Experimental study on the superfinishing process optimization for zirconia ceramic bearing raceway

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Abstract. Using superfinishing machine to perform a superfinishing research test on the raceway of ceramic bearing, the study aims to figure out the effect of all the superfinishing parameters on the surface roughness and raceway profile precision of zirconia ceramic bearing, analyze the changing tendencies in raceway surface roughness and profile precision, and optimize the superfinishing process of ceramic bearing. As suggested by the present study, the effect of superfinishing stone pressure on the surface roughness and profile precision of raceway is most significant. The surface roughness and profile precision of the raceway increase first and then decrease with rising workpiece tangent speed, keeps growing with rising superfinishing stone, and decrease first and then increase with higher long oscillating speed. As the short oscillating speed is raised, the roughness improvement rate falls but the raceway profile precision improvement rate rises first and then drops. According to the results, the optimal superfinishing process parameters are as follows: workpiece tangent speed: 300M/min, superfinishing stone pressure: 0.8N/mm^2, long oscillating speed: 800U/min, and short oscillating speed: 1,900U/min.

1.Introduction

With outstanding performance, the ultra-precision full-ceramic bearing made of engineering ceramic is gradually applied to such high-end technical fields as spaceflight, military, and energy development [1]. The superfinishing, the last procedure in bearing ring's raceway grinding and processing, can greatly improve the surface quality and profile precision of the finely ground bearing ring's raceway, bearing accuracy and service life. Gabriel Dontu et al [2] conducted a superfinishing test on the bearing ring in order to analyze the circumferential and axial residual stress at the bottom of bearing ring's raceway. ZX Huang et al [3] discussed the formation mechanism of raceway's geometrical precision and the methods for alleviating surface pattern change on the workpiece.

The author adopted zirconia ceramic bearing's outer ring as the research object to study such process parameters as workpiece tangent speed, superfinishing stone pressure, and long/short oscillating speed and the rules about their effect on the raceway roughness and profile precision.

2. A theoretical analysis of the superfinishing of raceway

In the rough superfinishing stage of zirconia ceramic bearing, greater superfinishing stone pressure, quicker superfinishing stone oscillating speed and slower workpiece tangent speed were set in order to effectively get rid of the defects on the surface of the finely ground raceway [4,5]. The greater superfinishing stone pressure can provide high forward cutting force so that the diamond grains could produce more significant cutting effect on the surface of raceway; the quicker superfinishing stone oscillating speed can raise the frequency of grinding and cutting of raceway surface by the surface of superfinishing stone within the same time; and the slower workpiece tangent speed prolongs the action time of superfinishing stone on the surface of raceway within same time so that the action frequency of superfinishing stone on raceway surface and the removal rate get improved at the same time.

The superfinishing cutting angle is:

$$\theta = \arctan\frac{v_a}{v_w} = \arctan\frac{Af\cos\alpha \pm BF\cos\beta}{D_w n_w}. \qquad (1)$$

Where A is the long oscillating range (mm) of superfinishing stone and B is the short oscillating range (mm), f is the long oscillating frequency of superfinishing stone and F is the short oscillating frequency (DH/min), Dw is the raceway bottom diameter of bearing ring (mm), nw is the revolving speed of the bearing ring (r/min), αis the long oscillating amplitude (°), and βis the short oscillating amplitude (°).

The cutting angle can affect the superfinishing state. The higher the cutting angle θ is the stronger the superfinishing stone's cutting effect and superfinishing efficiency will be. However, in such case, the surface roughness of the post-processing raceway remains high [6].

3. Experimental plan

3.1 Experimental conditions

The specimen used in the experiment was zirconia ceramic bearing's outer ring with a raceway surface roughness of 0.25~0.35μm and raceway profile precision of 5~7. The superfinishing stone was diamond (granularity: 3,000; hardness: O). In the experiment, Bearing Star 111k bearing raceway superfinishing machine was used. The bearing raceway was tested with Surtronic25 roughness profile gauge in terms of roughness and profile precision of the bearing raceway.

3.2 Experimental design

An orthogonal experiment of four factors and four levels L16 (4^4) was carried out [7], and the superfinishing was set to last 5 seconds. After the experiment was done, the improvement resulting from the superfinishing processing was compared among different groups. The factors and levels in the orthogonal design are as shown in Table 1.

Table 1 Factors and levels in the orthogonal design

Level \ Factor	Workpiece tangent speed [M/min]	Superfinishing stone pressure [N/mm^2]	Long oscillating speed [U/min]	Short oscillating speed [U/min]
1	150	0.8	800	1600
2	250	0.6	900	1900
3	350	0.4	1000	2200
4	450	0.2	1100	2500

4. Experimental results and analysis

4.1 Effect of workpiece tangent speed on experimental results

As shown in Eq. 1, as the workpiece tangent speed was raised, the cutting angle became smaller, the cutting effect of superfinishing stone was weakened, but the raceway's surface roughness decreased. In the meantime, the bearing raceway was more frequently exposed to the superfinishing stone within the same time so that the improvement rate rose. In accordance with Fig. 1, the roughness improvement rate and profile precision increased first and then decreased with rising workpiece tangent speed. When the workpiece tangent speed was 250~350M/min, the superfinishing yielded the best improvement effect on the raceway roughness and profile precision. When the workpiece tangent speed was low, the grain trajectory interval was quite close and the grains acted more on the surface. As the workpiece tangent speed was further raised but the superfinishing stone oscillating speed kept unchanged, the grain trajectory interval was enlarged so that the acting effect of grains on raceway surface became less significant. The fine grindings resulting from the cutting can also block the superfinishing stone and lead to reduced roughness and profile precision improvement rates.

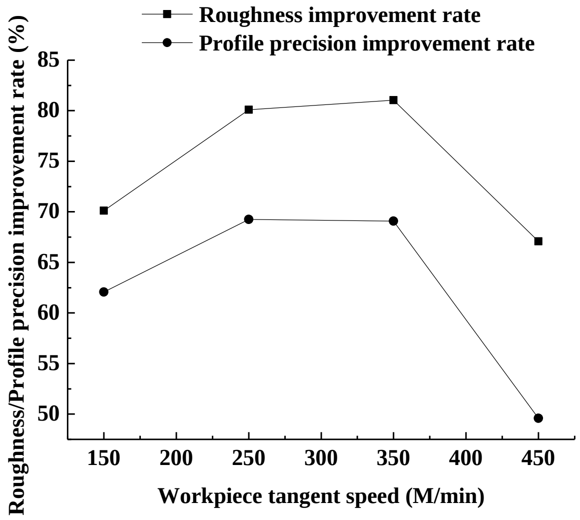

Fig. 1 Effect of workpiece tangent speed on roughness/profile precision improvement rate

4.2 Effect of superfinishing stone pressure on experimental results

As indicated in Fig. 2, when the superfinishing stone pressure became higher, the roughness and profile precision improvement rates rose first and then tended to remain stable. Due to such factors as grinding heat, some defects may exist on the surface of the grounded raceway. During the superfinishing process, with rising superfinishing stone pressure, the cutting effect on the raceway surface also got improved gradually and the surface defects of the raceway could be removed within a short period of time. Since the superfinishing stone was in oscillating movement, it matched the raceway surface after taking the shape. As the superfinishing stone pressure became higher and higher, the superfinishing stone's removal ability was also gradually improved. After certain time, the superfinishing stone would be able to cut the raceway surface at a uniform speed, resulting in gradually stabilized roughness and profile precision improvement rates. When the superfinishing stone pressure was 0.8N/mm^2, the roughness and profile precision improvement rates were most significant.

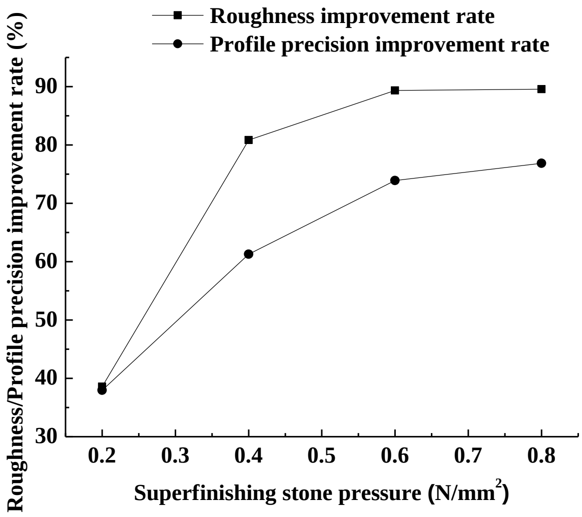

Fig. 2 Effect of superfinishing stone pressure on roughness/profile precision improvement rates

4.3 Effect of long oscillating speed on experimental results

As suggested by Fig. 3, with rising long oscillating speed, the roughness improvement rate fell first and then tended to be stable. The roughness and profile precision improvement rates reached the highest values when the long oscillating speed was 800U/min. As the long oscillating speed was raised, it can be inferred from Eq. 1 that larger superfinishing cutting angle and enhanced cutting effect of superfinishing stone would be caused. The profile precision improvement rate increased first with higher long oscillating speed but rose later. With raised long oscillating speed, the cutting angle became enlarged and the superfinishing stone exerted a more significant cutting effect on the raceway surface to greatly improve the original profile and bring down the profile improvement rate. When the long oscillating speed was further raised, the effect on superfinishing stone was also strengthened so that its self-sharpening performance became more outstanding and the profile precision improvement rate got improved.

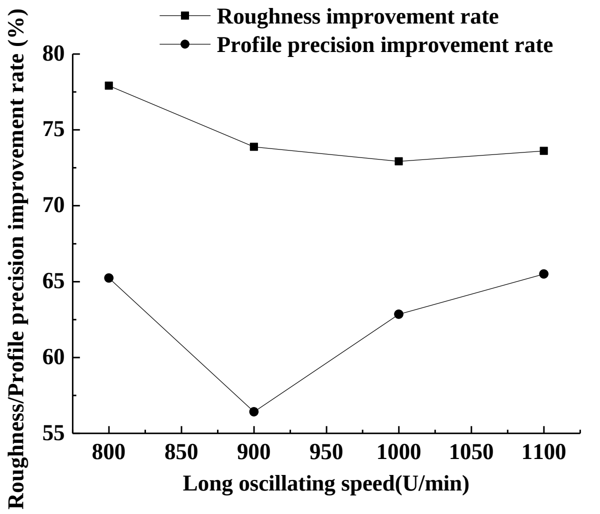

Fig. 3 Effect of long oscillating speed on roughness/profile precision improvement rates

4.4 Effect of short oscillating speed on experiment results

Short oscillating means the oscillating of small amplitude during the long oscillating process. In a long oscillating cutting period, short oscillating cutting happens for several times. It can be inferred from Eq. 1 that the cutting angle keeps changing in the compound oscillation. The phenomenon is more self-evident when the short oscillating speed becomes higher, and the raceway surface roughness can be significantly reduced. In accordance with Fig. 4, with growing short oscillating speed, the surface roughness improvement rate fell, whereas the profile precision improvement rose first and then decreased. With improved short oscillating speed, the surface material removal capacity of the raceway was ameliorated with removal of surface metamorphic layer resulting from grinding heat and formation of arc raceway and better profile precision. As the short oscillating speed kept growing, the material removal effect on raceway surface was further enhanced, which caused removal processing of the raceway after the removal of original defects, lower profile precision and reduced improvement rate.

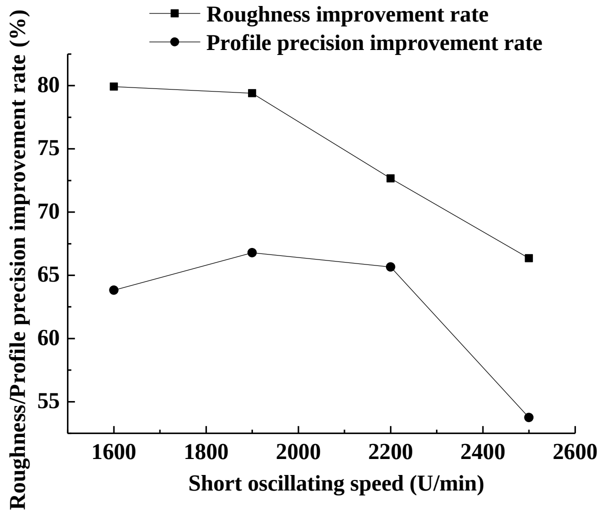

Fig. 4 Effect of short oscillating speed on roughness/profile precision improvement rates

5. Conclusion

This experimental study investigates the effect of superfinishing parameters in the zirconia ceramic bearing superfinishing on raceway roughness and raceway profile precision, and theoretical formulas and superfinishing mechanism are used to analyze and reveal the rules about the effects of it.

The zirconium ceramic bearing raceway quality is closely related to the superfinishing parameters, workpiece tangent speed, superfinishing stone pressure and long oscillating speed can be appropriately increased to improve the quality of the ceramic bearing raceway, but the short oscillating speed is not too high. Raceway roughness and raceway profile precision of the ceramic bearing were greatly improved by optimized superfinishing process.

In the superfinishing stage, superfinishing oil acts on the surface of the raceway to produce a superfinishing oil film. At the same time, superfinishing stone has less removal of engineering ceramic raceway surfaces, whether there will be chemical changes between the surface of superfinishing stone, superfinishing oil and workpiece raceway to generate new substances, these issues have yet to be further studied.

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