Research on Manufacturing Method of Surface Integrity of Large-size Bearing Raceway with Excellent Service Performance

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Abstract. The quality of the bearing ring raceway surface layer directly affects its service performance. Surface defects such as micro-cracks, high tensile stress state and tissue damage caused by improper processing methods seriously damage the surface integrity of the work-piece and reduce bearing fatigue strength or fatigue life. In this paper, through the theoretical analysis and surface integrity manufacturing technology of abrasive flow polishing for high service performance bearings, the basic theoretical method for improving the surface quality of large bearings is established. This achieves the performance-driven manufacturing requirements required for high service performance bearing parts and innovative manufacturing methods for improving the quality of the bearing ring raceway surface.

Keywords: Excellent Service Performance, Bearing Raceway, Surface, Integrity Manufacturing

The bearing raceway surface layer and microscopic appearance are shown in Figure 1. When the surface of the bearing ring is ultra-precision processed, although the roughness and surface topography only change in the micron and submicron range, it can greatly improve the rated life of the rolling bearing and increase its life by more than 30%. The reason is known from the fracture mechanics. The greater the surface roughness value of the metal, the deeper the surface groove marks, the smaller the radius of the bottom, the more severe the stress concentration, and the worse the fatigue resistance. [1] Therefore, it is a development trend to improve the surface roughness quality and fatigue life of the bearing ring raceway. However, it should be pointed out that from the viewpoint of the formation mechanism of the lubricating oil film, the lower the roughness value, the better the better, and it also has the optimum interval value, which requires further study.

In addition to the effect of surface topography and roughness on the serviceability of rolling bearings, residual stress acts as an unstable stress state. When the applied load interacts with the residual internal stress, the internal stress is redistributed and the shape dimensional accuracy of the work-piece changes. When the load is unloaded, the internal stress is again redistributed, so that its distribution has a great influence on the fatigue performance of the rolling bearing. [3] Caruso S et al. pointed out that during the use of parts, residual tensile stress will promote the formation and expansion of fatigue cracks and reduce the service life of the work-piece. Therefore, the ideal stress
distribution is residual compressive stress. [2, 4] Therefore, to reduce stress concentration, changing the high tensile stress to compressive stress technology is another development trend.

This paper combines the urgent needs of China’s industrial strong foundation engineering, and aims to restrict the technical bottleneck of high efficiency precision polishing of China's excellent service performance bearing. Through the intersection of mechanics, mechanics, control and other disciplines, this paper studies the interdisciplinary fields such as machine tool dynamics, abrasive flow feedback control and uniform flow field formation in the visco-elastic abrasive flow polishing of large-size bearing inner and outer ring raceways.

1. Verification of the Scheme Feasibility

1.1 Feasibility Analysis of Basic Principles

(1) The viscoelastic fluid abrasive group polishing process can realize the motion and control based on Newtonian fluid by statistically analyzing the grinding force model and force transmission process of the abrasive grain group in the micro surface layer. The fluid abrasive grain group has good fluidity [9], which conforms to the analytical theory of statistical mechanics and has the mechanical characteristics of Newtonian fluid in the extrusion process. Its control theory is mature, and the control method is large and the adjustment range is large.

![Figure 1 Bearing Raceway’s Surface Layer and Microtopography](image1)

Figure 1 Bearing Raceway’s Surface Layer and Microtopography

![Figure 2 Abrasive Cutting Model of Abrasive Grain Group on Microscopic Surface](image2)

Figure 2 Abrasive Cutting Model of Abrasive Grain Group on Microscopic Surface

(2) The viscoelastic fluid abrasive group polishing process can modify the surface microscopic features of the part, reduce the residual stress and improve the work hardening strength. As shown in Fig. 1, the larger the surface roughness value, the deeper the surface groove marks, the more severe the stress concentration, and the worse the fatigue resistance. During the extrusion process, the fluid abrasive grain group can reconstruct the surface micro-morphology in the mesoscopic scale, and automatically adjust the cutting depth of the abrasive grain group. When the hard point is encountered, a certain concession will occur (Fig. 2). In this way, the metal lattice is not broken and the work-piece is flexed and deformed during the cutting process, and the metal surface lattice is not damaged. This eliminates defects such as residual stress and micro-cracks in the previous process, improves the fatigue strength and corrosion resistance of the part, and improves the fatigue life of the work-piece. [4, 5]
1.2 Feasibility Analysis of Key Technologies
(1) The distribution law of expected processing parameters of pressure, velocity and flow during the polishing process of viscoelastic fluid abrasive grains can be obtained.

In January 2016, the research team completed the study of high-efficiency, high-efficiency and precision super-finishing equipment for large-size rolling bearing ring raceway grinding flow. The research on the optimization of process parameters for precise control of viscoelastic fluid abrasive grain finishing process has achieved initial results. The precise control of the viscoelastic fluid abrasive particles has been achieved initially, and the distribution rules of the processing parameters such as pressure, velocity and flow rate of the random abrasive grain group have been obtained.
(2) Through the fixture reverse technology, in the process of extrusion and polishing of viscoelastic fluid abrasive grains, the surface to be machined is uniformly ground, and the process parameters are optimized and corrected.

The three-dimensional measurement technology is used to directly measure the three-dimensional measurement of the bearing ring raceway surface of different types and structures. Combined with the three-dimensional modeling, the inner film fixture of the bearing ring raceway is reversely manufactured, and the inner membrane cavity conforming to the bearing ring raceway surface is obtained. Further optimize the cross-sectional area of the cavity mold cavity, improve the flow field, increase the fluidity and processing efficiency, optimize the process parameters, and achieve uniform grinding and polishing.

1.3 Feasibility Analysis of the Scheme Implementation
In the process of “high-efficiency, high-efficiency and precision super-finishing equipment for large-size rolling bearing ring raceway grinding flow”, the research team developed a viscoelastic fluid abrasive flow finishing test equipment. Based on the results of previous research, we will further carry out in-depth research on the rolling subject in this direction. That is to say, the research on the pressure field and the speed field uniformization control principle of the complex surface abrasive flow polishing, and the mechanism of the viscoelastic abrasive medium on the surface of the part and the low roughness surface creation method are studied.

2. Research Method and Technical Route

2.1 Research Method
Analytical method for the flow characteristics of viscoelastic fluid abrasive grains: using the conservation equation of energy momentum in fluid mechanics, the power law equation in rheology or the fractional mechanical model of viscoelastic body in soft matter mechanics. [8,9,10]

The method for establishing the quantitative removal model of materials: using the Preston equation, the single-particle cutting model of Rabinowicz in friction and wear, or the mechanical conservation equation of fluid abrasive per unit volume.

The analysis method of the distribution law of residual stress: the plastic strain incremental integration method and the relaxation calculation method satisfying the residual stress-strain boundary condition in the rolling contact problem.

Prediction method of fatigue life: verified by the bearing life tester using Neuber strain life method and finite element analysis method.

2.2 Technical Route
(1) Study on Interface Mechanical Behavior of Viscoelastic Fluid Abrasive Flow
Combined with the basic test results, applied fluid mechanics, statistical mechanics and statistical theory. The flow characteristics of viscoelastic abrasive flow were modeled and simulated, and the distribution of parameters such as pressure, velocity and flow rate of the surface of the viscoelastic abrasive flow was obtained. Then the interface mechanics and finite element analysis method are applied to model and simulate the mechanical behavior between the extruded contact surface and the
material removal surface. The cutting action model under different working conditions of rolling and slipping of random abrasive grain groups is obtained, as shown in Fig. 2.

(2) Theoretical Modeling and Numerical Simulation of Functional Surface Micromorphology

Based on the knowledge of the influence of the dynamic surface of the random medium on the polished surface and the surface dynamics of the machined surface, the knowledge of grinding principle, friction and wear model and Preston equation were used to establish a quantitative material removal model for the viscoelastic fluid. The Gaussian distribution and the GW contact model are used to predict the distribution of surface roughness and residual stress of the abrasive particles in the viscoelastic fluid abrasive grain group, and to combine the roughness and residual stress in the basic test to characterize the surface integrity. The curve chart analyzes the mapping relationship between the performance of the fatigue life index and the like.

(3) Flow Field Control of Uniform Viscoelastic Fluid Abrasive Particles based on Reversed Fixture

The 3D scanning technology is applied to the 3D scanner, and the surface topography data of the bearing to be tested is input into the computer, and then the point cloud model obtained by the 3D scanning is spliced and stitched in the computer to form a 3D simulation model. Furthermore, the 3D simulation model is repaired, processed to form a 3D solid model, and then the processed surface of the work-piece is extracted in the 3D solid modeling software, and the contour processing is performed to obtain the contoured surface of the fixture required for production. Finally, the contoured surface of the 3D fixture is directly imported into the 3D printer, and the profiling fixture with complex structure, cavity, or curved surface is directly generated by 3D printing. This achieves an established control of the trajectory of the viscoelastic fluid abrasive population.

(4) Perfect Test Equipment and Optimization and Inversion of Viscoelastic Fluid Abrasive Polishing Parameters

By analyzing the mapping relationship between the processing parameters of viscoelastic fluid abrasive flow and the surface integrity parameters of excellent service performance, the process parameter control domain of surface roughness reconstruction and high tensile stress to compressive stress transformation is established, and the processing parameters are optimized.

(5) Polishing Effect Evaluation

The experimental study on the flow polishing of viscoelastic fluid on the raceway surface of large-size bearings was completed. Evaluate the surface micro-morphology of the viscoelastic abrasive flow after cutting, hardening and modifying the metamorphic layer, and form a relatively complete key technical device, technical data and process specifications.

3. Possible Problems and Solutions

This research object is the creation mechanism of surface integrity. On this basis, the method of transforming tensile stress to compressive stress of large-size rolling bearing ring raceway is deeply studied. The problems and solutions that may be encountered are as follows:

Question I: The viscoelastic fluid abrasive flow processing is caused by the improper design of the clamp, and the ferrule raceway is “rounded” and “over-thrown”. [6]

Solutions: By controlling the grinding process parameters of the ferrule, the machining allowance of the viscoelastic fluid abrasive flow polishing process is increased. And through the shape of the flow path of the rolling bearing ring clamp to prevent “rounding” and “over-throwing” caused by uneven pressure.

Question II: Verification of the test results of the large service rolling bearing excellent service performance after the viscoelastic fluid abrasive flow processing.

Solution: The rolling bearing life test is carried out by the rolling bearing life tester, the test bearing is verified by the working conditions of the variable load, and the test report is issued by the authoritative inspection department.

Question III: Due to the limitation of the size of the cylinder and the fixture of the abrasive flow machine, the viscoelastic fluid abrasive flow polishing method cannot be used.

Solution: Considering the range of products of the local bearing company, the rolling of the rolling
bearing ring raceway with a nominal outer diameter of 90 mm to 430 mm is carried out. In this way, the needs of local bearing enterprises are met, and the difficulty of project implementation is also reduced, and the feasibility of the project is guaranteed.

4. Conclusion
The quality of the bearing ring raceway surface layer directly affects its service performance. Especially in the process of material micro-removal, surface defects such as micro-cracks, high tensile stress state and tissue damage caused by improper processing methods seriously damage the surface integrity of the work-piece and reduce bearing fatigue strength or fatigue life. [5] The abrasive flow polishing method of the excellent service performance bearing based on the surface integrity manufacturing technology can effectively improve the high service capacity of large-size bearings. This can effectively meet the performance-driven manufacturing requirements required for bearing parts and is a new process and new method to improve the quality of the bearing ring raceway surface.

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