29th Nordic Seminar on Computational Mechanics
NSCM-29
R. Larsson (Ed.)
2016

ANALYSIS OF THE STEADY STATE FORCE TRANSMISSION BETWEEN A TWO-DISC ROTOR DAMPED BY MAGNETORHEOLOGICAL SQUEEZE FILM DAMPERS AND ITS FRAME

NSCM-29

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Key words: Two-disc Rotors, Magnetorheological Squeeze Film Dampers Modelling, Bilinear Material, Model Reduction, Force Transmission, Controllable Force Reduction.

Summary. A frequently used technological solution for reducing forces transmitted between the rotor and its frame consists in adding damping devices to the rotor supports. The control of their damping effect with the intention to achieve their optimum performance is enabled by magnetorheological squeeze film dampers. The presented work is focused on the study of the effect of magnetorheological squeeze film dampers on minimizing amplitude of the force transmitted to the rotor frame. The developed mathematical model of the rotor is discrete. The magnetorheological dampers are represented by springs and nonlinear force couplings and the magnetorheological oil by bilinear material. The proposed approach is completed with an efficient procedure for determination of the stiffness and damping parameters of the model rotor system. The steady state solution of the equation of motion is obtained by application of the trigonometric collocation method. The performed computational simulations confirmed that control of the damping effect decreases the force transmitted to the rotor frame. The developed approach reduces the computational efforts, speeds up the analysis, highlights the studied phenomena, and increases stability of the computational procedures.

1 INTRODUCTION

Unbalance is a main source of excitation of lateral vibration of rotors and of increase of forces transmitted to their frame. A frequently used technological solution for suppressing these undesirable effects consists in placing damping devices between the rotor and its casing.

The controlled damping in the rotor supports is enabled by application of magnetorheological squeeze film dampers. The principles of their work and practical experience with their applications are reported in a number of publications [1-4]. Magnetorheological oils belong to the class of fluids with a yielding shear stress. The flow occurs only in those areas where the shear stress exceeds a limit value - the yielding shear stress. In areas, called a core, where the shear stress is lower the magnetorheological oil behaves as solid matter. The mathematical model of a squeeze film magnetorheological damper in which the lubricant is represented by Bingham material is reported in [5-6]. The modelling of magnetorheological oil by bilinear material [7] arrives at increase of stability of the computational procedures in which the mathematical model of the magnetorheological squeeze film damper is implemented.

The main parts of a magnetorheological squeeze film damper are two concentric rings between which there is layer of magnetorheological oil. The inner ring is coupled with the shaft by a rolling element bearing and with the damper housing by a squirrel spring. Lateral vibration of the rotor squeezes the lubricating layer which produces the damping effect. The magnetic flux generated in electric coils passes through the lubricating film. As resistance against the flow of magnetorheological oils depends on magnetic induction, the change of the current changes the damping effect. The pressure distribution in the full oil film between the damper rings is governed by the Reynolds equation adapted to bilinear material [7].

The aim of the research presented in this paper was to study influence of magnetorheological squeeze film dampers on minimizing the forces transmitted between the two-disc rotor and its frame. A new procedure, in which the rotor is represented as a discrete system, magnetorheological dampers by springs and force couplings and the magnetorheological oil by bilinear material, has been developed for this purpose. Its merits are speeding up the computations and highlighting the phenomena that are the subject of the investigations.

2 THE MODEL ROTOR SYSTEM

The proposed approach to study the influence of magnetorheological squeeze film dampers on the force transmitted to the rotor frame is based on setting up two model systems, reduced and primary ones. The reduced system is discrete. It consists of absolutely rigid discs coupled by massless elements to which the bending stiffness and internal damping are assigned. The equation of motion of the discrete rotor system is set up in the frame of reference rotating together with the rotor. After its transformation to the inertia space it takes the form

$$\mathbf{M}\ddot{\mathbf{x}} + \left(\mathbf{B}_P - \omega\mathbf{G} + \mathbf{B}_M\right)\dot{\mathbf{x}} + (\mathbf{K} + \omega\mathbf{K}_C)\mathbf{x} = \mathbf{f}_H + \mathbf{f}_A \,. \tag{1}$$

$\mathbf{M}$, $\mathbf{B}_P$, $\mathbf{B}_M$, $\mathbf{G}$, $\mathbf{K}$, $\mathbf{K}_C$ are the mass, external and material damping, gyroscopic, stiffness and circulation matrices of the reduced system, $\mathbf{f}_H$, $\mathbf{f}_A$ are the vectors of hydraulic damping and applied forces, respectively, $\mathbf{x}$ is the vector of the generalized displacements of the reduced system, ω is the angular speed of the rotor rotation, and $(\dot{\ })$, $(\ddot{\ })$ denote the first and second derivatives with respect to time.

Elements of vectors $\mathbf{q}_K$ and $\mathbf{q}_B$ are negatives of the internal generalized forces by which the coupling elements act on the model discs

$$-(\mathbf{K}+\omega\mathbf{K}_C)\mathbf{x}=\mathbf{q}_K\,, \tag{2}$$

$$-\mathbf{B}_M\dot{\mathbf{x}}=\mathbf{q}_B\,. \tag{3}$$

The elements of the coefficient matrices in (2) and (3) are unknown. To determine the stiffness coefficients one generalized displacement (x_j) is chosen, the corresponding generalized internal force is set to one and all other generalized displacements of the reduced system are set to zero. These conditions are used as the boundary conditions imposed to the primary system. Consequently, the chosen displacement x_j and the generalized internal forces related to the zero displacements are calculated. The utilization of equation (2) enables to express the stiffness coefficients in the j-th column. This procedure is repeated for all generalized displacements of the reduced system. Subsequently, an analogous approach is applied to determine elements of the damping matrix in relation (3). Only instead of the generalized displacements, the generalized velocities of the reduced system are used.

3 THE VIBRATION ANALYSIS OF A TWO-DISC ROTOR

The investigated rotor consists of a stepped shaft and of two discs. At both its ends it is coupled with the frame by magnetorheological squeeze film dampers (Fig. 1). The rotor turns at constant angular speed and is loaded by its weight and by unbalance of both discs. The squirrel springs are prestressed to eliminate their deflection caused by the rotor weight.

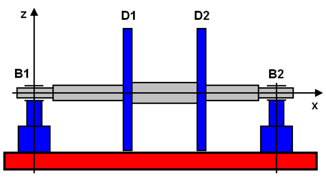

Figure 1: The investigated rotor

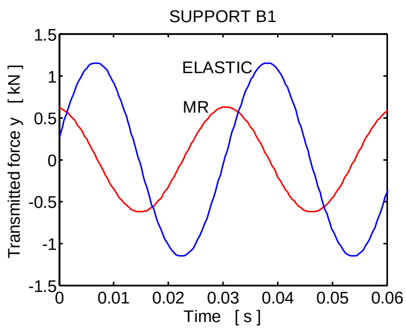

Figure 2: Elastic and damping force

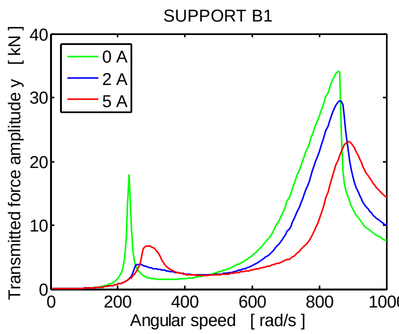

Figure 3: The force - speed relation

The task was to analyse the effect of the magnetorheological squeeze film dampers on supressing the force transmitted to the rotor frame in the specified interval of angular velocities 0 - 1000 rad/s.

The total transmitted force has two components, elastic caused by deflection of the squirrel spring and magnetorheological hydraulic (Fig. 2). The dependence of amplitude of the time varying component of the total force transmitted to the rotor frame at location of support B1 on speed of the rotor rotation is drawn in Fig. 3. The results show that rising damping in the rotor supports shifts the force maximum to higher angular velocities. It is also evident that the maximum reduction of the transmitted force is reached by application of a lower current in vicinity of the first critical speed and of higher one close to the second critical velocity. This clearly shows the advantage of controlling the damping in the rotor supports.

4 CONCLUSIONS

The paper deals with a novel approach to investigation of a two-disc flexible rotor the vibration attenuation of which is controlled by magnetorheological squeeze film dampers placed in the rotor supports. The developed mathematical model is based on application of a discrete system which is intended to perform the dynamical study and on tuning its stiffness and damping parameters by a more complex primary one. The magnetorheological dampers are represented by springs and nonlinear force couplings and the magnetorheological oil by bilinear material. The principal merits of the developed procedure consist in the possibility of investigation of complicated rotor systems, in reducing the computational effort, in increase of stability of the computational procedures, and in highlighting the phenomena that are the subject of the dynamical study.

The research work reported here was made possible by the Czech Science Foundation (project no. 15-06621S) and the National Programme of Sustainability (project LQ1602 - IT4Innovations excellence in science). The support is highly acknowledged.

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