Preparation Process of Sliding Bearing of Precision Motorized Spindle

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Abstract. Aiming to realizing the high efficiency and high precision of manufacture, the requirements of the bearing manufacturing process were pointed out for the application of high-precision motorized spindles. A standardized bearing manufacturing process was proposed. Furthermore, the manufacturing process flow was verified with three steps of manufacture of sliding bearing, including 3D modelling, simulation processing, bearing processing. Stiffness and vibration of the sliding bearing manufactured were tested on motorized spindle bearing testbed. The result showed that the sliding bearing manufactured has the characteristics of high rigidity and low vibration, and meet the requirements of precision motorized spindle. Process design method in this paper provides an important reference for high-precision bearing manufacturing.

1. Introduction
The direction of machine tool technology researches is high efficiency and high precision at present. For example, milling of aero-engine impeller should ensure design geometric accuracy of blade profile to meet aerodynamic requirement, which provide better maneuverability and bigger take off power for modern warplanes [1]. Again for instance, large-caliber optical lenses need more efficient manufacturing process to shorten the process of exact-grinding and polishing from several weeks to one week [2]. Motorized spindle is the power source for achieving high efficiency and high speed for machine tool. But for the motorized spindle, high efficiency and high precision is a pair of contradictions [3]. For the motorized spindle which shaft is support by rolling bearing, excessive speed will lead to decrease of spindle rotation accuracy, the main reason of which is heat of the coils caused change of fit clearance between rotor and bearing. The root of the problem is rolling bearing lack damping characteristics [4]. Replacing rolling bearing with sliding bearing can resolve the defect of rolling bearing. Although support stiffness of rolling bearing is double larger than sliding bearing with the same size, the rotor supported by sliding bearings can get higher speed, which is 3-4 times higher than the rotor supported by rolling bearing [5][6].

Sort by the way of lubrication, sliding bearings include liquid bearing, gas bearing and electromagnetic bearing. But, the support stiffness of gas lubricated bearing is so low although it can use in the higher speed working condition, so it is unfit use in a motorized spindle work for milling [7]. While electromagnetic bearing need electromagnetic induction to control the clearance with rotor, which will produce coupling action against spindle motor coils to make bearing operation unstable [8].
So, it is a feasible scheme to use liquid lubricated bearing. There are several materials commonly used for liquid lubricated bearing, like steel, tin bronze and Babbitt metal. Babbitt bearing is a kind of bimetallic bearing, the Babbit of bearing surface form a whole with metallic matrix [9].

The purpose of this paper is design a manufacturing process of sliding bearing using the scientific method, to provides an important reference for high-precision bearing manufacturing.

2. Manufacturing process design of sliding bearing of precision motorized spindle

2.1. General process of sliding bearing manufacturing

The manufacturing of sliding bearings is generally based on manuals and experiences. The main problems faced in process design are: (1) How to meet the required manufacturing accuracy, including dimensions and tolerances; (2) How to meet the technical requirements for bearing linings, including adhesion and defect control; (3) How to obtain higher reliability and lifetime. General process of bearing manufacturing is shown in the Figure 1.

![Figure 1. General process of bearing manufacturing](image)

2.2. Design principle of sliding bearing manufacturing process

Aimed to the requirements of high efficiency, high precision, high stiffness of manufacture, the requirements of the bearing manufacturing process were pointed out for the special application of high-precision motorized spindles. Design purpose of manufacturing process is the selection of bearing manufacturing program, processing equipment and quality inspection equipment. The following ways are usually used to estimate the manufacturing quality of sliding bearing:(1) Measured dimension error of bearing. Dimension error is the difference between work piece dimension and drawing dimension, work piece dimension can be measured by vernier calliper or micrometer. While for high precision bearing which has special requirements, it can be measured by three coordinates measuring instrument. (2) Measured surface error of bearing. Surface error of bearing mainly include internal lubricated surfaces and external mounting surface, measured index are surface runout and surface roughness. (3) Measured defect and bonding strength of Babbitt layer. Internal defect of Babbitt can be detected by penetrant test or ultrasonic testing; bonding strength can be measured with universal tensile testing machine. (4) Measured static-dynamic characteristic of bearing. Static and dynamic characteristics of bearing were measured by bench test which simulated the work conditions of bearing. (5) Measured life of bearing. Lift test of bearing is carried out on bench test too. According to enlarging load applied or increasing test speed, simulation of long-time operation of bearing was realized to estimate life.

2.3. Design of sliding bearing manufacturing process

This paper considers the bearing manufacturing evaluation criteria and process design principles, based on a large number of basic research carried out by the studying team on the motorized spindle system, proposes a standardized sliding bearing manufacturing process. Refine and concretize the design method of the sliding bearing manufacturing process, and integrate design decentralization of traditional manufacturing processes, thereby improving the efficiency and quality of the bearing manufacturing. Machining process flow chart of sliding bearing for high precision motorized spindle was shown in Figure 2. Processes include manufacture and detection, the core links were manufacture of bearing shape and preparation of Babbitt layer. Advanced CNC machine tool, reasonable machining parameters and high digital centrifugal casting machine will be the guarantee to achieve high quality manufacture.
3. Manufacturing example and property tests of the bearing

3.1. Manufacturing example of the bearing

The bearing to be manufactured is a hybrid bearing, and which was designed for a kind of high precision motorized spindle. Structure diagram of the bearing is shown in the Figure.3. And the values of main design parameters are listed in the Table 1.

![Figure 3. Structure diagram of the bearing to be manufactured](image)

![Figure 2. Machining process flow chart of sliding bearing of precision motorized spindle](image)

**Table 1. The values of main design parameters of the bearing**

| Parameter             | Value   | Parameter             | Value   |
|-----------------------|---------|-----------------------|---------|
| Radial motion error $\varepsilon_r/\mu m$ | 0.3     | Design speed $n/r/min$ | 6000    |
| Axial motion error $\varepsilon_a/\mu m$ | 0.3     | Inside diameter $r/\ mm$ | 85      |
| Radial stiffness $K_r/N/\mu m$            | 1000    | Outside diameter $R/\ mm$ | 100     |
| Axial stiffness $K_a/N/\mu m$             | 1000    | Width $B/\ mm$         | 90      |

The manufacturing process of bearing was strictly in accordance with the figure.2. Several core links of the manufacturing process are described as follows. First of all, a 3D model of the bearing to be manufactured was built by UG software. The model is shown in the Figure.4, from which the appearance of the bearing after manufacture can be seen clearly. Then, machining simulation of the bearing was carried out by VERICUT software according to the 3D model. Machine tool in the machining simulation is a milling-grind machine (DMG HSC75), which is the same as that in the actual processing of the bearing. The manufacturing process sequence of the bearing is rough Machining-Babbitt casting-finish machining. The simulation results show that all the machine processes of the bearing could be carried out on the machine tool smoothly, indicating there has no interference between each machinery process. The total time of machining processes was 576 min. screenshots of the machining simulation are shown in the Figure.5.
3.2. Property test of bearing

Schematic diagram and photo of testbed were shown in Figure 7. Rotor of testbed was derived by coil directly, the same as actual motorized spindle.

Test data were measured under different speed ranging from 500 r/min to 4000 r/min, the data was measured every additional 500 r/min. The test period of amplitude was 0.20s. Maximum amplitude under each speed was considered as corresponding amplitude. Fig. 9 showed the test data under speed 4000 r/min.

The amplitude and stiffness of rotor under each test speed were shown in Fig. 10. The maximum horizontal amplitude and vertical amplitude of rotor are 3.2 μm and 3.0 μm respectively. When speed is 500 r/min, the stiffness of bearing is minimum, i.e. 3.2×107 N/m. It presented that the sliding bearing manufactured design method meet the requirements of precision motorized spindle and
grinding of thin-walled Aluminium alloys components and optical lenses, signifying reliability of process design method.

![Figure 9. The amplitude and stiffness of rotor under each test speed](image)

4. Conclusions
The requirements of the bearing manufacturing process were pointed out for the special application of high-precision motorized spindles. A standardized bearing manufacturing process was proposed. According to the proposed process, a bearing was manufactured, and the performance of the bearing was evaluated. The evaluation results showed that the bearing has the characteristics of high rigidity and low vibration, and it meets the requirements for high-precision spindles. Process design method in this paper provides an important reference for high-precision bearing manufacturing.

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