Experiment Study on the Vibration Characteristics of inner Journal of Sliding Bearing

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Abstract. Sliding bearings are widely used in various types of rotating machinery due to the development of modern industry. The oil film pressure produced by the sliding bearing has very strong nonlinear characteristics. In order to study the dynamic characteristics of sliding bearing in experiments, in this paper, a sliding bearing test rig is restructured. A special acquisition system is designed to measure the vibration of the journal in sliding bearing. The acquisition system consists of optical fiber displacement sensors, pre-processor, data acquisition device, host computer. Several experiments were carried out by the test rig under different rotational speeds, different eccentric masses, and different bearing loads. The effects of the rotational speed, eccentric mass and bearing load on the dynamic characteristics are analyzed and some conclusions are obtained which is consistent with the theory.

1. Introduction
Owing to its low friction, long life, high accuracy and low noise, sliding bearings have a wide range of applications in rotating machine such as turbine and precision machine tool. With the development of modern industry, the rotating machines are working in higher speed and heavier load, and the operation stabilities have become more important. Hence, they have more requirements for sliding bearings and it needs further researches of sliding bearings.

The oil-film force of sliding bearings is nonlinear. It may cause oil whirl and oil oscillation with the increase of rotational speed, and damage the machine eventually [1]. There are numerous studies of oil-film model at present. Zheng [2] investigated the nonlinear characteristics of rotor-bearing system by numerical analogy. Adiletta [3] studied and modified the model of short sliding bearing. Manshoor [4] established a three-dimensional turbulence model for sliding bearing. Through numerical simulation of ANSYS, they found that turbulence has no effect for thin film lubricated sliding bearing.

But the studies of the experiment of sliding bearings are still lacking. Li [5] introduced a general design scheme of a sliding bearings test rig, which includes rotor system, drive system, lubrication system, control system and acquisition system. Hu [6] designed a test machine of large radial bearings and thrust bearings. The radial bearings are located in the inside of the support bearing and the thrust bearings are located in the outside of the support bearing in the test machine. Yang [7] designed a sliding bearings test rig with variable support. The shaft is supported by test radial bearings, and thrust bearings are used at the end of the shaft to ensure rotation accuracy and reduce vibration.

The vibration characteristics of journal are related to the lubrication state in sliding bearing. So it is significative to obtain the vibration characteristics of journals. The measuring methods of vibration characteristics of journal are the same as the measurements of oil film thickness of sliding bearings. Feasible methods of this measurement include eddy current, resistance, capacitance, discharge voltage, optical method and ultrasound [8]. Besides, optical fiber displacement sensor has the advantages of
high sensitivity, small volume, high accuracy, anti-electromagnetic interference and corrosion resistance [9]. It is appropriate for measuring oil film thickness and micro-vibration.

In practice, it is sometimes difficult to measure the oil film thickness at each position of a sliding bearing. A general method is to select several points on a certain cross-section circle for measurement, and then calculate the center of axis and the oil film thickness at each point through geometric relations. Huang [10] calculated the center of axis using two perpendicular sensors. Zhang [11] compared three different settings of sensors: two-point, three-point and four-point. He showed that the calculation from two-point to four-point decreases gradually, but the measurement system becomes more and more complex.

In this paper, the vibration characteristics of journal are investigated using a restructured sliding bearings test rig. Optical fiber displacement sensors, fixed in a special sliding bearing, are used to acquire the vibration. Experiments are perfected to verify the feasibility of improved test rig. The vibration characteristics of the journal are observed with the increase of rotational speed, eccentric mass and bearing load.

2. Design of sliding bearings test rig

The sliding bearing test rig includes rotor system, lubrication system, drive and control system and acquisition system. The lubrication system pump lubricating oil into sliding bearing. The drive and control system, which has sensors to control the speed and drives rotor system. The acquisition system contains several optical fiber displacement sensors, which can extend into the bearing to measure the vibration of the Journal. All the systems are designed base on Machinery Fault Simulator of Spectra Quest, and the restructured test rig is showed in Fig. 1.

![Figure 1. The restructured test rig.](image)

The rotor-bearing system is similar to Jeffcott rotor. A disk is located on the mid of two sliding bearing. The rotor system is driven by an electric motor. A flexible coupling connects the shaft and motor. The rotational speed of motor is monitored by a photosensor and the feedback of sensor is sent to host computer to control the motor speed.

2.1. Lubrication system

The main function of lubrication is to provide lubricating oil with stable pressure for two sliding bearings. Lubrication system includes the motor, oil pump, filter, oil tank, oil pipe, joint, valve, pressure gauge and sliding bearing. The detailed schematic of lubrication system is shown in Fig. 2.
After running the rotor, the motor of pump run and create negative pressure at the inlet of pump. Under the action of atmospheric pressure, the lubricating oil is filtered through the filter and pressed into the outlet of pump. Then the oil is pushed to a dividing device. One part enters two sliding bearings, the other part returns to the tank through a flow control valve.

2.2. Acquisition system

Acquisition system is used to measure the vibration of rotor system including the vibration of journal in sliding bearing. The acquisition system consists of sensors, preprocessor, data acquisition device, host computer.

The vibrations of the disk and journal in sliding bearing are measured by double-circle coaxial optical fiber sensors. The output of this sensor is the ratio of the signal intensity of the two-loop optical fiber, which can effectively eliminate the intrinsic interference such as the change of reflectivity. Fig. 3 shows two probes of sensor. The probe in Fig. 3(b) is used to measure the vibration of disk. The probe in Fig. 3(a) is used to measure the vibration of the journal in sliding bearing. In order to fix the probe in sliding bearing, the front end of the probe is designed as a slender tubular. And the working medium of this probe is oil instead of air.

(a)  

(b)

Figure 3. The probes of sensor.
To install sensors, it is needful to design brackets for fixing and positioning. Especially the sensors for measurement of the inner journal should be assembled in sliding bearing. Therefore, the sliding bearing must be restructured. The scheme of bearing restructuring is to process through-hole in bearing bush, showed in Fig. 4.

The bearing holder also needs to restructure. The split structure is applied and the angel of sensors probe is rotated 45 degrees from horizontal. The modified sliding bearing made up of bush, holder and sensor probe is showed in Fig. 5(a). Fig. 5(b) is the bracket for measurement of disk’s vibration.

3. Experiments and analysis of results
Experiments of the sliding bearing test rig in this paper are perfected, and the vibrations of the disk and journal in sliding bearing are measured. Control variable method is employed in the experiment to investigate the vibration characteristics of the journal with the increase of rotational speed, eccentric mass and bearing load. In the process of speed variation, the interval of rotational speed is 5 Hz. Screws can be attached in the disk to increase the eccentric mass. Regarding the weight of shaft and
disk as the load of sliding bearing, the load can be changed by replacing the disk. The experimental procedure is described as follows:

1) The disk is not installed in the beginning of experiment, and the weight of shaft is the bearing load. Increase the rotational speed at certain interval gradually and measure the vibration signals at different speeds.

2) Install a disk to change the bearing load and repeat the above process.

3) Attach a screw in the disk to increase the eccentric mass and repeat the above process.

3.1. Experiment results

According to reference [12], the acquired data often contain various noise, which will interfere with the vibration characteristics. Holospectrum is used to extract the main vibration component from acquired vibration signal. In holospectrum, motion orbit is supposed as ellipse, describing in horizontal and vertical direction as following:

\[
\begin{align*}
    x &= A \sin(\omega t + \alpha) \\
    y &= B \sin(\omega t + \beta)
\end{align*}
\]

(1)

The values $A, B, \omega, \alpha, \beta$ in above form are determined by spectrum.

In this paper, the vibration is obtained from acquired data by three-point method [11]. Then the spectrum analysis is carried out to extract the holospectrum. The vibration characteristics based on experimental results under different rotational speeds, bearing loads and eccentric masses are studied.

3.1.1. Effect of rotational speed. Fig. 6 shows the spectrum and holospectrum of the vibrations of journal in the rotational speed of 10Hz, 25Hz and 40Hz. With the increase of rotational speed, the vibration amplitude of the journal has increased gradually, but the eccentricity of the 1X holospectrum has decreased.

![Figure 6. The spectrum and holospectrum of the vibrations of journal.](image-url)
Figure 7. The spectrum and holospectrum of the vibrations of the disk.

Fig. 7 shows the spectrum and holospectrum of the vibrations of the disk in the rotational speed of 10Hz, 25Hz and 40Hz. With the increase of rotational speed, the vibration amplitude of the disk has increased gradually too. The eccentricity of the 1X holospectrum has decreased slightly.

3.1.2. Effect of bearing load. Fig. 8 shows the spectrum and holospectrum of the vibrations of journal at bearing load is 0.7kg and 1kg. With the increase of bearing load, the vibration amplitude of the journal has decreased, but the eccentricity of the 1X holospectrum has increased.

Figure 8. The spectrum and holospectrum of the vibrations of journal.
3.1.3. Effect of eccentric mass. Fig. 10 shows the spectrum and holospectrum of the vibrations of journal at two cases: a). There is little eccentric mass of disk without additive masses; 2) 0.0165kg additive mass be attached to disk. With the increase of eccentric mass, the vibration amplitude of the journal has increased significantly, and the eccentricity of the 1X holospectrum has increased slightly.

Figure 10. The spectrum and holospectrum of the vibrations of journal.
4. Conclusion

In this paper, a sliding bearing test rig is designed and built. Optical fiber displacement sensors are fixed in special sliding bearing to measure the vibration of journal. Experiments of this test rig are perfected, and the vibrations of the disk and journal in sliding bearing are measured. After analyzing the experimental results, the effects of rotational speed, bearing load and eccentric mass on the vibration characteristics of journal and disk are obtained. Based on the common rotor model and oil film force model, those effects are also analyzed by numerical simulation. Comparing the experimental results with the numerical results, it is found that the variation regularity is basically the same: With the increase of rotational speed, the amplitude of the journal and disk have increased gradually, the eccentricity of the 1X holospectrum has decreased. With the increase of bearing load, the amplitude of the journal and disk have decreased, the eccentricity of the 1X holospectrum of journal has increased, but the eccentricity of the 1X holospectrum of disk has decreased. With the increase of eccentric mass, the amplitude of the journal and disk have increased, but the eccentricity of the 1X holospectrum has hardly changed.

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