Temperature field and thermal stress field of continuous casting roller bearing

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Abstract

The work condition of continuous casting roller bearing was high temperature, large load and complex. If the heat, which the bearing accepted could not be distributed effectively and cooling was not in place, the high temperature would cause bearing thermal deformation and rupture under high loads, resulting in bearing premature failure, affecting the entire casting steel production. The cooling way for the continuous casting roller bearing seat was by the internal cooling water holes which in the bearing seat. Based on the ANSYS, the temperature field of continuous casting roller bearing seat was analysed. The three-dimensional geometric model and the CAE model of the bearing seat was established, and the synthesize convection heat transfer coefficient of bearing seat would be obtained through analysed the principle of heat transfer. Took it as the boundary condition, and load the temperature in the real-time condition. Analysed temperature field of the continuous casting roller bearing seat in the stable work condition, got the overall distribution of bearing seat. Meanwhile, it could draw the conclusion that thermal load what bearing carried was the cause of bearing damage through the thermal stress analysis of the continuous casting roller bearing. It provided advice and guidance on appropriate optimization of the bearing to improve bearing life. And just the above analysis provided a theoretical guidance for the design and installation of continuous casting roller bearing

Keywords: continuous casting roller, bearing seat, temperature field, CAD three-dimensional geometric model, CAE model, stress field, thermal coupling field

1 Introduction

Continuous casting roller bearing was an important part in continuous casting machine, which provided important support for continuous casting roller, and the work environment was complex. The billet which come out from the continuous casting machine crystallizer was forced cooling through spraying water in the secondary cooling zone(the continuous casting machine's line segment, curved segments and sector segments called the secondary cooling zone), in order to make the billet shell quickly cooled to prevent breakout. Nevertheless, when the billet come out from the crystallizer and reached the casting machine straightening section, it was still at a temperature above 900 ℃.And the billet contacted with the continuous casting roller directly, at this moment, the highest point of the bearing seat at the two ends of the continuous casting roller was very close with the billet. If the heat that bearing accepted could not be effectively dissipated, and the cooling inadequate, then the high temperature would cause bearing thermal deformation and rupture under large load, resulting in premature bearing failure, thereby affecting the whole casting steel production. Under the current experimental conditions, most researchers used a thermal sensor to measure the temperature of the research object. However, due to the structure of the bearing, it could not be installed a temperature sensor inside the bearing, resulting the temperature of the bearing inner ring raceway, outer ring raceway and rolling element could not be measured. So that the data of theoretical analysis could not be verified, this was a serious impediment to the development of theoretical bearing thermal analysis studies. The bearing was analysed by ANSYS finite element analysis software in this paper, the ANSYS finite element analysis software had a great function of thermal analysis and processing, and it could easily solve the coupled thermo mechanical problem. Through the simulation analysis on the continuous casting roller bearing, the distribution of temperature field, stress field and comprehensive stress of continuous casting roller bearing could be obtained. Investigated the mechanism of bearing damage, and analysed the impact of thermal stress on the bearing damage and bearing life, it had the vital significance to the structure optimization of bearing under high temperature. Therefore, the interior of the bearing seat must be cooling to ensure the bearings run under the specified temperature range.

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2 The CAD and CAE model of continuous casting roller bearing

2.1 THE CAD THREE-DIMENSIONAL GEOMETRIC MODEL OF CONTINUOUS CASTING ROLLER BEARING

According to the bearing model and drawings that provided by a steel plant, using the current mainstream three-dimensional CAD design software to build a three-dimensional CAD integral assembly model of the casting roller bearing, as shown in Figure 1.

In the assembly model of continuous casting roller bearing, the bolt hole on the end cover has been simplified without affecting the casting roller bearing thermal stress, temperature field and stress field analysis.

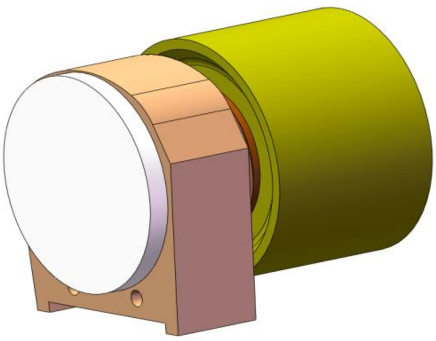

FIGURE 1 The three-dimensional CAD assembly model of continuous casting roller bearing

2.2 THE CAE MODEL OF CONTINUOUS CASTING ROLLER BEARING

In strict accordance with the size and structure of 3D CAD model, using CAE pre-processing simulation software to build the grid model for CAE analysis.

In the process of solving thermal analysis , using ANSYS for its calculation and analysis. In the ANSYS finite element analysis software, according to the requirements of the ANSYS unit type, while taking into account the entire bearing assembly models were three-dimensional solid model, the author chose the common SOLID70 unit. Mesh generation was performed in the bearing assembly model, as shown in Figure 2. And meshing assembly model was the most difficult task, because of its internal cooling water pipe, the internal gridding must be distinguished, in the shape of extremely irregular, we used tetrahedral mesh and pentahedral mesh. However, in this part, the mesh quality was not better than hexahedral mesh, but the number of tetrahedral meshes and pentahedral mesh was few, it had less impact on the temperature field of the entire model.

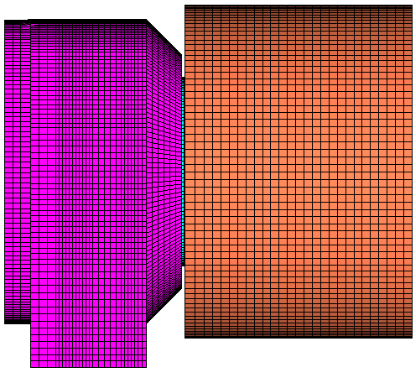

FIGURE 2 The three-dimensional mesh model of continuous casting roller bearing

Mechanical properties of materials of the main components of continuous casting roller bearing assembly, such as shown in Table 1 [1].

TABLE 1 Mechanical properties of the materials of the main components

Main components	Materials	Strength limit σ_b (MPa)	Yield limit σ_s (MPa)
bearing seat, end cover	Q345-D	470-630	345

Continuous casting roller assembly was comprised of a bearing seat, a bearing cover, bearing ring and continuous casting roller. Physical parameters of model materials was shown in Table 2 [2-4], bearing seat material was Q345-D.

TABLE 2 Physical parameters of the materials

Materials	Density (kg/m^3)	Specific heat (J/kg·°C)	Thermal conductivity (W/m·K)	Linear expansion coefficient (10^{-6}/°C)	Elastic modulus (Gpa)	Poisson ratio
Q345-D	7.85E3	460	44	13	206	0.28

3 The mathematical model description and boundary conditions determination of continuous casting roller bearing thermal analysis

Thermal simulation analysis was used to calculate the temperature distribution of a system or components, resulting in obtaining the corresponding thermal physical parameters (such as the system gained or loss calorific value, thermal gradient, heat flux etc.). Because it was calculated by temperature as the basic parameters, the thermal analysis was also known as the temperature field calculation. Due to temperature rise caused by the thermal radiation of continuous casting roll bearing in the steel-making process did not change with time, so the heat transfer process of continuous casting roll bearings could be approximately regarded as the steady-state heat transfer process, met the following heat conduction equation [5],

$$\frac{\partial T}{\partial t}=\frac{k_2}{\rho C_p}\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial z^2}\right), \quad (1)$$

In the equation, x, y, z was the coordinates of system; k_2 was the thermal conductivity coefficient of the material, $W/(m \cdot K)$; ρ was the density of the material, Kg/m^3; C_p was the specific heat of the material, $J/Kg \cdot °C$; T was the temperature function, °C; t was the time, s.

Throughout the heat transfer system, also included thermal conduction and thermal radiation of high temperature billet for continuous casting roller, and thermal radiation of high temperature billet for bearing seat. Taking into account a lot of radiation heat transfer plane, and it was highly nonlinear, we have to take a long time to calculate. Therefore, the author simplified the radiation to take the form of convective heat transfer instead of the form of radiation heat transfer, which was to select an equivalent convective heat transfer coefficient instead of radiation heat transfer.

In general, the natural convection coefficient was 5 to 10, the equation for the calculation was [6],

$$h = 1.826\left(\frac{T_s}{T_s - T_a}\right)^{1/3}, \quad (2)$$

where h was the convective heat transfer coefficient of casting roller bearing and the ambient air; T_s was the temperature of continuous casting roller bearing, °C; T_a was the temperature of the air around the continuous casting roller bearing, °C.

According to the theory of heat transfer [7], using the Equation (3) to calculate the convection heat transfer coefficient of continuous casting roller bearing, bearing seats, continuous casting roller and air.

$$h_c = N_u \lambda / L, \quad (3)$$

where h_c was the surface heat transfer coefficient (i.e., heat exchange coefficient), $W/(m^2 \cdot K)$; N_u was the Nusselt number; λ was the thermal conductivity, $W/(m \cdot K)$; L was the characteristic length, m.

The author translated the radiation heat transfer of billet and surrounding environment into the convective heat transfer, their equivalent convective heat transfer coefficient expression [8] was:

$$h_r = \varepsilon B(T_s^2 + T_a^2)(T_s + T_a), \quad (4)$$

where h_r was the equivalent convective heat transfer coefficient of the continuous casting roller and the ambient air, $W/(m^2 \cdot K)$; B was the Boltzman number, 5.67e-8 $W/(m^2 \cdot K^4)$; ε was the blackness, the radiation heat transfer coefficient of the billet and surrounding environment was 0.8.

Therefore, the composite heat transfer coefficient was,

$$h = h_c + h_r. \quad (5)$$

If the temperature of ambient air around the continuous casting roller was 300°C, and the convective coefficient of the continuous casting roller and ambient air was $15W/(m^2 \cdot K)$, it could use the Equation (4) to calculate the convection coefficient after conversion, so, the convection coefficient of the continuous casting roller and surrounding environment was 33.4 $W/(m^2 \cdot K)$.

4 The thermal simulation analysis of continuous casting roller bearing

Because the heat source of the temperature field was the high temperature billet which was out of the crystallizer, the working environment of continuous casting roller bearing was complex, and the bearing was wrapped in the inside of the bearing seat. According to the bearing seat temperature, roller temperature, ambient temperature and cooling water temperature to calculate the bearing temperature, and used ANSYS to simulate.

The distribution of temperature field of the continuous casting roller bearing assembly has been calculated through the thermal analysis, as shown in Figure 3. The simulation results indicated the temperature of the entire assembly reduced from the continuous casting roller to bearing seat, showed stratified distribution. And the temperature field was essentially a symmetrical distribution.

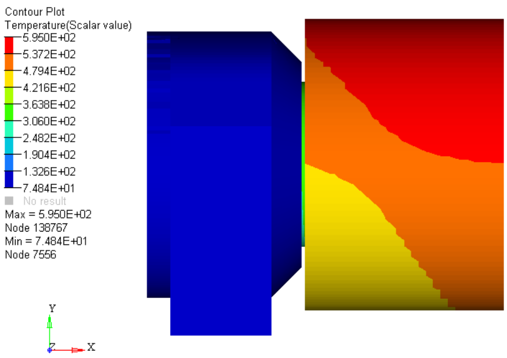

FIGURE 3 The temperature field of continuous casting roller bearing assembly

The analysis result of temperature field of continuous casting roller bearing seat as shown in Figure 4. Due to the bearing seat was provided with cooling water, it made the temperature inside the bearing seat cavity remain at normal working temperature range, so the temperature inside the bearing seat was not very high [9]. The highest temperature place was the part, which close to the casting roller end. Because of the continuous casting roller temperature was very high, this part was subjected to the thermal radiation from the millet and continuous casting roller, then the temperature of this part increased.

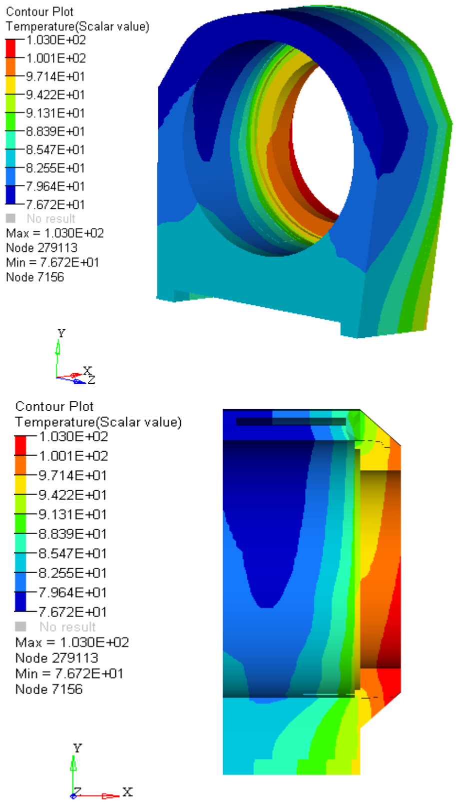

FIGURE 4 The temperature field of continuous casting roller bearing seat

Figures 5 and 6 were the stress field and thermal-stress coupled field simulation results of the continuous casting roller bearing when the bearing seat was provided with cooling water. It could be seen from the figure that the distribution of continuous casting roller bearing stress field was that the part close to the bottom of the bearing seat had a maximum stress and the stress of the part at the top of the bearing seat was 13.77MPa, which was similar to the actual situation. Thermal-stress coupled field distribution of casting roller bearing were the stress increased in the direction of X axis and decreasing in the direction of Y axis, which was consistent with the distribution of temperature field, also consistent with the actual situation.

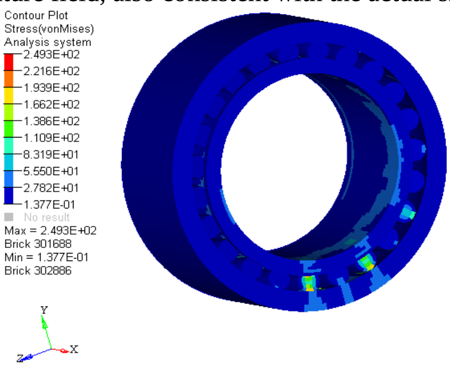

FIGURE 5 The stress field of the continuous casting roller bearing when the bearing seat was provided with cooling water

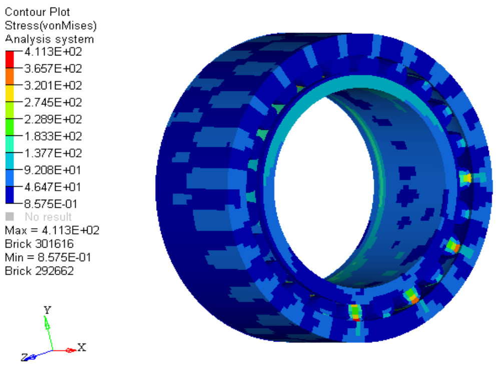

FIGURE 6 The coupled thermo-mechanical field of the continuous casting roller bearing when the bearing seat was provided with cooling water

Extracted the results and compared with the measured temperature of the temperature sensor (provided by the steel mill), then we could know that the simulation temperature of the outer surface of the bearing seat and continuous casting roller was essentially same to the measured temperature, and the maximum error between them was less than 9%. It indicated that the finite element simulation analysis results of the continuous casting roller bearing temperature field were correct and effective (Table 3).

TABLE 3 The simulation temperature of the main parts of the continuous casting roller bearing seat contrasted with the measured temperature

Position	Simulation temperature (°C)	Measured temperature (°C)	Error
Top of bearing seat	83.8	90	6.9%
Inclined plane of bearing seat	98.9	110	8.4%
Side of bearing seat	81.2	75	8.3%

5 The thermal stress analysis of continuous casting roller bearing

In order to easily observe the impact of thermal stress caused by temperature on bearing, here listed the stress field [10] and the thermal-mechanical coupling field sketch map of the bearing under the condition of cooling water. By comparison, we could clearly see that the bearing was subjected to a great stress caused by temperature.

Figures 7 and 8 were the stress field and coupled thermo-mechanical field simulation results of the continuous casting roller bearing outer ring when the bearing seat was provided with cooling water. It could be seen from the figure that the outer ring was obviously subjected to the thermal stress caused by the temperature under the action of coupled thermo-mechanical.

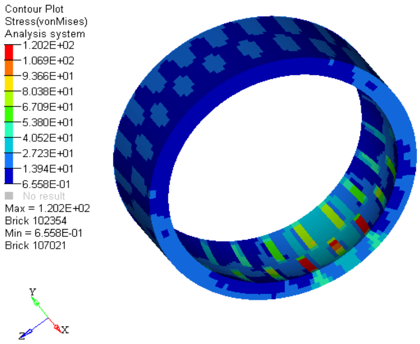

FIGURE 7 The stress field of the continuous casting roller bearing outer ring when the bearing seat was provided with cooling water

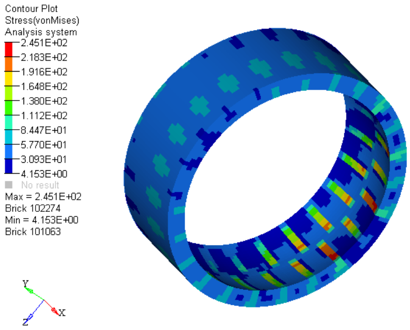

FIGURE 8 The coupled thermo-mechanical field of the continuous casting roller bearing outer ring when the bearing seat was provided with cooling water

Figures 9 and 10 were the stress field and coupled thermo-mechanical field simulation results of the continuous casting roller bearing inner ring when the bearing seat was provided with cooling water. It could be seen from the figure that the stress obviously concentrated in the contact part of the rolling element and inner ring.

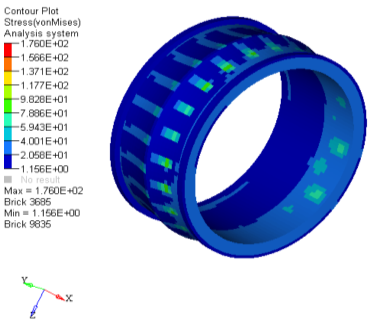

FIGURE 9 The stress field of the continuous casting roller bearing inner ring when the bearing seat was provided with cooling water

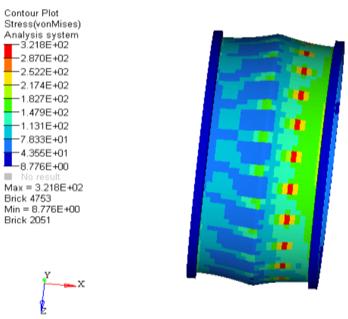

FIGURE 10 The coupled thermo-mechanical field of the continuous casting roller bearing inner ring when the bearing seat was provided with cooling water

Figures 11 and 12 were the stress field and coupled thermo-mechanical field [10] simulation results of the continuous casting roller bearing rolling element when the bearing seat was provided with cooling water. It could be seen from the figure that the part which the bearing was subjected to the maximum stress was the rolling element, and the minimum stress was the outer ring. Meanwhile, each of the rolling element was subjected to stress differently and the gap was obvious. In this paper, the stress analysis was the steady-state analysis, it could be speculated that when the bearing during operation, the stress which the rolling element was subjected was variable, and had a great span, but it would cause the fatigue failure of the bearing.

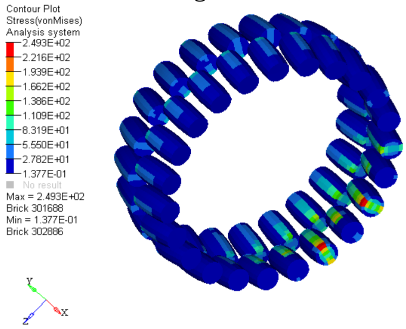

FIGURE 11 The stress field of the continuous casting roller bearing rolling element when the earing seat was provided with cooling water

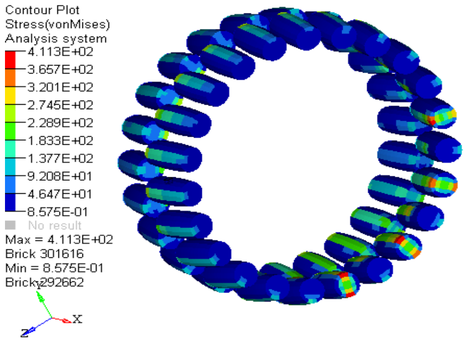

FIGURE 12 The coupled thermo-mechanical field of the continuous casting roller bearing rolling element when the bearing seat was provided with cooling water

As shown in Table 4, statistical analysis of the maximum stress and thermal stress simulation results of the casting roller bearing showed that the stress of continuous casting roller bearing almost doubled, the influence of temperature on the bearing load was also very obvious, and less than the allowable stress only 20.4MPa.Therefore, when the continuous casting roller bearing worked in high strength conditions, it was rather liable to be invalidated. And this situation indicated the continuous casting roller bearing failure was significantly related to temperature. Although the inner ring temperature was the highest, the maximum stress which it suffered was still smaller than the rolling element, thus, the rolling element was the part which suffered the maximum stress.

TABLE 4 The maximum stress and thermal stress of each part of the continuous casting roller bearing result comparison

	Maximum stress (MPa)	**Maximum thermal stress (MPa)**	**Allowable stress of bearing material (MPa)**
Continuous casting roller bearing	249.3	411.3	
Outer ring	120.2	245.1	431.7
Inner ring	176.0	321.8	
Rolling element	249.3	411.3	

6 Conclusion

When the bearing seat in the steady state operation, using the finite element analysis software to analysis the distribution of the temperature field, then, according to the analysis result, it could be seen that the inner ring of the bearing had a highest temperature and the outer ring lowest when the bearing seat was provided with cooling water, and the temperature transfer from the inner to the outer ring, but in the direction of X axis (i.e. from the continuous casting roller to the end cap),a large temperature gradient would generate a high thermal expansion stress. Under the extreme conditions, the bearing temperatures up to 103 ℃, higher than the normal operating temperature of high-temperature grease, which made the lubrication system failure, resulting in the failure of the bearing. The analysis provided theoretical guidance for the design and installation of the continuous casting roller bearing seat.

Meanwhile, by the result of the bearing thermal stress analysis under the steady-state operation of the bearing seat, it could be seen that the stress was concentrated in the rolling element, and the maximum stress was close to the allowable stress of the bearing material. Therefore, in order to improve the life of the bearing by reduced the maximum stress of bearing, we could consider to change the structure of the rolling element without changing the overall structure of the bearing. In summary, it provided theoretical guidance for the design and installation of continuous casting roller bearing.

Acknowledgments

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