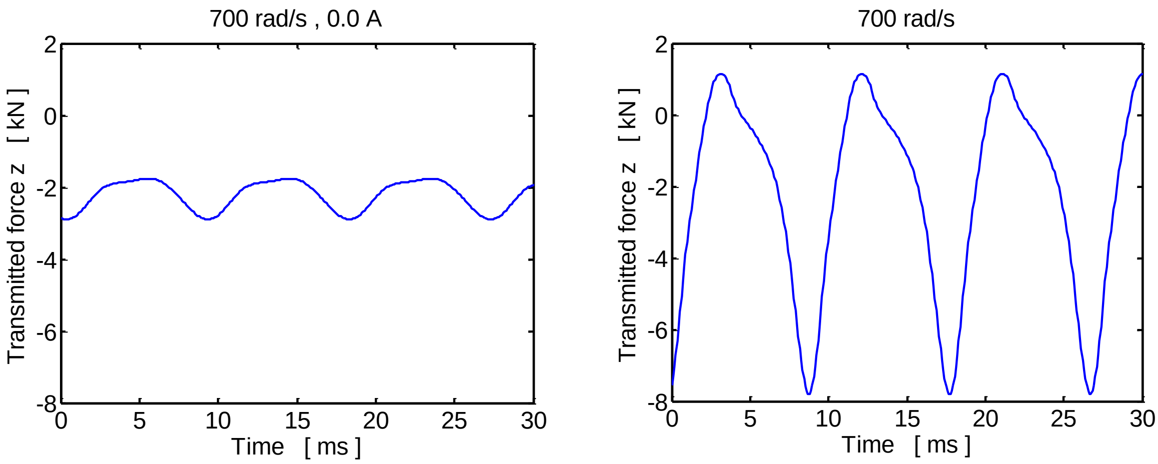

Fig. 4: Time history of the force transmitted to the stationary part (speed of rotation 700 rad/s).

In Fig. 5 there is depicted the distribution of images of eigenvalues of the transition matrix set up over the span of time of one period in the Gauss plane for three angular velocities. The results are related to the case when the rotor is supported only by hydrodynamic bearings. The right figure shows that one eigenvalue is greater that 1, which implies, the synchronous vibration becomes unstable.

The diagrams in Fig. 6 show dependence of magnitude of leading eigenvalue of the transition matrix of speed of the rotor rotation. Its evident that application of the studied support element shows much lager stability of the synchronous vibration than the hydrodynamic bearing and that lower or higher damping produced by the magnetorheological damper does not destabilize the vibration.

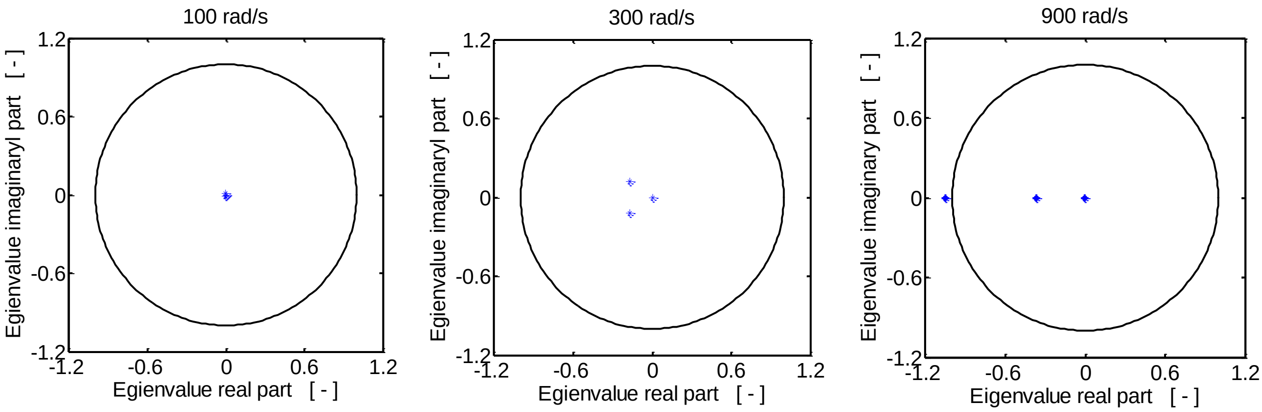

Fig. 5: Distribution of eigenvalues of the transition matrix in the Gauss plane.

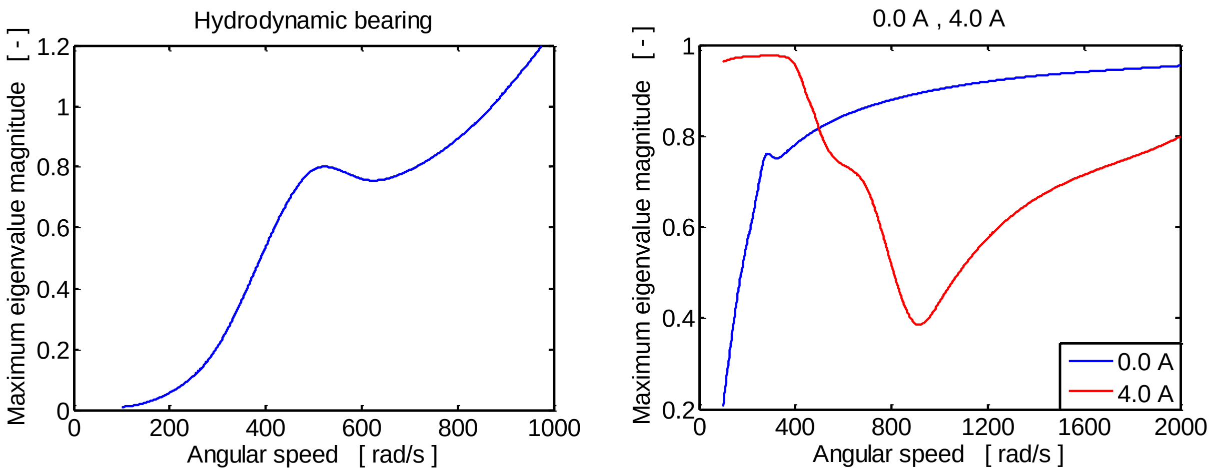

Fig. 6: Dependence of magnitude of the leading eigenvalue of the speed of rotation.

5. Conclusions

The studied controllable support element makes it possible to utilize advantages of fluid film bearings. The results of computational simulations show that its application in comparison with hydrodynamic bearings enables to achieve (i) the same vibration amplitude in the interval of low angular speeds by increasing the damping, (ii) decrease of the force transmitted to the stationary part by reducing the damping and (iii) significant extension of the velocity interval of stable synchronous rotor oscillation.

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