Design and Research of Bearing Reliability Test Bed Based on Multi-Dimensional Vibration Loading

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Abstract. Rolling bearings are widely used in aviation, aerospace and other important fields, and their reliability is greatly affected by external vibration excitation during service. Due to the large volume and high cost of the combined structure of shaking table and test chamber, this paper designed a dynamic reliability test bed specially for rolling bearings to study the influence of external vibration excitation with different directions, frequencies and amplitudes on vibration signals and service life of rolling bearings. The test bed is loaded with external excitation by means of electromagnetic shakers in two directions, and the flexible material is used to realize the displacement of the test chamber under two external excitation directions at the same time. The bearing vibration loading life test carried out by this test bed has important guiding significance for the design of rolling bearing. The experimental results show that the test bed can apply axial and radial vibration loads of 1-800Hz sinusoidal waveform, and the vibration acceleration can reach 1g, which can simulate the effect of actual working conditions.

Keywords. Rolling bearing, test bed, vibration loading, flexible material.

1. Introduction

As one of the commonly used rolling bearings, deep groove ball bearings play a very important role in the field of modern machinery. They are widely used in aviation, aerospace, machine tools, high-speed rail and other high-end mechanical equipment fields [1-3]. The actual operating conditions of high-end equipment put forward extremely strict requirements on the performance of deep groove ball bearings themselves. Most of the domestic deep groove ball bearings are difficult to meet the actual needs of the above high-end fields. Therefore, most of the deep groove ball products in the high-end fields in China actually rely on imports, and its localization is one of the bottlenecks in the field of national basic parts and components.

Generally, due to the size error, machining error and assembly of parts, rolling bearings will produce vibration responses of different degrees in the use process, and the equipment is inevitably affected by external environmental excitation in the actual use process, and the vibration behaviour of bearings under external excitation has a great influence on the bearing life. It is of great significance to study the actual response of rolling bearings under external excitation to improve the reliability of bearings [4-5]. However, due to the neglect of the influence of external factors on bearing tests in the design process of test methods, almost all bearing test stands on the market are not capable of providing external excitation [6-10]. Therefore, a rolling bearing test stand that can simulate external vibration excitation is designed and built. It is of great practical significance to obtain rolling bearing vibration response under various external excitation through experiments.
At present, many domestic units have carried out a variety of studies on different bearing conditions. Wan He et al. from Henan University of Science and Technology designed a rolling bearing testing machine for automotive supercharger according to the development requirements of automotive supercharger rolling bearings, with axial loading only, maximum load of 500N and maximum speed of 90000 r/min [11]. Li Yunfeng et al. [12] of Harbin Institute of Technology designed and built a test and research platform to simulate the harsh working conditions of aviation intermediary bearings. By accurately controlling load and other work-time spectra, the automatic operation and control of the tester can be realized, and the real-time storage of test process parameters can be realized by monitoring the running state of the test. Southwest Jiaotong University [13] developed a high-speed railway bearing test bed based on vibration for high-speed train axle box bearings. By applying vertical excitation to the test system through a 20T water-cooled shaking table, the vertical non-smooth working condition of the actual high-speed railway line was simulated, and the application process of external vibration excitation in one direction was considered and simulated. Li Zheng, Tsinghua University, etc. [14] for extraction and analysis of planet carrier bearing dynamic loading signal, using the vibrator and the form of load lever arm on the bearing outer ring radial vibration excitation, developed a kind of dynamic load to simulate one-way bearing loading device, can be applied to impose unilateral external vibration bearing test rig.

In this paper, a bearing test bed that can simultaneously realize the application of axial and radial external vibration excitation is designed. Two separate electromagnetic shakers are used as external excitation sources to test the rolling bearing vibration data under external vibration excitation. A bearing test method based on external vibration excitation is proposed, and a test is carried out for deep groove ball bearing 6205. The influence of external vibration excitation with different directions, frequencies and amplitudes on the reliability of rolling bearings was analysed.

2. Test Bed Population
The design principle of the rolling bearing reliability test bed based on multidimensional vibration is to load the outer ring of the test bearing with vibration excitation by two electromagnetic shakers from the axial and radial direction of the test bed respectively, and at the same time provide constant static load by hydraulic loading method. Through the innovative structural design, the interaction between loading directions will not occur in the process of realizing the simultaneous application of high frequency excitation in the external two directions. At the same time, the test bed itself also has the characteristics of reasonable mechanical structure, simple installation and operation, accurate test data collection and strong adaptability and adjustment ability. The test bed is composed of mechanical structure main part, motor driving part, hydraulic static load loading part, vibration loading part, lubrication and cooling part and signal transmission and analysis part. The technical parameters of the test bed are shown in table 1. The actual structure distribution of the test bed is shown in figure 1.

| Table 1. Main parameters of electromagnetic shaker. |
|-----------------------------------------------|
| Technical parameters | Value |
| Maximum vibration frequency (Hz) | 800 |
| Maximum vibration force (kN) | 0.5 |
| Maximum speed (r/min) | 12000 |
| Maximum static load (kN) | 10 |
| Bearing diameter range can be tested (mm) | 20-50 |
| Number of bearings available for test | 2 |
3. Test Bed Vibration Loading Structure
The vibration loading structure can apply axial and radial vibration excitation to the test bearing based on the low-frequency vibration condition of the bearing test chamber in actual operation. Vibration system indicators: vibration frequency (sinusoidal, random) 1~800Hz, acceleration ≥1g, amplitude ≥0.2mm. In this paper, the electric shaker is selected as the vibration generator, which can output the corresponding simulated vibration excitation according to the input signal source data.

The working mode of vibration loading system is as follows: waveform generator generates current signal of excitation force waveform and outputs it to power amplifier; The power amplifier receives the current signal, amplifies it, and outputs it to an electric shaker; The input voltage of the electric shaker is rated, and the input current amplitude is set by the power amplifier. The electric shaker applies the exciting force to the bearing box through the jacking rod, and the jacking rod selects a flexible thin rod with good elasticity to protect the shaker.

The working excitation force \( F_z \) of the shaker can be calculated by the following formula

\[
F_z = K_f I
\]

where, \( K_f \) is a constant, and \( I \) is the input current.

The main parameters of electromagnetic shaker are shown in table 2.

Table 2. Main parameters of electromagnetic shaker.

| Technical parameters          | Value       |
|------------------------------|-------------|
| Frequency range (Hz)         | 1~800       |
| Maximum vibration force (N)  | 500         |
| Maximum amplitude of vibration (mm) | -10~10    |
| The force constant (N/A)     | 16          |
| The peak current (A)         | 30          |
| Working temperature(°C)      | -20~70      |

Figure 1. The actual structure distribution of the test bed.

Figure 2. Installation diagram of vibration loading device.
The multi-dimensional vibration system of the test bed exerts axial and radial excitation on the bearing box. In order to prevent the gravity of the bearing box from affecting the effect of the excitation force, the two vibration systems are set in the horizontal direction, and the installation scheme is shown in figure 2. The head of the electric shaker is connected with the bearing box through the excitation rod, and the excitation force is transferred to the bearing box by the excitation rod; The main body of the electric shaker needs to be fixed. The electric shaker is installed on the shaker support, which is fixed to the L-shaped platform by bolts.

Under the action of excitation force, the bearing box needs to be able to produce relative displacement with the mounting table of the base, so as to finally realize the vibration displacement of the bearing box, so the bearing box has a certain translational freedom in the horizontal two directions.

Because of bearing box vibration amplitude is small, bearing box and connected by flexible material base, on the premise of guarantee the installation stiffness, using the flexible material load after the traces of deformation produced, realize the bearing box and the relative displacement between the base plate, and according to the test to choose the natural rubber as flexible interlayer processing of raw materials.

The flexible material connection scheme is shown in figure 3. The flexible material sandwich is added between the four anchor bolt holes of the box under the bearing box and the installation plane of the test bed base. The anchor bolt connects the upper gasket of the flexible material, the lower box foot and the lower gasket of the flexible material to the installation plane of the base of the test bed through the thread to constrain the displacement of the bearing box in the vertical direction; There is a certain clearance inside the anchor bolt hole of the lower box body to ensure the vibration displacement allowance in the horizontal two directions of the bearing box; When the vibration force in the horizontal direction is used in the bearing box, the shear deformation in the direction of the vibration force can be realized due to the flexible material gasket, so that the bearing box produces the relative displacement of the base of the test bed, and finally the multi-dimensional vibration of the bearing box is realized.

4. Design of Test Plan for Test Bed
Test bed of the external vibration loading reference test chamber of shafting installation direction of axial and two radial direction load, the test bed test to load test of two directions, respectively in a fixed static load conditions, were measured and read not load moment under the vibration data with different vibration excitation load level of bearing vibration data, were compared.

During the test, a radial static load of 1000N was applied through the hydraulic loading system, and the motor speed was 1000r/min. The test time of each group was 30 s. The axial and radial tests were divided into 3 groups according to different frequencies and different excitation forces for comparative analysis.

Specific test parameters are shown in table 3.
Table 3. Test scheme operating parameters.

| The test group   | Frequency (Hz) | Force (N) |
|------------------|----------------|-----------|
| Axial group 1    | 100            | 32        |
| Axial group 2    | 500            | 32        |
| Axial group 3    | 100            | 64        |
| Radial group 1   | 100            | 32        |
| Radial group 2   | 500            | 64        |
| Radial group 3   | 100            | 64        |
| Coupling group   | 100            | 32        |

5. Test Bed Test Results Analysis

The test bed after assembly is shown in figure 1. Tests are carried out according to the above test groups and test parameters, and vibration signals are collected for comparative analysis. The comparison of measured vibration data of radial group 3 and frequency domain transformation of radial group 1 are shown in figure 4 and figure 5 respectively.

As shown in the figure, three sets of radial vibration signal of ideal, can clearly see the frequency of the waveform constituting the contrast and amplitude, and obtained by fast Fourier transform spectrum diagram can obvious radial group 1 external vibration main frequency components in vibration signal, determining the validity of the test bed radial external vibration excitation applied.

Comparison of vibration data measured in axial group 3 and frequency domain conversion in axial group 1 are shown in figure 6 and figure 7 respectively.

As shown in the figure, the three groups of axial vibration excitation signals are relatively ideal. Although vibration signals due to the damping of flexible material itself is not the ideal sine waveform signal, can still clearly see the frequency of the waveform constituting the contrast relationship.
between amplitude, and obtained by fast Fourier transform spectrum diagram can clearly see that the axial group 1 external vibration main frequency components in vibration signal, to determine the effectiveness of the test bed radial external vibration excitation applied.

Comparison of vibration data measured by the coupling group is shown in figure 8.

![Figure 8. Vibration signal diagram of axial and radial excitation applied simultaneously.](image)

As shown in the figure, when axial and radial excitation are applied at the same time, due to the structure of the test bearing box, the stiffness and damping in different directions are not the same, resulting in different amplitude of vibration signals under the same external excitation parameters, and the amplitude of axial vibration signals is larger. The shaft and radial vibration signals are more obvious, which proves the effectiveness of applying shaft and radial external vibration excitation simultaneously on the test bed.

6. Conclusion
The actual test results show that: Developed in this paper, based on the reliability of the rolling bearing in the multidimensional vibration test bed, the structure design more reasonable, can change the size of the test shaft by changing the collar, use range wide, runtime system stable and reliable work, respectively through external axial and radial vibration excitation applied test as well as the coupling vibration excitation, testing effect is good, and able to run for a long time, It can fully meet the test needs of practical bearing vibration reliability research.

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