Influence of a Control System in an Active Journal Hybrid Bearing on the Energy Parameters of its Operation

Denis Shutin, Leonid Savin, Roman Polyakov

Abstract**—**Energy efficiency is an essential parameter of bearings, especially in heavy-duty and complexly loaded rotary machines. Control systems integrated in fluid-film bearings are able to expand the range of operating modes of such systems. It allows searching for modes with lower power losses due to friction than can be reached in convenient passive systems. This study shows influence of the controller type, its settings and setpoint value on such power losses in rotary machines with journal hybrid bearings. The obtained results of the study allow choosing and tuning controllers of such bearings so that power losses due to friction are minimized.

Keywords**—**Active bearing; fluid-film bearing; hybrid bearing; control system; proportional controller; adaptive controller; power losses; friction.

I. INTRODUCTION

Energy efficiency is one of the most important qualities of modern technical systems, including rotating machinery. Rotary machines usually perform a large amount of mechanical work. Thus, reduction of power losses provides significant economic benefits during its operation.

Friction in bearings is a significant factor of power losses in rotary machines. Some types of bearings, such as active magnetic bearings and bearings with gas lubrication, provide extremely low value of friction. Though, its application in rotating machinery is limited due to different reasons, such as high price, complexity (magnetic bearings) or limited load capacity (gas bearings). Fluid film bearings provide higher power loss due to friction than the types of bearings mentioned above but are often applied to heavy and complexly loaded machinery due to its high load capacity. Thereby, there is an actual problem of minimization of energy consumption in fluid-film bearings.

Power losses in fluid film bearings depend on many factors. Influence of design parameters on energy efficiency has been studied in various works, e.g. [1,2]. Generally, optimization of design parameters in order to reduce power losses is a challenging task, especially if it is necessary to optimize many parameters. It may be solved using modern computing means including algorithmic means. So, paper [3] shows application of genetic algorithms for solving the mentioned problem.

However, there are limits in energy efficiency in conventional approach to designing bearings when only passive components are used. This is due to physical limitations of the operating modes. Active control technologies became available for allying in fluid-film bearings due to development of computational facilities and hardware used in control systems. Using active control elements in fluid-film bearings allow sufficient expanding the range of available operating modes. Some of these new modes may provide better energy efficiency of the rotor-bearing system than traditional solutions.

II. BACKGROUND OF THE PROBLEM

Control systems can sufficiently change operation of rotor-bearing systems. In active bearings the rotor is able to make movements in modes that are unavailable in conventional passive bearings. Moreover, parameters of rotor motion in active bearings are constantly controlled and corrected if necessary. It makes possible obtaining various specific operation modes including rotor movement modes with minimal power loss due to friction.

Approaches and solutions used in active fluid-film bearings are relatively new, so the problems of energy effective rotor motion have been almost not considered by researchers. So, the main problem of the present study was investigation of the basic rotor operation modes that can be provided by active bearings in terms of energy efficiency.

Control laws and their parameters determine the specific rotor motion modes in active bearings. Different bearing parameters can be adjusted by control system, e.g. stiffness, damping or directly the rotor position inside the bearing. Control of stiffness and damping is easier to implement but such control techniques can influence the rotor behavior only in general, uncertainties in some operation modes still can exist. Direct control of the rotor position is the most difficult and resource intensive task, but such systems provide full control of rotor motion in most of cases. This principle is implemented in an active journal hybrid bearing (AJHB) that is the object of the present study.

Since the rotor position is the controlled parameter in AJHB, the setpoint can be set at any place inside the bearing, not only at the dynamic equilibrium curve (a hypothetic curve

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describing the set of possible positions of a perfectly balanced rotor at different rotation frequencies, see figure 1). So, determining of the setpoint values corresponding to minimal power loss due to friction in the bearing is the first of the particular problems being solved in the present study.

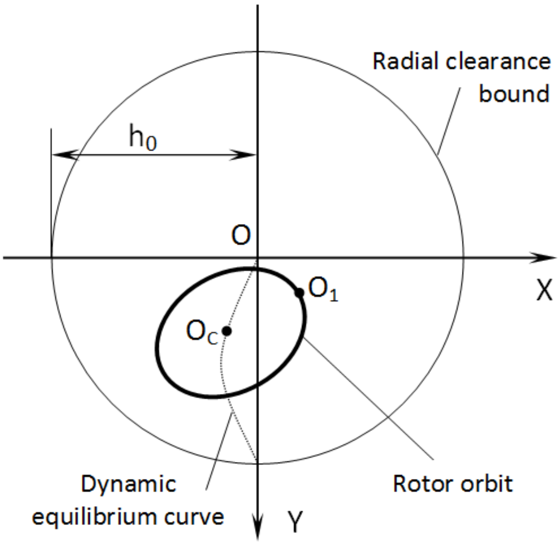

Fig.1. Position of rotor in the bearing

It has previously been shown that different types of controllers in AJHB can successfully reduce rotor vibrations level [4]. Wherein no evaluation of influence of the control system on power losses in the rotor-bearing system has been carried out. In this regard power loss due to friction in passive and active journal hybrid bearings with various types and settings of controllers have been investigated and compared in the present study.

III. Active Hybrid Bearing as the Object of the Study

A. *Design and operation*

AJHB is a hybrid bearing where the lubricant pressure at supply points can be separately adjusted by pressure control devices, such as servovalves. It leads to change of pressure distribution in the bearing and controllable change of force acting on rotor and creating the load capacity. This force changes rotor position described by coordinates X and Y of its central point within the radial clearance bound (figure 1). The principle of operation of AJHB is shown in more details in [5].

B. *Control system*

The AJHB control system is a closed-loop system with two loops corresponding to rotor coordinates X and Y. The general structure of a control system is shown in figure 2, where SA is a setpoint adjustment device, CNV is a signal converter, A is a signal amplifier, SV is a servovalve, RBU is a rotor-bearing unit, MC is a measurement channel, X_0 and Y_0 are setpoint values, ε is a control error signal, u is a control signal and p is pressure control signal. Controller CTR operates according to proportional or adaptive control law. The cross-connections C appear only with adaptive controller. The more detailed description of the control system and control laws is shown in [4].

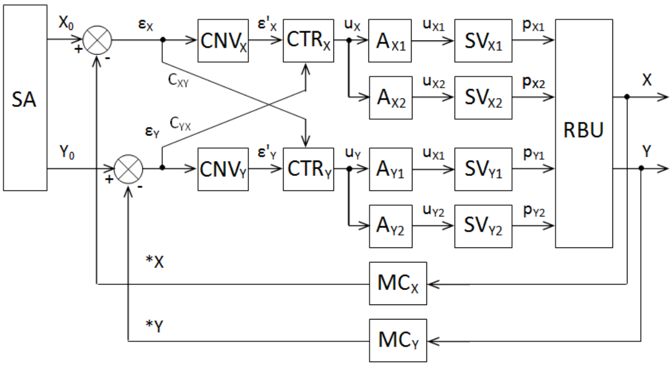

Fig.2. Structure of the AHB control system

C. *Modeling*

Modeling of operation of AJHB has been implemented on solving the Reynold's equation describing the pressure distribution in the bearing; equations describing dynamics of a rigid rotor; equations describing operation of the control system. Derivative equations have been solved using the finite differences method. Iterative solving of the quasi-stationary task allows obtaining the set of rotor positions. The modeling process is described in more details in [5]. The equation used for calculation the power of friction force N_F is:

$$N_F = \omega \frac{D}{2} \int_0^L \int_0^{\pi D} \left[\frac{h}{2} \frac{\partial p}{\partial x} + \frac{U \mu K_x}{h} \right] dx dz \qquad (1)$$

where ω is rotation speed, D and L are bearing diameter and length, h is a function describing the gap between the rotor and the bearing, U is a linear speed of a point on the rotor surface, p is lubricant pressure and K_x is the turbulence coefficient.

The specific parameters of the bearing modeled during this study were: rotor diameter is 40 mm, radial clearance is 100μ, bearing length is 60 mm, rotor mass is 6 kg, lubricant is water, maximum lubricant pressure is 0.5 MPa, temperature is 20 ^{0}C, the servovalve time constant is 1/250 s.

IV. Results and Discussion

A. *Control law and power losses*

Estimation of influence of control system on power losses in a hybrid bearing has been made by simulation its operation during 200ms with rotation speed of 3000 rpm and constant imbalance value of $5 \cdot 10^{-4}$ m. Simulation has been carried out for passive JHB (AJHB with the control system turned off and constant lubricant pressure in all injection points) and for active JHB with two types of controller – proportional and adaptive. The gain of the proportional controller varied from 1 to 15 with step of 1. In the adaptive controller the adaptation coefficient varied from 0.2 to 3 with step of 0.2. The adaptation coefficient sets how fast the total controller gain changes depending on the control error value. For each set of the system's parameters the power loss at each simulation iteration has been calculated according to the equation (1). Total energy loss due to friction during all the simulation period has been calculated using numeric integration. The obtained data is shown in the figure 3.

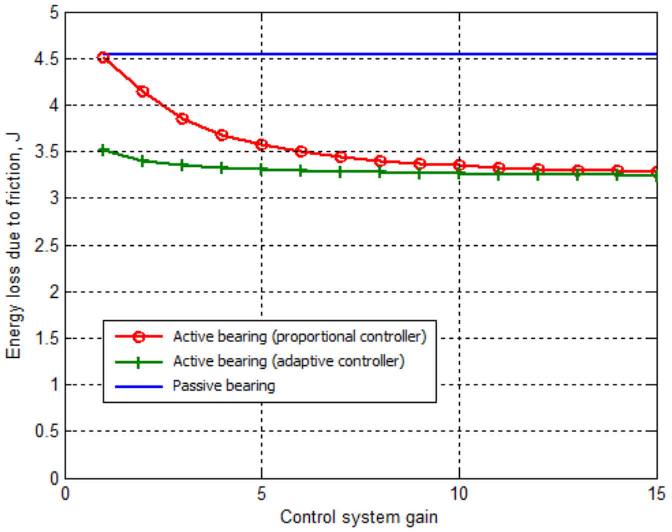

Fig.3. Energy loss with different controller types and settings

As can be seen from the obtained data, active control system in fluid-film bearings provides lower energy consumption with both proportional and adaptive controllers. Increasing the gain of the proportional controller leads to reduction of power loss due to friction simultaneously with the reduction of the rotor oscillations amplitude. Decreasing the energy consumption level is up to 26% less than in the passive bearing. The adaptive controller provides better decreasing of energy consumption due to the fact that it continuously increases the control system gain. For both controller types energy consumption decreases down to the same level. It is due to limitations of power of the control systems impact. Increasing its power would allow achieving even lower energy consumption.

B. Setpoint and power losses

In order to estimate the influence of the setpoint position on power losses in the bearing the area of possible setpoints values has been covered by a mesh. The nodes of the mesh are distributed with the step of $\pi/8$ in the circumferential direction and with the step of 1/10 of the radial clearance h_0 in the radial direction. Then a number of computational experiments has been held with the setpoint of the control system corresponding to each node of the mesh. The scheme illustrating the distribution of the setpoints is shown in the figure 4.

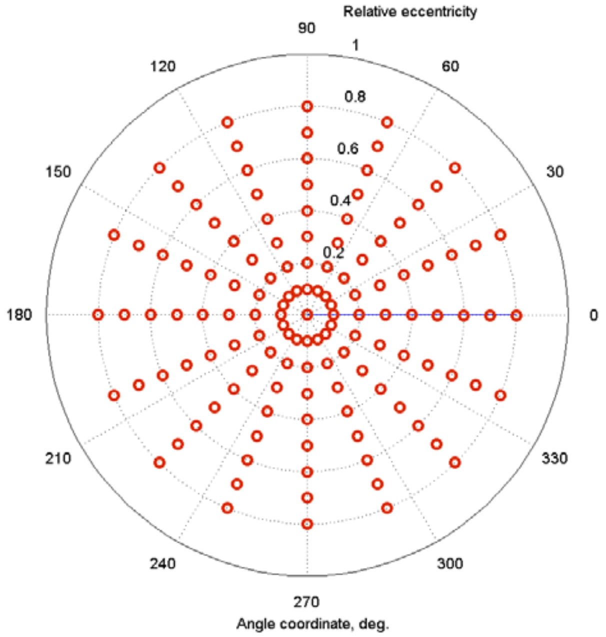

Fig.4. Setpoints values of the modeled system

Simulation has been carried out for each setpoint value with the following parameters: duration of simulation period is of 100 ms, rotation speed is of 3000 rpm and the constant imbalance value is of $4\cdot10^{-4}$ m. Energy loss due to friction has been calculated the same way as it was described above. The obtained data is shown in the figure 5.

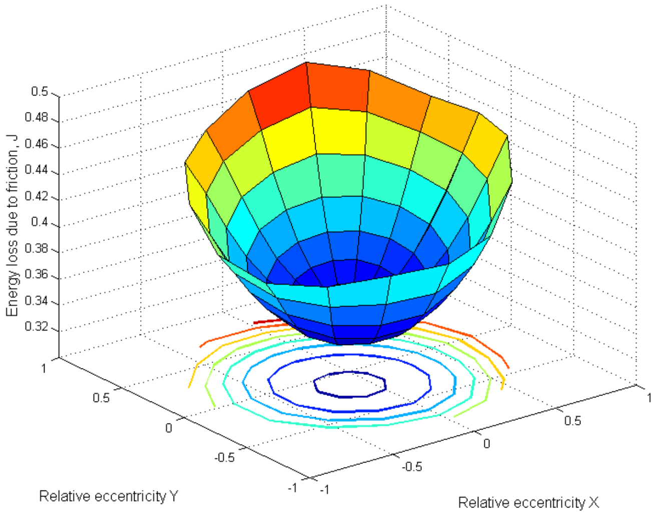

Fig.5. Energy loss for different setpoints

Modeling shows that there is a conditional area in the bearing that provides minimal friction when the setpoint of the control system is within this area. Distancing of the setpoint from this zone leads to growth of energy loss due to friction.

It should be noted that in the AJHB the actual position of the rotor orbit center may not match with the setpoint, especially at high eccentricity values in the direction from the center of the bearing opposite to the gravitation vector. The example of such situation is shown in the figure 6.

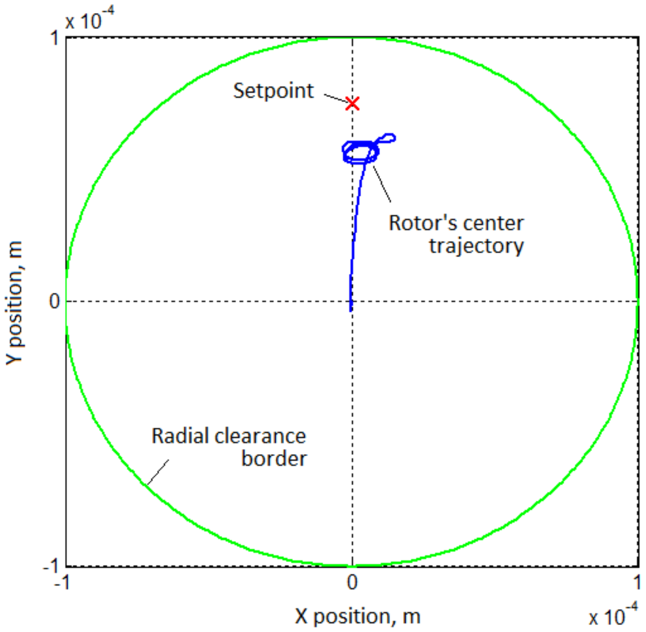

Fig.6. Mismatching of setpoint and actual position of the orbit center

It is due to the limited power of the control signal (the pressure of the lubricant injection). Its power can be increased by increasing the lubricant pressure before the pressure control device. However it also leads to increase of the energy amount required for pumping the lubricant. So, the ratio between the reduction of power losses due to friction the way described above and the additional energy consumption by elements of the control system of AJHB has to be additionally investigated.

C. Estimation of the particular case of power losses reduction

Applying together the results shown above allows showing the possible effect of reduction of power loss due to friction in fluid-film bearings by using control systems with direct rotor positioning function. The operation of the active and the passive journal hybrid bearing has been simulated with the parameters as follow: duration of simulation period is of 10 s, rotation speed is of 3000 rpm and the constant imbalance value is of $8 \cdot 10^{-4}$ m. The controller of the AJHB was the adaptive controller with the adaptation coefficient of 1. The setpoint in the AJHB has been chosen according to the diagram similar to that shown in the figure 5, the coordinates of the setpoint were: 0 m at the X axis and $0.6 \cdot h_0$ ($-5 \cdot 10^{-5}$ m) at the Y axis. The result of simulation with these parameters is shown in the figure 7 as the Experiment I. Another value of the setpoint in the simulated system matched the position of the rotor center at the dynamic equilibrium curve with the coordinates: $0.05 \cdot h_0$ ($-0.5 \cdot 10^{-5}$ m) at the X axis and $2.3 \cdot h_0$ ($2.3 \cdot 10^{-5}$ m) at the X axis. The result of simulation with these parameters is shown in the figure 7 as the Experiment II. Experiment III shows the result for the passive bearing.

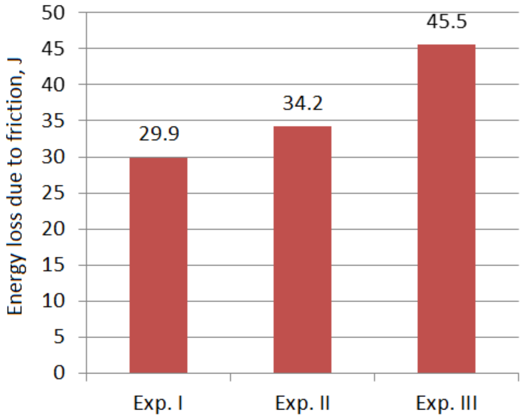

Fig.7. Comparison of energy loss due to friction in passive and in active bearings

Using active control system in the bearing resulted in reduction of energy loss due to friction of 25% without the forced change of the rotor orbit position. Placing it to the more energy efficient position by setting another setpoint value resulted in additional reduction of energy loss of 9%. In general the energy loss has been reduced by 34% comparing to the passive bearing.

V. CONCLUSION

Summarizing the present study we can say that integration of control systems in fluid film bearings allows providing reduction of power loss due to friction. The results obtained in the present study will be used for improving control systems of AJHB, namely at developing the control algorithms providing minimal power loss due to friction. The calculation modules created during the study will be used for tuning the control systems of AJHB.

With that, there is a need for the further research in energy efficiency of rotating machinery with AJHB. It is necessary to study the ratio of the benefits in energy consumption obtained by applying the control system in fluid-film bearings and the energy consumption of the control system itself. After the study a range of parameters of the rotor-bearing system will be determined that would provide energy saving from the point of view of economic efficiency.

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