Effect of non-uniform cooling on distortion and ellipticity in bearing quenching

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The bearing outer ring is often non-uniformly deformed after quenching. The ellipticity of the bearing is also an evaluation indicator for quality control. However, the mechanism of this non-uniform deformation of bearings has not been fully revealed. In this paper, the cooling curves of the inner and outer surfaces of the bearing outer ring were measured separately. Based on the measured cooling curves, the cooling rates were calculated, and the heat transfer coefficients at the measurement points on the inner and outer walls of the bearing outer ring were calculated using the inverse analysis method. The heat transfer coefficients at measurement points on the inner and outer walls of the bearing ring were calculated under different quenching postures, revealing the non-uniform heat transfer mechanism during the bearing quenching process. The quenching processes of two materials, GCr15C and 16MnCr5l, were simulated according to the metal thermodynamics theory and the multi-field coupling calculation method. Through the simulation, the results of distortion of the bearing sleeve after quenching were obtained, and the ellipticity values of the bearing sleeve after quenching were obtained according to the distortion results to verify the distortion mechanism of the bearing sleeve during the quenching process.

Keywords: *quenching distortion of bearing, ellipticity of bearings, cooling curve, heat transfer coefficient*

1. Introduction

Bearings as an important part of mechanical equipment, usually bearings need to be used under high speed and high load conditions. In particular, the performance and machining accuracy of the shaft collar have a great influence on the use of the bearing. For example, the roundness machining error of the bearing sleeve alone has an important influence on the bearing installation, the reduction of vibration and noise during the operation of the bearing, and the service life of the bearing. Therefore, it is one of the important indicators to evaluate the performance and quality of the bearing sleeve [1]. And bearings to achieve these high performance and high life, heat treatment quenching tech-nology are indispensable. However, during the quenching process, the bearing will undergo very complex nucleation and vapor film boiling. The thin film boiling and vapor film rupture are not uniform in the circumferential direction, which is likely the reason why bearings are prone to oval deformation. This uneven deformation, even if it is somewhat eliminated in the subsequent machining process, can cause the problem of uneven hardness distribution on the bearing surface, thereby reducing the strength and wear resistance of the bearing surface again [2]. Inoue and Ju proposed the Metallo-Thermo-Mechanics theory and a numerical simulation method based on multi-field coupling [3]. The theory and the numerical simulation method provide the basis for the prediction of quench deformation.

2. Experimental Methods

2.1 Experimental equipment

In Figure.1, the equipment is mainly composed of a control box, a heating furnace, and a cooling device. The control box can control the temperature of the bearing heating and the rapid lifting of the guide rod. The heating furnace adopts a vertical tube furnace with a maximum temperature of 1200℃. During heating, argon or other protective gases can be introduced. The cooling device consists of a quenching tank and a pre-heating tank in which a heater and mixer are placed. The quenching tank is connected to the preheat-ing tank by an oil pump and oil circuit. And a channel is connected in the middle of the lower end of the quenching tank, so that coolant can be sprayed into the quenching tank from the bottom by an oil pump according to the required flow through. The quenching tank is then returned to the preheating tank from the middle and upper part of the quenching tank through the oil circuit so that the coolant can be circulated to ensure that the temperature of the coolant in the quenching tank (except near the sample) can be con-trolled at the experimentally set temperature value. The measurement resolution of the cooling curve can reach 1/1000s.

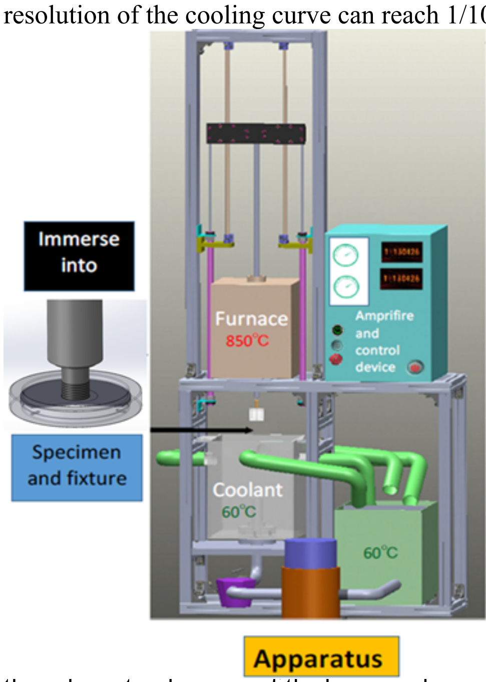

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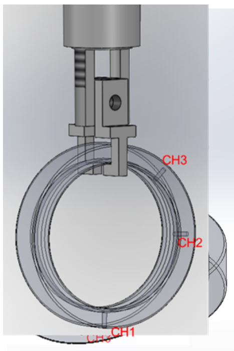
Fig.2(b) shows
the schematic diagram of the bearing sleeve placed at a 45° angle during quenching, the angle between points CH1 and CH2, as well as CH3, is 90°. Fig.2(c) shows the schematic diagram of the bearing sleeve vertically placed during quenching, in which the angle between CH2 and CH1 is 90°, and the angle between CH3 and CH1 is 135°.



(a) (b) (c)

Figure 2. Three ways of fixing the bearing rings. (a)The bearing sleeve placed horizontally; (b)The bearing sleeve placed at an inclination of 45°;(c) The bearing sleeve placed vertically.

2.3 Experimental results

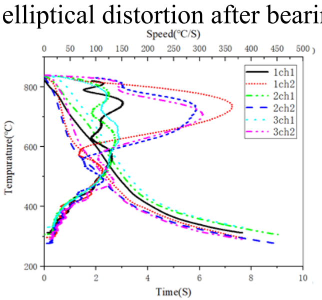
In order to ensure the accuracy of the experiment, we conducted three cooling curve tests for each placement method under the same process conditions and calculated the cooling speed curve according to the cooling curve.

From the result chart of Fig.3 for horizontal placement, the cooling curves and cooling rate curves of points CH1 and CH2 on the inner wall of the bearing are quite close, while the cooling curves and cooling rate curves of the outer wall are completely different. The experimental results show a high reproducibility of cooling curves and cooling rate curves.

From the result chart of Fig.4 for inclined placement, the cooling curves and cooling rate curves of points CH1, CH2, and CH3 on the inner wall of the bearing are slightly different. the results show a high reproducibility of the cooling curves, while the reproducibility of the cooling rate curves has slight deviation. The cooling curves and cooling rate curves of points CH1 and CH2 on the outer wall of the bearing are slightly different, and the cooling rate curve of point CH3 is completely different from those of points CH1 and CH2, with a noticeably higher cooling rate than points CH1 and CH2. The experimental results show a high reproducibility of cooling curves and cooling rate curves.

From the result chart of Fig.5 for vertical placement. The cooling curves and cooling rate curves of points CH1 and CH2 on the inner wall of the bearing are the same, while the cooling rate of point CH3 is significantly lower than that of points CH1 and CH2. The cooling curves and cooling rate curves of points CH1, CH2, and CH3 on the outer wall of the bearing are different, and it can be clearly seen from the cooling rate curves that CH1 is greater than CH2, and CH2 is greater than CH3. The experimental results show a high reproducibility of cooling curves and cooling rate curves.

From the measured cooling curves and calculated cooling rate curves, due to the complex phenomena of the heated fluid during the quenching process, the axial cooling rate of the bearing has significant differences, resulting in different heat transfers on the bearing ring surface. From the experimental results, it can be inferred that the uneven heat transfer of the bearing sleeve is the main cause of the elliptical distortion after bearing quenching.



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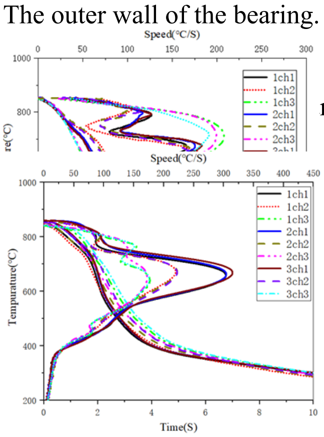
horizontal placement. (a)The inner wall of the bearing; (b) The outer wall of the bearing.



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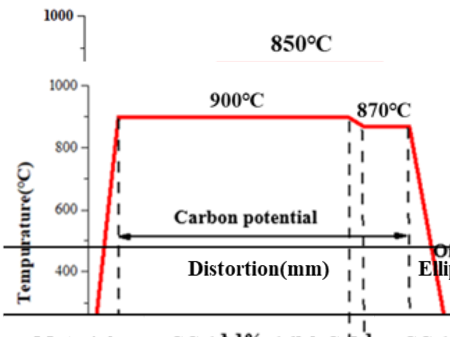
3. Results of Simulation

In order to compare the results of the three placement methods, we carried out a multi-field coupled numerical simulation for the full process of carburizing and quenching a bearing sleeve. A 3D gear geometry model was first created using GID software with a 3D six-sided element mesh. The total number of nodes in the model was 14080 and the total number of elements was 12000. In order to compare the simulation results more accurately, the node positions taken for each simulation result are the same. The node positions are near the thermocouple Ch1, Ch2 and Ch3 measurement points (All three measurement points are on the contact surface of the bearing).

3.1 Bearing sleeve heat treatment process

GCr15 high carbon steel and 16MnCr15 low carbon steel materials are simulated using different heat treatment processes. The GCr15 material uses the process shown in Fig.6, the bearing was heated in the furnace for 20 minutes to reach 850°C, then held for 20 minutes and finally quenched in cooling oil at 60°C. The 16MnCr5 material uses the process shown in Fig.7, after the bearing was heated in the furnace for 20 minutes to reach 900°C, 1.1% carbon potential was introduced into the heating furnace and held for 150 minutes. Then, the carbon potential introduced into the furnace was reduced to 1.0% and the furnace temperature was reduced to 870°C, after holding at 870°C for 30 minutes, it was quenched in cooling oil at 60°C.



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iterial is 0.00016. From the simulation results cally placed bearing at 90°, The bearing

	Distortion(mm)		Ellipticity values	
Material	GCr15	16MnCr5	GCr15	16MnCr5
Horizontal placement	0.0643	0.0279	1.00105	1.00026
45° placement	0.0409	0.0232	1.00059	1.00011
90° placement	0.0440	0.0231	1.00061	1.00020

ellipticity of the GCr15 material is 0.00061, and the bearing ellipticity of the 16MnCr5 material is 0.00020.

4. Conclusions

In this paper, we propose an experimental method for measuring the cooling variation of the bearing sleeve during quenching. Through the experiments, we measured the cooling curves of the bearing sleeve quenched by horizontal placement, inclined at 45° and vertical placement, calculated the cooling rate curves based on the cooling curves. The cooling curve measurement method proposed in this paper gives results with good reproducibility. By comparing the cooling curves, cooling rate curves, and heat transfer coefficients of the three placement methods for bearing sleeves, we found that the axial heat transfer of the bearing sleeve is uneven. Among them, the bearing sleeves placed at a 45-degree and vertically at 90 degrees have more uniform axial heat transfer during the quenching process compared to the horizontally placed bearing sleeves. Through the simulation, the results of distortion of the bearing sleeve after quenching were obtained, and the ellipticity values of the bearing sleeve after quenching were obtained according to the distortion results to verify the distortion mechanism of the bearing sleeve during the quenching process.

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