DYNAMIC LOADING SYSTEM FOR AIR BEARING TESTING
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Abstract:
Reducing friction between moving surfaces helps reducing the overall energy consumption of mechanical machinery in industry. Air bearings offer very low friction between the bearing and its counter surface, but their behaviour under static and especially dynamic loading is difficult to predict.

In this paper, a test system for studying the behaviour of bearings under static and dynamic loading is presented. The test system consists of a piezo actuator controlled by computer that is generating the load for a aerostatic thrust bearing. The bearing is loaded against a large circular counter surface. During the tests measurements of the loading force, frequency, air consumption and the air film thickness between the bearing and the counter surface are collected on a PC.

Results show that the presented test rig can be used to determine the dynamic characteristics of air bearings.

Key words: dynamic loading system, piezo actuator, air bearings, frequency, counter surface.

1. INTRODUCTION

Air bearings are typically used in applications where frictionless and high precision motion is required. Typical examples of high precision application are high precision measurement systems [1][2]. Air bearing application exploiting low friction can be found in laboratory equipment and in devices moving heavy loads on floor. The need to reduce power consumption and improve efficiency of different machines opens new possibilities for air bearing technology. For example, oil lubricated journal bearings have tendency to transform energy to heat [3]. To meet the requirement of low power consumption, air bearings must be able run without extensive leakage in industrial applications at rough environment under dynamic loading.

The main characteristics of air bearings are load capacity, air gap height and air consumption. These characteristics are typically measured in laboratory conditions. These measurements are based on static loading of the air bearing on a rotating counter surface [4], or a rotating runner [4][5]. Several attempts to model the dynamic behaviour of thrust air bearings have been made [6][7]. In order to experimentally determine the characteristics of air bearing under dynamic load the test setup was developed. Obtaining result of the dynamic response will not only aid in predicting the behaviour of air bearings in typical applications but also help the design of air bearings for new, more robust industrial environments [8].

2. METHODS

2.1. Test rig structure
Dynamic loading system is designed to be movable and easy to use in different test setups. This makes it possible to use different types of counter surfaces and different load directions. Considering that the system is built on a 30 mm thick steel base plate that can be fixed to various locations. The basic concept can be seen in Figure 1.
The test rig is attached to the large-size lathe (1M65). It was chosen as a base for the test rig because of the rigid structure and precise guide ways. It offers also a simple mechanism to adjust the preload of air bearing.

2.2. Loading and load measurement
A piezo actuator was selected for this study because it provides the required load and displacement. The fast piezo actuator makes it possible to load bearing dynamically with different wave forms. The used piezo actuator can provide a load up to 2500 N, which meets the loading requirement. The actuator is designed to provide a displacement of 60 μm at 100 V input. Preload of the air bearing is adjusted with the hand screw of the tool side in the lathe.

The 5 kN force transducer (HBM U2B), that measures the bearing load, is fixed between piezo actuator and 20 mm diameter shaft. Air bearing is fixed to the shaft by a threaded stud and a ball joint. The ball joint ensures the parallelism between air bearing and counter surfaces. The 20 mm diameter shaft is guided by aerostatic bearings (New Way S302001). The whole loading system is fixed on a rigid steel base plate.

2.3. Air gap height measurement
The air gap height between the bearing surface and the counter surface is measured with three displacement transducers. Using three displacement transducers allows the measurement of the bearing alignment, as well. The displacement transducers are attached to the bearing via a fixing collar.

This same measurement configuration has been used in the previous air bearing studies successfully [4]. Test system needs high precision displacement measurement so eddy current sensors were chosen (MicroEpsilon, 1mm measurement range). Eddy current sensors are very sensitive to the material type, surface quality, geometry and inhomogeneity in the counter surface material. Thus the sensors were calibrated by pushing the bearing against the counter surface with 100 N preload and measuring the actual zero positions of each sensor. During the calibration the air feed for the bearing was disconnected.

Measuring the air gap height with displacement sensors directly attached to the bearing minimizes the errors occurring from the deformation of the test system. The force measurement was placed between the piezo actuator and the shaft, which was supported by nearly frictionless air bearings, to minimize the error generated by friction forces.
2.4. Air supply
Air bearings need stable and high quality air feed to work properly. A precision regulator with a gauge (SMC IR1020) was fitted to the air feed line. The system pressure was set to 5.2 bar during the tests. Air consumption in the bearing during the tests is measured using two different flow meters (SMC PFM710, measuring range 0.2…10 l/min and FESTO SFE3, measuring range 5…50 l/min) to ensure wide measuring range. Air quality was guaranteed using a service unit between shop air supply and test system that consisted of a filter (SMC air filter), two separators (mist separator AFM20, micro mist separator AFD20) and pressure regulator (SMC AR20).

2.5. Data acquisition
The data coming from the sensors and measurement devices are recorded on a PC. To ensure sufficient resolution and sampling rate in the recording, a 14-bit analogue-to-digital board running at 10 kHz, was used. To avoid aliasing in the recording an analogue low pass filter at 2.5 kHz was used before the data sampling. Average duration of measurements was 10 seconds. Data from each measurement was stored in a PC for analysis. During static loading tests the measurement results were based on the average of each channel. Analyses of the dynamic measurement were based on the synchronous averages of the force, displacement, air consumption and air pressure. When running sweep tests to find resonant frequencies of the system, raw data was used to see the behaviour of the system.

2.6 Test Bearing
The test bearing was an aerostatic orifice type air bearing (Nelson Air Corp., FP-C-040) with surface diameter of 100 mm and cylindrical height of 25 mm. The orifice type bearing has 12 equally spaced orifices of 190 µm on a circumference of diameter 63 mm. The connection of the air bearing to the piezo actuator was made by a linking shaft with diameter of 20 mm and a ball mounting screw on which the air bearing sits. The connecting shaft was axially aligned in position by the aid of two cylindrical air bearings which allows the axial movement of the shaft as it distributes the applied load axially on the counter surface. The rear end of the shaft is fixed to a force transduce which measures the applied load and the transducer is mounted on a Piezo-actuator which produces the required load.

2.7 The Counter Surface
A stationary surface fixed firmly to a lathe chuck was used. The counter surface is a large disk of diameter 400 mm with surface roughness of 0.89 µm and 0.76 µm at the radial and circumferential direction respectively.

2.8 Test Categories
Three testing categories were used to study the test rigs performance:
- Low frequency dynamic loading (1 Hz)
  a. Low load (500 N)
  b. High load (1500 N)
- High frequency dynamic loading (200 Hz)
  a. Low load (500 N)
  b. High load (1500 N)
- Frequency sweep dynamic loading (1…400 Hz)
  a. Low load (500 N)
  b. High load (1500 N)
These categories were chosen to see how the test rig behaves under relatively low loading in varying frequencies. The higher load level was chosen to be near the test bearings nominal loading level.

3. RESULTS
3.1 Dynamic measurements at 1 Hz
Dynamic loading was first measured with adjusting the preload to low load (500 N) first and then to high load (1500 N) and by giving the piezo sinusoidal signal of 1 Hz,
so that the amplitude of the force produced by the piezo would be 70 N. Air pressure was 5 bar. The forces and the air gaps can be seen in Figures 2 and 3.

3.2 Dynamic measurements at 200 Hz
The frequency of the load was risen up to 200 Hz sinusoidal signal with same amplitude that was in measurements with 1 Hz. Air pressure was 5 bar. The forces and the air gaps can be seen in Figures 4 and 5.

3.3 Behaviour of the system through frequency range 1...400 Hz
The behaviour of the whole system was tested by sweeping the frequency of loading force from 1 Hz to 400 Hz keeping the same dynamic loading during the measurement. The force creation and air gap can be seen as a function of frequency in the Fig. 6 and 7.

Fig. 2. Force and air gap of dynamic loading at 1 Hz, 500 N preload.

Fig. 3. Force and air gap of dynamic loading at 1 Hz, 1500 N preload.

Fig. 4. Force and air gap of dynamic loading at 200 Hz, 500 N preload.

Fig. 5. Force and air gap of dynamic loading at 200 Hz, 1500 N preload.
4. CONCLUSION

Adding piezo actuator to a air bearing test rig made it possible to run controlled tests with different dynamic loading patterns. By measuring the load, air gap height, air consumption and air pressure it was possible to see the behaviour of the air bearings under various dynamic loads. During sensor calibration it was noted that the system can keep static loading which might be problematic for piezo actuators. The piezo amplifier’s feedback control system was capable to keep the force stationary.

Under low frequency (1 Hz) dynamic loading seen in Figures 2 and 3 the piezo actuator can produce desired sinusoidal force. Under this low frequency loading the air film thickness change was congruent with the force.

Higher frequency loading (200 Hz), Figures 4 and 5, the force generated by the piezo actuator follows less accurately the sinusoidal input signal. Air film thickness shows same kind of behaviour as the force figure although the response is even more uneven. This is partly caused by the force fluctuation.

The behaviour of the test system can be seen in Figures 6 and 7. The amplitude of dynamic force generated by the piezo actuator falls at the frequency of 180…200 Hz and again after 230 Hz. This is supposed to be caused by the test systems dynamic properties. The air film thickness follows the force variation. Variation in air film thickness has local minimum at the frequency of 180…200 Hz and falls again after 230 Hz respectively.

The system works well under low loading frequencies but under higher frequencies the force amplitude starts to drop. Better understanding about the results and their causes could be accomplished by measuring the piezo actuators movement directly in addition to the air film thickness measurements.

No resonances in the mechanical structure of the system were detected under tests. This gives confidence that the system is suitable for this kind of testing. The structure allows easy change of air bearing and it can be fixed to various test beds. This test system makes it possible to easily run tests with various loads and frequencies so that dynamic properties of air bearings can be measured under well controlled and variable loading conditions.

With the built dynamic loading system it is easy to determine if the air bearings are suitable for different environments, like rough industrial circumstances.
5. REFERENCES


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