Simulation Analysis on the Static Characteristics of High Speed Milling Motorized Spindle

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Abstract. The structure design and the static characteristics of the motorized spindle determine the machining quality and cutting performance of high speed CNC machine tools. In this paper, the ANSYS finite element software is used to analyze the static characteristics of the high speed milling motorized spindle, so as to verify the rationality of the structure design.

Introduction

In order to ensure the reliability and accuracy of the machining, high speed CNC machine tool must have good static performance. The motorized spindle system is the core component of high-speed CNC machine tool. The static stiffness of the motorized spindle will directly affect the processing performance. It is very important to analysis and optimization the spindle system structure static. So that can further improve the performance of the high-speed machine tool.

Table 1. Main design parameters of motorized spindle.

<table>
<thead>
<tr>
<th>Nr</th>
<th>Technical index name</th>
<th>Technical index value</th>
<th>Nr</th>
<th>Technical index name</th>
<th>Technical index value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sleeve diameter</td>
<td>170mm</td>
<td>7</td>
<td>Rotation precision</td>
<td>End runout &lt;2µm, Radial runout &lt;3µm</td>
</tr>
<tr>
<td>2</td>
<td>Maximum speed</td>
<td>18000rpm</td>
<td>8</td>
<td>temperature rise</td>
<td>Maximum speed to thermal equilibrium state, Front bearing peripheral &lt;25℃, Outer of the sleeve &lt;20℃</td>
</tr>
<tr>
<td>3</td>
<td>Rated speed</td>
<td>10000rpm</td>
<td>9</td>
<td>Vibration</td>
<td>At the maximum speed, the vibration speed &lt;0.4mm/s</td>
</tr>
<tr>
<td>4</td>
<td>Rated power</td>
<td>45kW</td>
<td>10</td>
<td>Noise</td>
<td>&lt;70-75dB</td>
</tr>
<tr>
<td>5</td>
<td>Tool system</td>
<td>HSK 63</td>
<td>11</td>
<td>Static clamping force</td>
<td>18kN</td>
</tr>
<tr>
<td>6</td>
<td>Tool cooling mode</td>
<td>Central cooling</td>
<td>12</td>
<td>Life</td>
<td>&gt;8000 Working hours</td>
</tr>
</tbody>
</table>

Figure 1. Schematic diagram of electric spindle structure in high speed milling.
Basic Design Parameters of High Speed Milling Motorized Spindle

The basic design parameters of high speed milling motorized spindle are shown in Table 1. Figure 1 shows the design of the high-speed milling spindle structure schematic.

ANSYS Static Characteristics Analysis of High Speed Motorized Spindle

High speed spindle static analysis is to calculate the static stiffness of the spindle system. The spindle static stiffness includes axial stiffness and bending stiffness. Bending stiffness is to produce radial displacement required for the spindle unit in the radial force. Axial stiffness is the axial displacement required to produce unit the spindle under the action of axial force. The general said the spindle stiffness mainly refers to the bending stiffness.

Figure 2. Simplified model of motorized spindle.

![Figure 2. Simplified model of motorized spindle.](image)

Figure 3. Grid division of electric spindle model.

![Figure 3. Grid division of electric spindle model.](image)

Constructing Geometric Model and Mesh Generation

In order to carry on the static simulation analysis of the spindle unit accurately and effectively, the finite element method is used to carry out the 3D modeling. When modeling, the whole electric
spindle unit model should be simplified. The rotor of the motor, front and rear bearing lock sleeve, locking sleeve of encoder and spindle body is in interference fit with the shaft core, can be simplified as excluded together, equivalent to the material density modeling according to the integration process of shaft. The angular contact ball bearing is simplified as an elastic support, and the pivot point is located at the intersection point of the contact line and the main axis of the main shaft. It is considered that the bearing only has the radial stiffness, and does not have the angular stiffness, so the support is further simplified to the radial compression spring mass unit. Each bearing in the circumferential direction equivalent distribution of four springs, ignore the bearing load and speed on the bearing stiffness, the stiffness of the bearing is considered to be a constant constant. The simplified modeling is shown in Figure 2

According to the principle of simplification, the finite element model of the motorized spindle is divided according to the above unit selection. The finite element mesh is obtained as shown in Figure 3. The model consists of 107937 units and 173217 nodes.

**Finite Element Loading and Solving**

When the maximum speed is 18000r/min, it is very important to analyze the bearing capacity of the main shaft under the action of cutting force. Cutting force can be calculated by the following formula [2]

\[
F_C = C_F \cdot a_e^{1.1} \cdot a_f^{0.8} \cdot d_t^{-1.1} \cdot a_p^{0.95} \cdot Z
\]  

(1)

In the formula \( F_C \)—cutting force, Kgf

\( C_F \)—influence co-efficient of work piece material on cutting force

\( a_e \)—milling contact arc depth, mm

\( a_f \)—feed per tooth mm/tooth

\( d_t \)—milling cutter diameter mm

\( a_p \)—milling depth mm

\( Z \)—The number of teeth in milling cutter

In this paper, the design of the motorized spindle unit, as follows: \( C_F=82; a_e=16 \text{mm}; a_f=0.1 \text{mm/tooth}; d_t=40 \text{mm}; a_p=2 \text{mm}; Z=6 \).

Calculation result \( F_C=2486 \text{N} \)

Milling feed resistance \( F_H=(0.3-0.4) \), the maximum value is 994N, so that the work piece is lifted or pressed the force \( F_V=(0.85-0.95) \), the maximum value is 2362N.

\[
F_H = \sqrt{F_V^2 + F_F^2} = 2563 \text{N}
\]  

(2)

As a way of supporting bearings fixed on the front end, rear end axial without restraint, radial load on the front end node \( F_F=2563 \text{N} \). As shown in Figure 4. The model of the motorized spindle is loaded to solve the structural analysis effect diagram after loading.

The bending rigidity of the spindle unit is \( K \), which is defined as the force \( F_r \) applied to the displacement direction when the radial displacement \( \delta \) of the front end of the spindle,

\[
F_r = \frac{F_F}{\delta} \text{ (N/µm)}
\]

Since the bending stiffness of the spindle is much more important than the axial stiffness, the stiffness of the spindle is often expressed by the bending stiffness. It can be seen from the figure 4, the front end displacement of the spindle DMX=5.512 µm, therefore, the static stiffness of the motorized spindle is

\[
K = \frac{F_r}{DMX} = \frac{2563}{5.512} = 465 \text{N/µm}
\]  

(3)
Conclusion

The spindle system is a key component of high speed machine tool. The static stiffness directly affects the machining accuracy. In this paper, the ANSYS finite element simulation software is used to calculate and analyze the static stiffness of high speed milling motorized spindle. By loading and solving the motorized spindle model, the static stiffness of the motorized spindle is 465N/μm. The structure of the spindle is verified to meet the design requirements of 480N/μm.

References
