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NUMERICAL AND EXPERIMENTAL STUDY OF ACTIVE THRUST FLUID-FILM BEARINGS WITH FIXED PADS

FLUID-FILM BEARINGS

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The field of research considering mechatronic bearings has been extended recently, although it shall still be considered quite undeveloped and innovative. Studies in this field consider three main possibilities of rotor-bearing units enhancement: design enhancement (textured surfaces, anti-friction coatings, tilting pads), lubricant properties enhancement (polymer additives, magnetorheological fluids), and introduction of intellectual technologies to the conventional designs. The latter is of the most promising trends, as the functionality of mechatronic bearings is significantly wider, than that of conventional hydrodynamic or hydrostatic bearings. So, the present research has been implemented in hopes to extend the theory of mechatronic bearings design further by means of presenting the results of modeling and experimental investigation of active thrust fluid-film bearings with fixed pads.

Investigation in the field of rotor's dynamic behaviour control in fluid-film bearings is carried out in the following fields: study of the possibility of profile adjustment of a gap between a rotor and a sleeve or a thrust disk of a bearing, e.g. tilting-pad and some foil bearings [1, 2]; study of the possibility of application of lubricants with adjustable parameters such as viscosity or density, e.g. ferromagnetic fluids [3, 4]; and study of hybrid fluid-film bearings [5, 6], where rotor's position can be adjusted by means of electrohydraulic devices like servo valves.

Numerical simulations of passive hybrid thrust bearings are a base for further modelling of active hybrid thrust bearings, the operational principle of the latter is as follows: a pump, located in the tank with the fluid (water, oil, etc.), supplies the lubricant into the housing of the bearing, which supports the rotor in the axial direction. The pressure data is acquired with the pressure sensors. The data on the present position of the rotor is acquired with a proximity sensor. The signal from the proximity sensor is then processed and compared with the set point value of the desired rotor's position, and necessary adjustments are implemented by means of changing the supply pressure using a servo valve.

Modeling of active thrust fluid-film bearings is based on determination of axial force in the fluid film, a result of joint solution of the Reynolds equation (1) and energy equation (2):

$$\frac{\partial}{\partial \varphi} \left[\frac{\Phi_{\varphi} h^3}{r K_{\varphi} \mu} \frac{\partial p}{\partial \varphi} \right] + \frac{\partial}{\partial r} \left[\frac{\Phi_r h^3}{K_r \mu} \frac{\partial p}{\partial r} \right] = 6\omega r \frac{\partial h_T}{\partial \varphi} + 6\omega r \sigma \frac{\partial \Phi_s}{\partial \varphi} + 12V_y, \quad (1)$$

where Φ_r , Φ_{φ} and Φ_s – radial, circumferential pressure and shear flow factors accordingly which are determined as described in [7,8], h – nominal film thickness, h_T – average film thickness considering elastic deformation due to asperity contact [7, 8], K_{φ} and K_r – viscosity coefficients determined according to [9], p – pressure, μ – dynamic viscosity of the lubricant and is a function of temperature: $\mu = \mu_{in} e^{-\lambda(T-T_s)}$, λ – temperature/viscosity coefficient, μ_{in} – viscosity of the supplied medium, T_s – temperature of the supplied lubricant, ω – angular speed of the shaft, σ – RMS roughness of the surfaces of the rotor's, V_y – velocity of the shaft in the direction of film thickness.

The solution of (1) in the present case requires the following boundary conditions for a single pad:

$$p|_{r=R_{out}} = p_a, p|_{r=R_{in}} = p_s, p|_{\varphi=0} = p|_{\varphi=\alpha_p}, \left. \frac{\partial p}{\partial \varphi} \right|_{\varphi=0} = \left. \frac{\partial p}{\partial \varphi} \right|_{\varphi=\alpha_p},$$

where p_a – ambient pressure, p_s – supplied pressure, i.e. pressure in the feeding chamber, α_p – angular extent of a single pad.

The pressure distribution in a fluid is greatly influenced by the temperature of the fluid and the surrounding surfaces. The temperature distribution is governed by the energy equation, which in many cases has to be solved for a three-dimensional flow. However, for relatively low rotational speeds as shown in [10] a two-dimensional energy equation gives quite accurate results. The energy equation for the present case is as follows:

$$\rho c_p \left(-\frac{h^2}{12\mu} \frac{\partial p}{\partial r} \frac{\partial T}{\partial r} + \left(-\frac{h^2}{12\mu r} \frac{\partial p}{\partial \varphi} + \frac{\omega r}{2} \right) \frac{\partial T}{r \partial \varphi} \right) = \mu \left(\left(\frac{1}{12} \left(\frac{h}{\mu} \frac{\partial p}{\partial r} \right)^2 \right) + \left(\frac{1}{12} \left(\frac{h}{\mu} \frac{\partial p}{r \partial \varphi} \right)^2 + \left(\frac{\omega r}{h} \right)^2 \right) \right), \quad (2)$$

where ρ – fluid's density, c_p – specific heat of the fluid, T – temperature.

The solution of (2) requires the following boundary conditions:

$$T|_{r=R_{in}} = T_s, T|_{\varphi=0} = T|_{\varphi=\alpha_p}, \left. \frac{\partial T}{\partial \varphi} \right|_{\varphi=0} = \left. \frac{\partial T}{\partial \varphi} \right|_{\varphi=\alpha_p},$$

where T_s – temperature of the supplied lubricant.

Numerical solution of (1) and (2) yields pressure and temperature distribution over the surface of the rotor's disk. The procedure is implemented in a series of iterations until a load capacity convergence condition is met.

Additional expressions allow consideration of the influence of a specific control system.

In order to verify the obtained numerical results, a series of experimental studies has been carried out, and based on the obtained comparison results, some conclusions could be drawn to form a number of recommendations regarding the design on active hybrid thrust fluid-film bearings given a specific application.

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REFERENCES

- [1] A. M. Haugaard, I. F. Santos, 2008, "Modeling of Flexible Tilting Pad Journal Bearings With Radial Oil Injection", *Proceedings of the STLE/ASME International Joint Tribology Conference*, pp. 335–337
- [2] G. Aguirre, F. Al-Bender, H. Van Brussel, 2008, "Dynamic stiffness compensation with active aerostatic thrust bearings", *PROCEEDINGS OF ISMA*, pp. 105-118
- [3] H. Urreta, Z. Leicht, 2009, "Hydrodynamic bearing lubricated with magnetic fluids", *Journal of Physics Conference Series*, **149**

- [4] A. Yu. Albagachiev, V.D. Danilov, 2016, "Magnetic liquid in the regime of hydrodynamic grease", *Bulletin of the Bryansk State Technical University*, **3**, pp. 90-93
- [5] P. Kytka, B. Riemann, R. Nordmann, 2000, "Application of Feedforward-Disturbance-Compensation and Input-Shaping to a Machinez-Axis in Active Hydrostatic Bearings", *Proceedings of the 9th International Conference on Motion and Vibration Control*
- [6] L.A. Savin, S.V. Mayorov, D.V. Shutin, A.Y. Babin, 2016, Rotor trajectories in fluid-film bearings, adjustment of them and energy efficiency parameters, *Proceedings of ICMRR MATEC Web of Conferences* **77**, 5 p.
- [7] N. Patir, H. S. Cheng, 1978, An Average Flow Model for Determining Effects of Three-dimensional Roughness on Partial Hydrodynamic Lubrication, *ASME J. Lubr. Technol.*, **100**, pp. 12–17
- [8] N. Patir, H. S. Cheng, 1979, Application of the Average Flow Model to the Lubrication Between Rough Sliding Surfaces, *ASME J. Lubr. Technol.*, **101**, pp. 220–229
- [9] N. Tepey, V.N. Constantinescu, 1964, Plain bearings: calculation, design, lubrication, *Publishing House of the Academy of Sciences of the RNR*, 458 p.
- [10] I. Chatzisavvas, A. Boyaci, A. Lehn, M. Mahner, B. Schweizer, P. Koutsovasilis, 2016, On the influence of thrust bearings on the nonlinear rotor vibrations of turbochargers, *Proceedings of ASME Turbo Expo 2016: Turbomachinery Technical Conference and Exposition*, 10 p.

KEYWORDS

Hydrodynamics:Hydrodynamic Bearings (General), Components:Hydraulic Valves, Hydrodynamics:Load-Carrying Capacity.