High-speed railway axle box bearing steady-state thermal network analysis model of temperature rise test

Xiaotong Li, Zhange Zhang*, Dong Zhu, Duo Li

School of Mechanical Engineering, Dalian University of Technology, Dalian, Liaoning116023, P R China

Abstract: In high-speed railway train in the course of operation, the high-speed axle boxes drive the axle box bearings to do continuous high-speed movement. Bearing's roller-raceway and roller-flange friction produce a lot of heat that make the surrounding parts of the thermal expansion and thermal deformation and the parts of the force state changes. Therefore, based on the test-bed of train bearing temperature rise test is necessary links for studying the performance of high-speed railway axle bearing. Dalian Diesel Locomotive Research Institute proposed and drafted the TB / T 3000-2000 *Thermal test method of axle box rolling bearing on axle box testing machine*[1]. In this paper, according to the stipulations of the above test method and bearing's thermal network analysis model, the temperature rise performance test of CRH3 high speed railway train group was carried out on the railway bearing testing machine dedicated to temperature research. The results are compared and analyzed, showing that the deviation between the theoretical value and the test value is less than 20%, thus verifying the correctness of the theoretical model.

Keywords: axle box bearing; thermal network analysis model; temperature rise performance test

1 Introduction

Along with the rapid development of the railway transport industry, high-speed railway trains on the bearing performance requirements are also increasing. Axle box bearing as the key part of the train walking part, it affects the operating condition and driving safety[2]. The most common faults in high-speed trains is hot shafts, thermal deformation, heat-generating shafts and so on. Therefore, the research on the temperature distribution of axle box bearings is of great significance.

It can be known that domestic and foreign scholars research is mainly for standard bearings. Non-standard bearings are not applicable. Some scholars have established a tapered roller bearing thermal network analysis model, but did not take into account the bearing's roller-raceway and roller-flange friction and the convective heat transfer between the spindle and the air environment on the temperature distribution and the lack of effective experimental verification[3-6]. In this paper, we establish the

* Corresponding Author (nicege@163.com)

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temperature network model of the axle box bearing temperature and obtain the temperature distribution of the whole bearing in the normal operation. Finally, we verified the correctness of the theoretical model by the railway Netrol-AT.50 / 1 bearing temperature testing machine.

2 Establishment of bearing's thermal network analysis model

2.1 Division of thermal network nodes in Axle box Bearing System

The whole bearing system is divided into eight hot network nodes according to the heat transfer relationship among the components of the bearing system [7]. The hot node distribution and the name are shown in Fig 1.

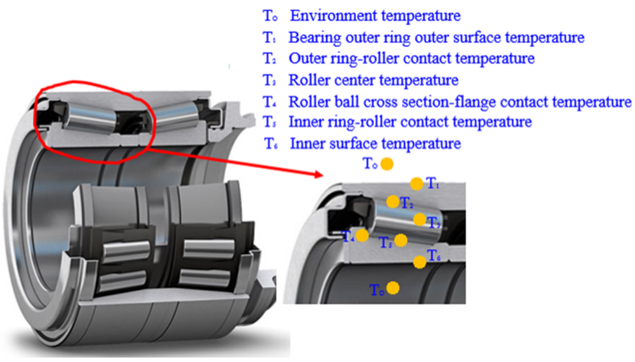


Fig. 1. Thermal network schematic diagram of bearing system

2.2 Establishment of thermal network model for axle .box bearing system

The thermal network method is used to solve the heat problem under steady state, which is based on the theory of heat transfer. The core is the conservation of heat. The seven related thermal network nodes are connected according to the heat transfer relation. The one-dimensional distribution hypothesis is based on temperature. The thermal network model of the axle box bearing system can be obtained as shown in Fig 2.

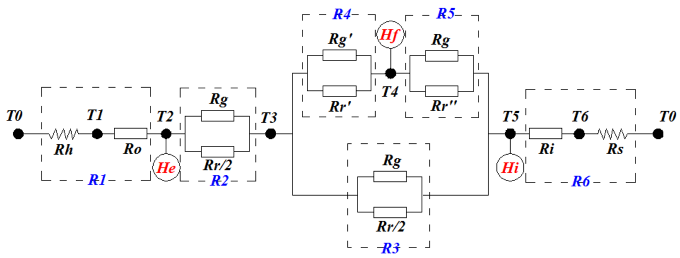


Fig. 2. Thermal network model of bearing system

According to the established thermal network model and the heat transfer relationship of the axle box bearing during the actual operation, the heat diffuse equation of the high iron axle box bearing in the case of thermal steady state can be listed.

$$\begin{cases} H_e = \dfrac{T_2 - T_0}{R_1} + \dfrac{T_2 - T_4}{R_2 + R_4} + \dfrac{T_2 - T_5}{R_2 + R_3} \\ H_f = \dfrac{T_4 - T_2}{R_2 + R_4} + \dfrac{T_4 - T_5}{R_5} \\ H_i = \dfrac{T_5 - T_0}{R_6} + \dfrac{T_5 - T_4}{R_5} + \dfrac{T_5 - T_2}{R_2 + R_3} \\ \dfrac{T_2 - T_3}{R_2} = \dfrac{T_3 - T_5}{R_3} + \dfrac{T_3 - T_4}{R_4} \\ \dfrac{T_3 - T_2}{R_2} = \dfrac{T_2 - T_1}{R_o} \\ \dfrac{T_2 - T_1}{R_o} = \dfrac{T_1 - T_0}{R_h} \\ \dfrac{T_5 - T_6}{R_i} = \dfrac{T_6 - T_0}{R_s} \end{cases} \tag{1}$$

$$\begin{cases} R_1 = R_h + R_o \\ R_2 = \dfrac{1}{2} R_r + R_g \\ R_3 = \dfrac{1}{2} R_r + R_g \\ R_4 = R_g' + R_r' \\ R_5 = R_g + R_r'' \\ R_6 = R_i + R_s \end{cases} \tag{2}$$

where, Rh, Ro, Rr, Rg, Ri, Rs are the bearing chock, bearing outer ring, rolling body, lubricating oil film, bearing inner ring, shaft thermal resistance; Rr 'and Rr "size depends on the position where taper roller ball end and inner ring contact. In addition, Rr '+ Rr "= Rr / 2.

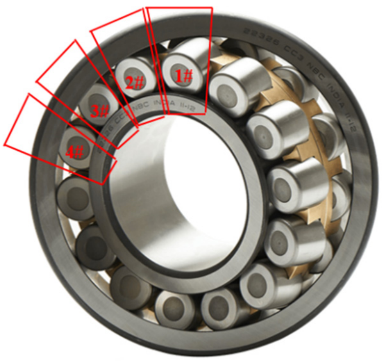


Fig. 3. Number of analysis cells

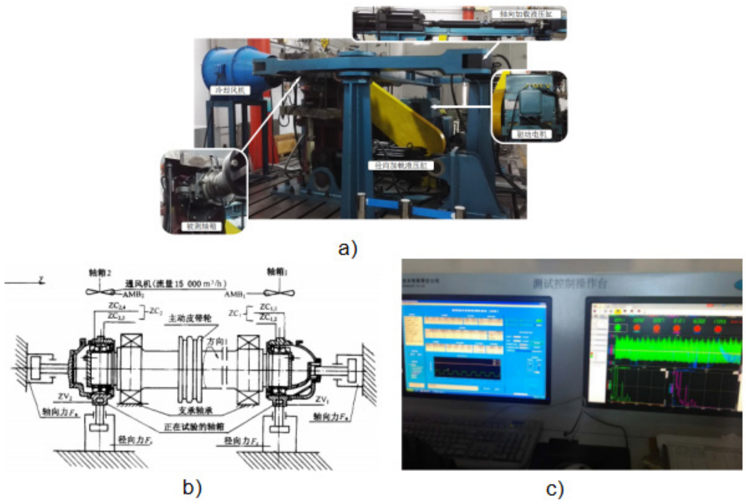
Define CRH3 type high-speed axle box bearing the largest loaded roller and contact inner and outer raceway as analysis unit of 1 #. And the adjacent roller raceway composed of the analysis unit followed by 2 # unit, 3 # unit, 4 # unit, and so on, the analysis unit diagram shown in Fig 3.

Through the above analysis, the steady state thermal network theory model of the axle box bearing is obtained, so the theoretical model of temperature distribution of axle box bearing can be easily obtained. Taking the axle box bearing of CRH3 high-speed trains as example, each roller is connected with the inner and outer rings as a solving unit to solve the thermal resistance of each component in each solution unit. In the end, the solution unit is established as a bearing whole and the temperature distribution of the whole bearing in the heat steady state is obtained.

3 Thermal test principle and test method of high-speed railway train

3.1 High-speed railway axle box bearing thermal test equipment

This test is carried out on a Netrol-AT.50 / 1 type railway bearing testing machine. The main body of the testing machine is horizontal structure including the main shaft, two test axle box, radial and axial load loading system, drive device, ventilation device and base, etc. The maximum speed of the motor is 5000r / min and the maximum radial load can be applied to 500KN and the maximum axial load is 250KN and the total ventilation of each axle box is 15000m^3 / h and the relative wind speed of the axle box in the same horizontal plane is 30km / h. It's physical map and structure diagram shown in Fig 4.



a) Railway bearing thermal testing machine b) Operation system platform c)Schematic diagram of thermal testing machine

Fig. 4. Thermal experiment machine of railway bearing

3.2 The choice of temperature measurement points

The temperature test of the axle box bearing totally include 12 points of which four main points monitor the measured axle box bearing temperature rise and the remaining measuring points are used to monitor the temperature of the observation zone, the supporting bearing temperature and the ambient temperature. It's important to ensure real-time monitoring and performance comparison of the entire axle box system and test system during the test time.

Because the axle box bearing inner ring rotation and the fixed outer ring, the temperature rise measuring point arrange in the bearing outer ring. Measuring points need to be close to the roller and raceway contact area, so that more directly and rapidly reflect the bearing temperature rise signal. Second, the placement of the measuring point should take into account the rigidity of the bearing system, so that bearing capacity and other operational performance is not affected. At the same time, the layout of the measuring point should take into account the surrounding environmental factors.

3.3 Setting of spindle speed

The bearing to be filled with the new grease will be subjected to a cycle test on a bearing test machine at a cycle of 4 hours. This experiment will be carried out for 85 cycles. The simulated vehicle run at measured speed for 340h and runs about 129200km. Each 4-hour cycle is divided into 2h positive direction rotation and 2h counter-direction rotation. The change in spindle speed during the 2h cycle is as follows. In the 0-15min, the spindle speed increases linearly with time; 15-105min, the spindle to the maximum speed of continuous rotation; 105-120min, the spindle stops rotating, and maintain continuous ventilation [8].

3.4 Apply bearing load

According to the *People's Republic of China Railway Industry Standard TB / T 3000-2000*, the measured value of the load applied to the bearing test machine on the axle box bearing is as follows:

Static radial force Fr, kN:

$$F_r = 1.2 \times 1/2 \times 9.81/10^3 \times m_1 \tag{3}$$

Where: 1.2 - safety factor; 1/2 correlation coefficient with axle box; 9.81 - gravity acceleration, m / s2; m1 - the mass of the shaft diameter, kg

Alternating axial force Fa, kN:

$$F_a = 1.2 \times 1/2 \times 0.5 \times \{0.85[10 + 9.81(m_1 + m_2)/(3 \times 10^3)]\} \tag{4}$$

Where: 1.2- safety factor; 1/2- correlation coefficient associated with axlebox; 0.5- factor specified in consideration of the average value encountered in actual use; 9.81 - gravity acceleration, m / s2; (m1 + m2) Weight, kg [9]

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3.5 Measurement and inspection

During the temperature rise test of the entire High-speed railway train bearing, the following parameters were measured:

(1) The bearing temperature of the load area (ZC) is measured by a thermocouple mounted on the bearing outer ring;

(2) The temperature of the observation zone of the axle box heat detector (ZV) is measured by a thermocouple sensor attached to the box box;

(3) The ambient temperature (AMB) is measured by a thermocouple which is set in the air flow to the test machine;

(4) The bearing speed is measured by the torque speed sensor;

After the end of the thermal test, we should check the bearing parts of the appearance and smooth running.

4 Test Results and Analysis of high-speed railway axle bearing

According to the above test method, temperature test is carried out with F-807811.12. TAROL130 / 240-B-TVP double row tapered roller bearings [10][11]. Apply radial force 91KN, axial force 17KN, axle maximum speed 2400rpm. Simulated train wheel diameter is 0.85m and speed is 385km / h.

Every 4 hours for a test cycle, each test cycle can be divided into 2h positive-direction rotation and 2h counter-direction rotation. Due to the symmetry of the axle box bearing structure, the influence of the rotation direction is light for the bearing temperature rise under the same load condition. Therefore, this paper chooses the first 120 min of each 4h cycle to be transferred as the study object.

The data is recorded once every cycle and we observe the record 1 # bearing test point 1 temperature changes, as shown in Fig. 6.

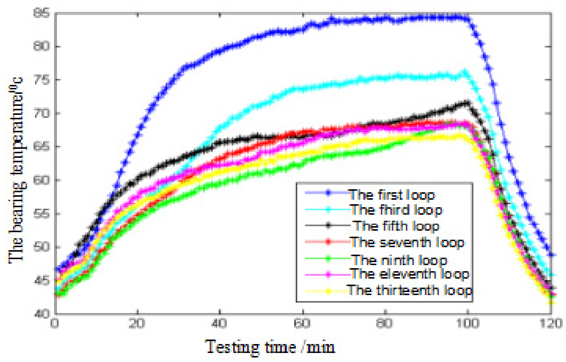
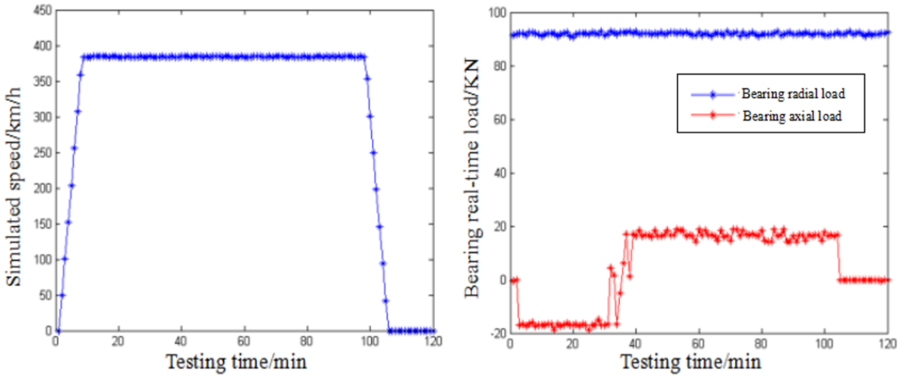


Fig. 5. Temperature's change trend of each circulation

As shown in Figure 6, the bearing measuring point temperature in the cycle of the trend is consistent. However, the bearing temperature has a dramatic increase in the first loop and the third loop. The reason is that the new bearings, although after a good lubrication procedures, are still serious running problems [12][13]. In addition, seventh, ninth, eleventh, thirteenth cycle of the temperature trend is similar. The maximum temperature difference is within 14%. At this time, the bearing components have entered the normal wear phase. Therefore, this paper selects the eleventh cycle of data for analysis.

According to the data feedback of the monitoring software, when the bearing is in the eleventh cycle, the rotational speed of the spindle and the load on the loaded bearing are shown in Fig. 7.



a) Bearing load condition b)The spindle load

Fig. 6. Schematic diagram of experiment conditions

Through the thermocouple sensor, the temperature change of the four measuring points of the two measured bearings in the eleventh cycle is collected and arranged in Fig. 8.

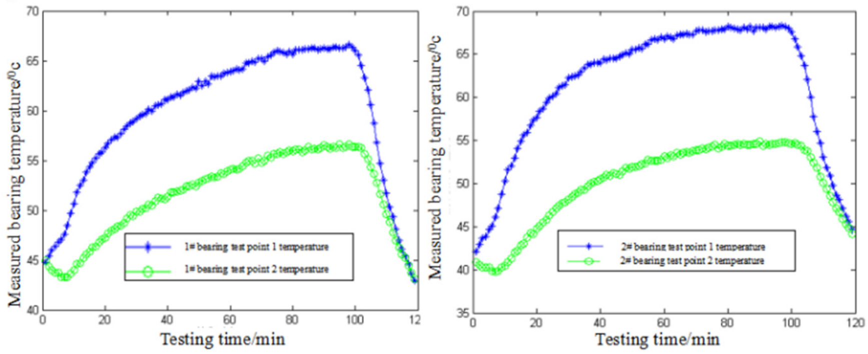


Fig. 7. Temperature change curve of measuring point

As shown in the Fig.8

1) The temperature trend of 1 # bearing and 2 # bearing is similar, but in the specific temperature and heating rate is slightly different. This is caused by the manufacturing error, surface quality, installation error and lubrication difference between the two bearings at the factory.

2) During the test, the temperature at the bearing test point 1 is always higher than the temperature at the test point 2. This is caused by the difference in the contact load of the different contact area rollers, which leads to the difference in the magnitude of the friction and the amount of friction heat.

3) At the beginning of the experiment, the heat generated by the friction is less than the heat dissipated around the bearing outer ring, so that the temperature drop. With the increase in speed, the friction heat gradually increased. when the friction inside the bearing heat is greater than the heat transfer to the outside, the bearing test point 2 temperature increased. Temperature variation and temperature difference of the same measurement points of the two bearings are shown in Fig. 9.

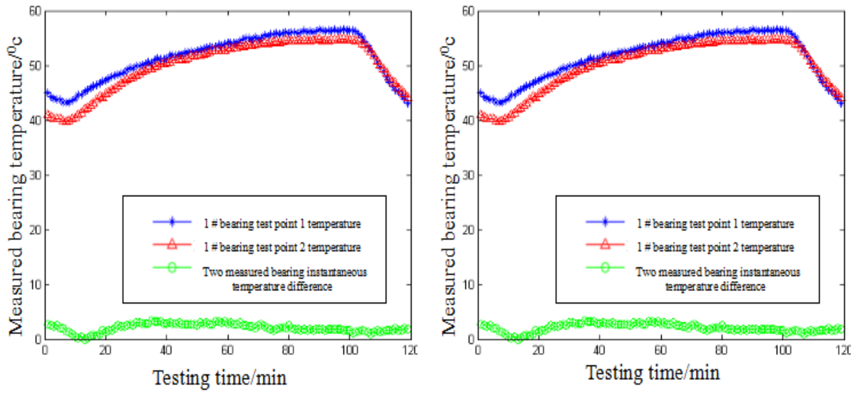


Fig. 8. Temperature difference between two bearings

As shown in the Fig.9

1) During the temperature rise test, the instantaneous temperature difference between the test point 1 and the test point 2 is very stable and maintained between 0°C and 4°C. The results meet the regulations [14] (The real-time temperature difference is less than the test regulations of 10°C.)

2) During the temperature rise test, the initial temperature at the same position of the two different bearings is very different (The initial temperature of the 1 # bearing test point 1 is 45.2°C and the initial temperature at the 2 # bearing test point 1 is 41.9°C. The initial temperature difference between the two measuring points is 3.3°C. The initial temperature of the 1 # bearing test point 2 is 45°C and the initial temperature at the 2 # bearing test point 2 is 40.9°C. The initial temperature difference between the two measuring points is 4.1°C). But, their final parking temperature is very close (The final stop temperature of the 1 # bearing test point 1 is 43.1°C and the final stop temperature at the 2 # bearing test point 1 is 44.5°C. The final temperature difference between the two measuring points is 1.4°C. The final stop temperature of the 1 # bearing test point 2 is 43.1°C and the final stop temperature at the 2 # bearing test point 2 is 44.2°C. The final temperature difference between the two measuring points is 1.1°C). It is indicated that the final steady temperature of the bearing is not related to the initial state during normal driving.

In this paper, based on the established theoretical model of temperature distribution, we calculate the temperature distribution of the bearing under the test load condition and obtained the theoretical value of the outer surface temperature distribution of the outer ring bearing under the limit load [15][16] . As shown in Fig 10.

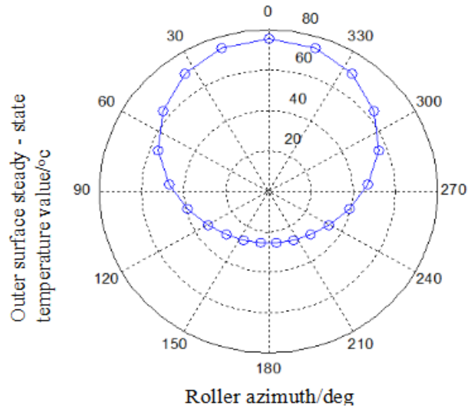


Fig. 9. Theoretical temperature value of experiment load

We get the following results.

1) During the temperature rise test, the 1 # bearing test point 1 is stable at about 54min after the start-up. The steady-state temperature is about 65.7°C and the theoretical value is 75.72°C and the difference is about 15.25%; The 1 # bearing test point 1 is stable at about 46min after the start-up. The steady-state temperature is about 67.4°C and the theoretical value is 75.72°C and the difference is about 12.34%.

2) During the temperature rise test, the 1 # bearing test point 2 is stable at about 65min after the start-up. The steady-state temperature is about 55.9°C and the theoretical value is 64.09°C and the difference is about 14.65%; The 2 # bearing test point 2 is stable at about 46min after the start-up. The steady-state temperature is about 54.6°C and the theoretical value is 64.09°C and the difference is about 17.38%.

5 Conclusion

This paper is based on the previously established friction and temperature theoretical model and the standard of railway bearing test. This article describes in detail the high iron axle box bearing thermal test device, test principle and test methods and introduces the working principle of the test bed, the choice of bearing points, load conditions set, test equipment, measurement and inspection. The deviation between theoretical and experimental values is 15.25%, 12.34%, 14.65% and 17.38%. The results show that deviation is less than 20%, which verifies the correctness of the theoretical model.

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