Factor analysis of bearing temperature distribution based on thermal network model

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Abstract: As a key part of train travel department, the frictional properties and temperature distribution of high-speed railway axle box bearing are affecting the running condition and safety of the train. The most common faults of the train, such as hot shaft and ignition axis, are closely related to heat. In the past, the research on the temperature distribution of axle box bearing has been mainly based on theoretical research and experiment research. The traditional theoretical research is not completely applicable, and the structure and operating conditions of bearing are not considered. Experiment research need a high cost, and cannot be analyzed the mechanism of temperature rise and the influence rule of each parameter index. According to above problem, this paper studied temperature distribution of high-speed railway axle box bearing, established bearing's thermal network analysis model. Based on this model, the factors affecting the temperature distribution of axle box bearings are analyzed。From the point of view of temperature distribution, including: The axle box bearing is generally at a low temperature distribution trend, and the highest temperature is appear in the contact area of roller and inner raceway. The increase of radial load will rise the temperature difference of each bearing part, while the increment of axial load will make the temperature distribution evenly. The increase of train's speed will increase the temperature value but cannot change the temperature distribution trend and so on. This provides a theoretical basis for temperature monitoring and fault prediction of axle box bearings.

Keywords: High-speed railway axle box bearing; Temperature distribution; Thermal network model

1 Introduction

1.1 Research background

High-speed railway transportation occupies a pillar position in the worldwide transportation system, It has many characteristics, such as high running speed, large traffic density, safe operation, high service quality, punctual running, high environmental protection, green traffic, high market share, good economic benefit,

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small energy consumption and so on [1], It has a strong competitive advantage both in long distance freight transportation over medium distance and in short distance passenger transportation in high density and large volume intercity transportation[2].

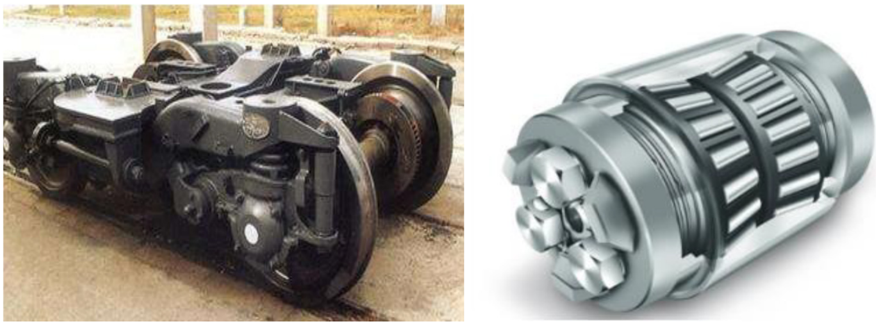


Fig.1 Axle box bearing of high speed railway carriage

With the rapid development of railway transportation industry, requirements for the causative performance of bearing of high speed train is also increasing. Axle box bearing is the key component of train running part, Its performance is good or bad, affecting the running state and driving safety, The most common faults in high speed train running, such as hot axle, thermal deformation and hot burning shaft, are closely related to the temperature distribution of the bearings, Therefore, the study of temperature distribution of axle box bearings has important application significance.

1.2 Research status at home and abroad

During the operation of rolling bearings, temperature rise and temperature distribution are one of the key factors that determine the reliability of bearings. If the temperature distribution of the bearing is not uniform or the temperature of a part rises sharply, will cause the uneven distribution of the thermal stress or thermal instability, thereby affecting the performance and life of bearing. Domestic and foreign scholars have carried out a great deal of research on the heat quantity and temperature distribution of rolling bearings.

Harris et al.[3-4]gave the formulas for calculating heat transfer coefficients under three heat transfer modes, heat transfer, heat convection and heat radiation, and through the calculation of bearing friction torque to calculate the frictional heat flux of rolling bearing, subsequently, the bearing is divided into thermal network nodes, a thermal network model of bearings is established, constructing and solving the heat balance equation. Chen et al.[5] established a temperature rise -thermal deformation model of the spindle during its operation, discussed the effect of friction heat of main shaft bearing on thermal expansion of spindle. Bercea et al.[6-7] took into account the interference fit, load conditions, lubrication parameters, overturning moment and other factors that are produced by the bearing assembly, established the DRTRB model of tapered roller bearings, obtained the power loss of the bearings, and then calculated the whole frictional heat of the bearings.

Kang[8] combined with Palmgren empirical formula, considering the bearing preload and gyro moment, studied the movement and stress state of the rolling body of high speed motorized spindle bearings, calculated the impedance of the bearing in the process of heat transfer, established the thermal temperature rise and heat network model of the bearing. Wang et al.[9]obtained the temperature field distribution diagram of the bearing by the finite element method. Li et al.[10] established the simulation model of bearing and obtained bearing components and the overall temperature nephogram by using the ANSYS software, and analyzed the bearing structure based on the results obtained, obtained the thermal-structural coupling deformation of the bearing. Wang et al.[11]organized the thermal analysis program of high speed cylindrical roller bearings, analyzed the law of local heat generation and the law of total heat generation of roller bearings under different working conditions. Wu[12]analyzed the friction heat source of tapered roller bearings, established a thermal network model of journal bearing, obtained the steady-state temperature of each part by Newton iterative method, and analyzed the influence of load condition on the temperature of each node, however, the thermal network model does not show the geometrical and contact characteristics of tapered roller bearings. Tang et al.[13] based on the heat network method to carry on the heat calculation to the high speed axle box bearing, and carried out the three-dimensional modeling and finite element temperature field analysis of the bearing, finally, the accuracy of the theory is verified by thermal test of railway bearings.

To sum up, there are many technical problems in high-speed railway train bearing technology in our country, the study of temperature distribution in axle box bearings is one of the important directions. The temperature distribution is an important performance index for feedback design and optimization of bearings, a series of studies have been made on the issue both at home and abroad, however, there are still some shortcomings:

The temperature field analysis of the finite element method can be applied to various non-standard bearings, and it has great advantages in the modeling of bearing and the visualization of the solution results, however, it is difficult to simulate accurately the lubrication conditions, external loads application modes of the actual bearing work; Some scholars have established a thermal network analysis model of tapered roller bearings, But it was not taken into account the influence of friction heat source between roller ball end face and inner ring edge, convection heat transfer between main shaft and air environment on temperature distribution; At present, the boundary conditions of the thermal network model are mostly the overall power consumption of the bearing, it is difficult to analyze the specific causes of heat sources, and the calculation of heat sources in each contact area is not accurate.

Therefore, it is of important academic and engineering significance to systematically study the temperature distribution of high speed axle box bearings.

Based on the CRH3 type high speed railway passenger train axle bearing as the research object, in view of the lack of direct and reliable temperature distribution research on high speed axle box bearings, a thermal network model of axle box bearing temperature is established, on the basis of the accuracy of the theoretical model, the paper analyzes the influencing factors, and then draws the conclusions of this paper.

2 Establishment and solution of steady heat network analysis model for axle box bearing

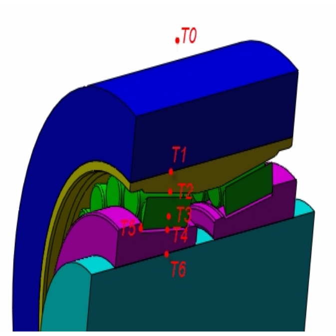
The heat network method is one of the most common methods for solving the steady-state heat distribution in a mechanical system, the solution principle is analogous to the current conduction process, engineering systems that need to be analyzed are assumed to be sources of heat, thermal resistance, etc. The thermal node is divided into the important points in the analysis system, subsequently, a heat transfer branch is used to connect the thermal node with the thermal resistance in the heat transfer circuit, and a closed or closed thermal network model is finally formed. Finally, based on the heat transfer theory, the heat flow equilibrium equations in the thermal network model are constructed. As shown in equation 2.1, the numerical solution of the system steady-state thermal analysis is solved [14].

$$\begin{cases} h_1(T_1, T_2, \ldots T_n) = 0 \\ h_2(T_1, T_2, \ldots T_n) = 0 \\ \ldots \\ h_n(T_1, T_2, \ldots T_n) = 0 \end{cases} \tag{1}$$

Among them, T_1, T_2, ..., T_n are the temperature of each heat node, the n unknowns constitute the heat balance equation of the system under test, the heat balance equations of each heat node are connected by a specific public node, and the specific needs are divided according to the actual needs of the system.

2.1 Establishment of steady heat network model for high speed axle box bearing system

Based on the heat source analysis of the high speed railway axle box bearings, according to the heat transfer relationship of each component of the bearing system, the whole bearing system is divided into 8 heat network nodes, and the heat node distribution and the name are shown in figure 2.1.



T0: Ambient temperature
T1:Outer surface temperature of outer ring
T2:Outer ring- roller contact temperature
T3:Roller center temperature
T4:Roller ball end face-rib contact temperature
T5:inner ring- roller contact temperature
T6:Inner ring inner surface temperature

Fig.2 schematic diagram of thermal network node in bearing system

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By using the thermal network method to solve the heat problem under steady state, before establishing the thermal network model and thermal equilibrium equations of the system, it should be assumed that all the heat sources generated in the axle box bearing system are derived from the friction heat inside the bearing, The heat transfer impedance of each component has nothing to do with the direction of heat flow. The components of the bearing are isotropic, and the heat transfer process is steady-state heat transfer. The temperature difference of each component is not significant, in the steady-state thermal analysis, the radiant heat transfer between the constituent parts can be ignored and the temperature of the oil and gas mixture inside the bearing housing is assumed to be the same and remains constant. The air temperature outside the bearing housing is the same and remains constant and ignores the thermal resistance at the mating and convective heat transfer between the roller and the surrounding oil and gas mixture, in this context, the thermal network model of the axlebox bearing system based on the heat transfer theory is shown in Figure 2.2.

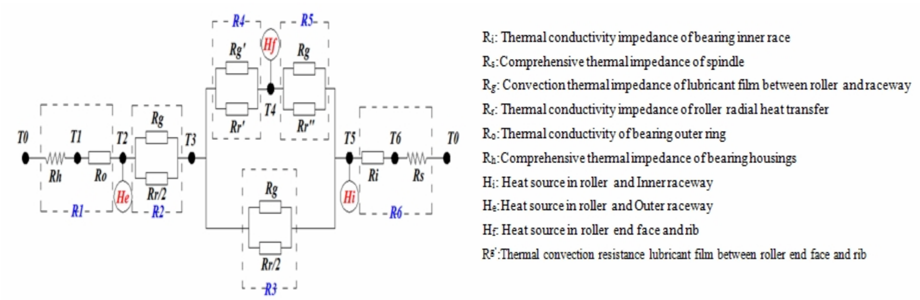


Fig.3 Thermal network model of bearing system

The contact analysis unit consisting of the roller with the largest load and the contact raceway between the internal and external raceway of the type CRH3 high-speed railway is defined as the 1# unit, 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 Figure 2.3.

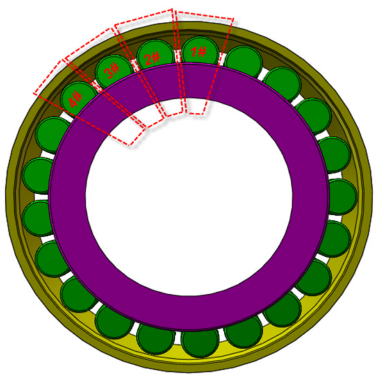
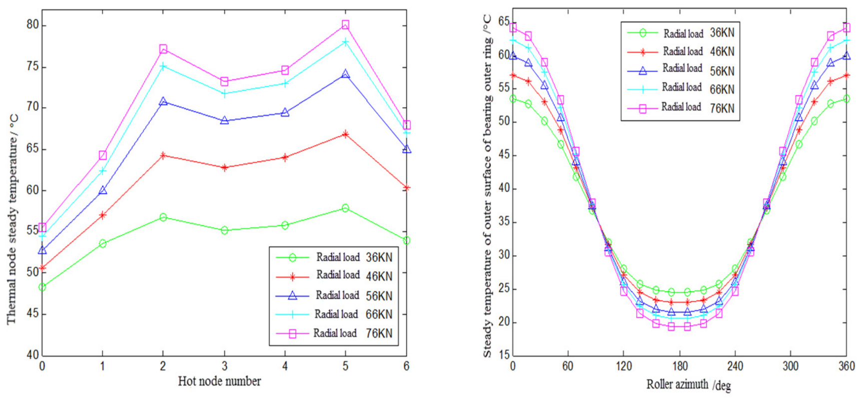


Fig.4 Schematic diagram of the analysis unit number

3 Analysis of Influencing Factors on Temperature Distribution of High Iron Axlebox Bearing

3.1 The influence of radial load on the temperature distribution

Take the CRH3 high-speed railway axle box bearing load the largest roller and contact with the inner and outer ring composed of 1 # analysis unit as the research object, train speed of 260km/h, axle box bearing bear the axial load of 5KN, the steady temperature values of each heat network node of 1# analysis unit are calculated respectively when the radial load of axle box bearing is 36KN, 46KN, 56KN, 76KN and 86KN, as shown in figure 3.1 (a). The steady temperature values of the outer ring of the bearing outer ring corresponding to different roller azimuth angles are analyzed, the influence of the radial load on the outer surface temperature of the outer ring is obtained, as shown in figure 3.1 (b).



(a) (b)

Fig.5 Influence of radial load to temperature distribution

As you can see from figure 3.1:

1) With the increase of radial load, the temperature of each heat node in the analysis unit of high speed railway axle box bearing increases.

2) In the case where the radial load of the bearing is small, the temperature value of each node in the analysis unit is not much different. With the increase of radial load, the temperature difference of each node in the unit is aggravated.

3) With the increase of radial load, the steady state temperature increment of each node gradually decreases and tends to be stable.

4) In each heat node of the unit, the ambient temperature is affected least by radial load, In the process of increasing the load from 36KN to 76KN, the increase rate is 14.86%, followed by the outer ring raceway temperature, the increase rate is 20.07%.

5) With the increase of the radial load, the temperature of the outer ring part corresponding to the bearing area is increased rather than the temperature of the

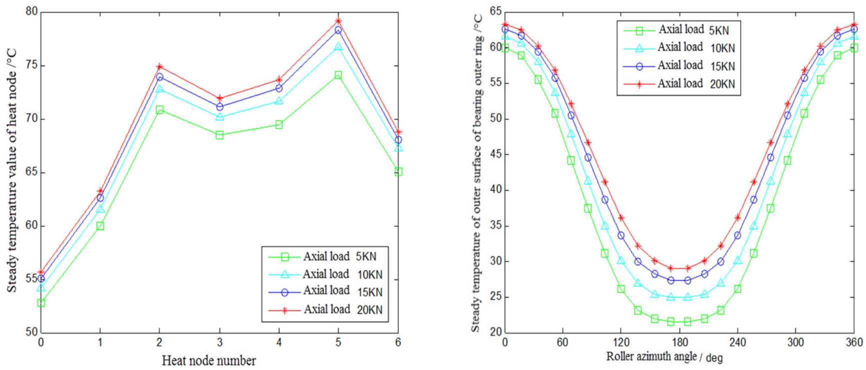
bearing area decreases, so the temperature difference between the various positions also increases, this is mainly due to the decrease in the number of load rollers as the radial load increases, and the roller-raceway contact load of the load-bearing area increases rather than the decrease in the roller-raceway contact load of the load-bearing area.

6) When the roller azimuth is 0°, that is the maximum load place, the temperature rise of the outer ring and outer surface is affected by the change of radial load.

7) Roller azimuth angle of 70-100°and 260-290°place, the temperature rise of the outer ring surface is affected least by the change of radial load, and almost no change.

3.2 Influence of axial load on temperature distribution of bearing

Take the above 1 # analysis unit as the research object, train speed of 260km/h, axle box bearing bear the radial load of 56KN, the steady temperature values of each heat network node of 1# analysis unit are calculated respectively when the axial load of axle box bearing is 5KN, 46KN, 10KN, 15KN and 20KN, as shown in figure 3.2 (a). The steady temperature value of the outer ring of the bearing outer ring corresponding to different roller azimuth angles is analyzed, and the influence of axial load on the outer surface temperature of the outer ring is obtained, as shown in figure 3.2 (b).



(a) (b)

Fig.6 Influence of axial load to temperature distribution

As you can see from figure 3.2:

1) Changing the axial load of axle box bearings, the temperature distribution trend of each node of the maximum roller analysis unit is basically the same, while the steady-state temperature value is slightly different.

2) With the increase of axial load, the steady-state temperature of each heat node in the unit increases.

3) The curvature of the curve of the temperature distribution under four kinds of conditions is not exactly the same, the steady temperature of the outer surface of the

bearing outer ring is increased from 59.93°C to 63.22°C, and the increase amplitude is about 5.49%, while the temperature of the inner raceway of the inner ring of the bearing is increased from 74.09°C to 79.17°C, and the increase amplitude is about 6.86%.

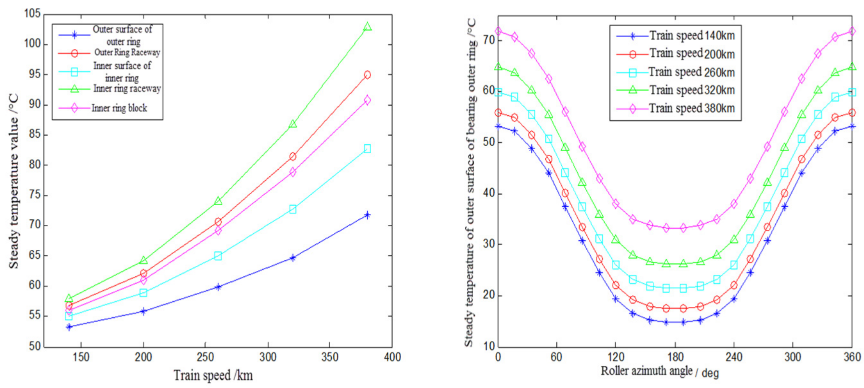
4) as the axial load increases, the steady-state temperature increment of each node decreases gradually and tends to be stable.

5) as the axial load increases, the steady-state temperature of the outer raceway of the bearing outer ring rises, but the degree of increase is different.

6) With the increase in the load of the axlebox, the temperature distribution of the bearing becomes even more uniform.

3.3 Influence of bearing speed on temperature distribution

Taking the 1 # analysis unit as the research object, the radial load of the axle box bearing is 56KN, the axial load is 5KN, the steady-state temperature of the outer surface of the outer ring, the outer raceway, the inner surface of the inner ring, the inner raceway and the roller-ribs contact point of the 1 # analysis unit at 140km, 200km, 260km, 320km, 380km, respectively value, The effect of bearing speed on temperature rise is shown in figure 3.3 (a). The steady temperature values of the outer ring of the bearing outer ring corresponding to different roller azimuth angles are analyzed, the influence of the bearing speed on the outer surface temperature of the outer ring is shown in figure 3.3 (b).



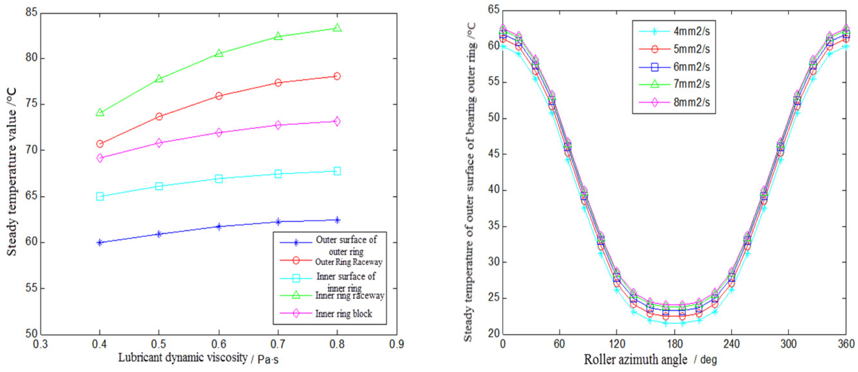
(a) (b)

Fig.7 Influence of speed to temperature distribution

As you can see from figure 3.3: With the increase of the running speed of the train, i.e., the increase of the bearing speed, the temperature of each part of the axle box bearing rises rapidly, The maximum temperature rise at the inner raceway is about 44.9°C,the increase of about 77.55% of the initial temperature, followed by the outer ring raceway, followed by the inner ring rib, inner ring inner surface and outer ring surface; With the increase of speed, the growth rate of steady state temperature increases gradually, when the train speed increases from 140km to 200km, the inner raceway temperature rises to 6.3°C, however, when the train speed from 320km to 380km, the inner raceway temperature rise to 22.01°C.

3.4 Influence of viscosity of bearing lubricant on temperature distribution

Taking the above 1 # analysis unit as the research object, the radial load of the axle box bearing is 56KN, the axial load is 5KN, the train speed is 260km, when it's dynamic viscosity of the grease is 4Pa • s-8 Pa • s, Calculates separately the steady state temperature value of the outer surface of the outer ring, outer raceway, inner ring inner surface, inner raceway, roller and rib of 1 # analysis unit, as shown in figure 3.4 (a). The steady temperature values of the outer ring of the bearing outer ring corresponding to different roller azimuth angles are analyzed, the influence of the viscosity of the lubricating greases on the temperature of the outer ring surface is shown in figure 3.4 (b).



(a) (b)

Fig.8 Influence of grease viscosity to bearing temperature's rise

As you can see from Figure 3.4:

1) the increase in grease viscosity will lead to increased temperature throughout the bearing.

2) The temperature change of the inner raceway in each node of the analysis unit is most affected by the viscosity of the grease, when the viscosity of the grease increased from $4mm^2/s$ to $8mm^2/s$, the temperature increased from 74.09°C to 83.35°C, the increase is 12.5%,the outer surface temperature of the outer ring is least affected by the viscosity of the grease, its temperature increased from 59.93°C to 62.47°C, the increase of 4.24%.

3) The change of the viscosity of the grease in the axle box bearings will affect the steady temperature value of each part of the bearing, but the temperature distribution tendency of the bearing is less affected.

4 Conclusions

In this paper, the parameter analysis of the thermal network analysis model of axle box bearing for high-speed railway is discussed. Obtained by analysis:

1) Increased radial load and increased axial load will cause the maximum steady-state bearing temperature rise.

2) For the bearing outer ring as a whole, the increase in radial load will increase the temperature difference between the various parts of the bearing, and axial load increases will make the temperature distribution more uniform.

3) In the high-speed railway common operating speed range, the train speed will increase the bearing temperature, when the train speed from 320km to 380km, the increase in inner raceway temperature is 22.01°C,but the increase in speed does not change the trend of temperature distribution.

4) The lubricant will increase the internal temperature of the bearing, but it will have little effect on the temperature distribution trend.

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References

1. Z.W.Jiang. High-speed railway development overview, ***Science and Technology Information*** 3(2007) 166.
2. D.L.Cheng, S.R.Li, J.H.Li.Technology of high-speed train technology development in the world, ***Journal of Ship Science and Technology*** 34 (2012) 131-135.
3. Harris. How to predict temperature increases in rolling bearings, ***Prod.English*** 7.
4. Harris. Prediction of temperature in a rolling bearing assembly, ***Lubr.English*** 3(1964) 145-150.
5. J. Chen. Characterizations and models for the thermal growth of a motorized high speed spindle, ***International Journal of Machine Tools and Manufacture*** 43(2003) 1163-1170.
6. Becae, S. Cretu. Double row tapered roller bearing analysis of the first part – model,. ***Foreign bearing technology*** 3(2005) 12-24.
7. Becae, S. Cretu. Double row tapered roller bearing analysis Part 1 - Results: fatigue life and heat loss prediction, ***Foreign bearing technology*** 4(2005) 8-15.
8. H. Kang. High speed motorized spindle bearing thermal analysis and experimental research, ***Journal of Mechanical Strength*** 6(2001) 797-802.
9. J.W.Wang, Q.An. Study on calorific value and temperature field of cylindrical roller bearing, ***Journal of East China University of Science and Technology*** 32(2006) 1130-

1133.
10. Y.G.Li, Y.J.Zheng, J.J.Li. Study on Coupling Deformation of Cylindrical Roller Bearings Based on ANSYS, ***Mechanical Science and Technology*** 11(2016) 18-21.
11. L.Q.Wang, G.C.Chen, L.Gu. High-speed cylindrical roller bearing heat generation ***Lubrication and sealing*** 8(2007) 8-11.
12. W.Wu, Z.Z.Yu. Thermal Analysis of Train Axle Box Bearing Based on Thermal Network Method. ***Electrical and Mechanical Integration*** 3(2015) 76-79.
13. W.C.Tang, M.J.Wang,G.D.Chen. Study on temperature distribution of axle box bearing in high-speed train. ***Journal of the China Railway Society*** 38(2016) 50-56.
14. Z.Liu, Y.S.Wang. Study on the temperature field of rolling bearing and its prospect. ***Mechanical Transmission*** 34 (2010) 88-91.