Analysis and Research on the Temperature and Thermal Change of NC Machine Tool Electric Spindle Based on ANSYS Software

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Abstract. With the improvement of CNC technology, CNC machine tools are gradually moving towards high speed, high precision and multi-function. Due to the comprehensive effect of internal and external heat sources, the thermal deformation of the motorized spindle has become the main factor affecting the machining accuracy of the machine tool in high-speed machining. ANSYS software is a large-scale general-purpose finite element analysis software integrating structure, fluid, electric field, magnetic field, and sound field analysis. It can interface with most CAD software, realize data sharing and exchange, and can effectively analyze the temperature and thermal changes of CNC machine tools. Therefore, this paper analyses the thermal deformation mechanism of the spindle of CNC machine tools in computer software, to provide the basis for reducing the thermal deformation of the motorized spindle of CNC machine tools in the future.

Keywords: CNC, Motorized Spindle, Finite Element Analysis, ANSYS Software, Computer Software

1. Introduction
At present, China has become a large country of machine tool production and consumption, but it is still a long way from a powerful country of machine tool. With the rapid development of information technology, CNC machine tools have gradually become the main force of machine tools[1]. Although under the guidance of manufacturing industry, China's machine tool production and consumption are very large, but the overall level of science and technology still needs to be further improved. On the other hand, with the increasing demand of modern CNC machine tools for productivity and machining accuracy, the spindle system which has a direct impact on machining accuracy has become an important component to be studied. Therefore, it is very important to analyze the temperature field and thermal deformation of the spindle of CNC machine tools, which is of great practical significance to understand the thermal deformation mechanism and temperature field of the spindle system[2].

2. Thermal deformation mechanism of spindle of CNC machine tool
Because of the continuous effect of unsteady heat source, the spindle of CNC machine tool is affected by different heat source under different processing conditions. In addition, the temperature field of the spindle is very complex because of the difference of the attribute, contact way and condition of each part[3].
2.1. Heat source analysis of spindle
Generally speaking, there are two main types of heat sources that the spindle receives in the process of operation, as shown in Figure 1 below. It can be seen that it is mainly the bearing heating and transmission parts.

![Figure 1. Main heat source analysis of spindle](image)

2.2. Heat dissipation analysis of spindle
The temperature of the spindle of CNC machine tool is different in different parts, and the heat transfer mode is shown in Figure 1 below[4].

The heat conduction of the internal parts of the spindle is transmitted from the inside to the outside, and convection occurs when contacting with the air. It can be seen that the main way of heat dissipation of CNC machine tool spindle is through air convection and internal cooling oil.

![Figure 2. Heat transfer diagram of main shaft](image)

3. Finite element model of thermal characteristics of spindle

3.1. Finite element method for temperature field calculation
The distribution of temperature in space-time is called temperature field.

\[ t = f(x, y, z, \theta) \]  

(1)

The surface formed by the same temperature point is called isothermal surface. It is impossible for isothermal surfaces with different temperatures to intersect[5].

The limit of the ratio of the temperature difference \( \Delta t \) of the two isothermal surfaces to the vertical distance \( \Delta n \) when \( \Delta n \) tends to zero, as shown in figure 3.

\[ \lim_{\Delta n \to 0} \frac{\Delta t}{\Delta n} = \frac{\partial t}{\partial n} \]  

(2)
\[ q = n \frac{t + \Delta t}{t} - \frac{t}{t - \Delta t} \]

**Figure 3.** Relationship between temperature gradient and heat flow direction.

Fourier's law is used to determine the size of heat flow caused by heat conduction when there is a temperature difference between the points of an object. In unit time, the heat transfer on unit heat transfer area is directly proportional to the temperature gradient.

### 3.2. Principle of finite element analysis of temperature field

The finite element method divides the object into finite elements, each element contains several nodes, and solves the heat balance equation of nodes under the boundary condition and initial condition by continuously distributing the temperature in time and space, and then obtains the temperature value of each node and other related physical quantities\(^6\).

### 4. Finite element modeling and analysis of temperature field of motorized spindle of CNC machine tool

#### 4.1. Finite element analysis of bearing temperature field

The physical properties of materials are important parameters in thermal analysis, including thermal conductivity, specific heat capacity, and coefficient of linear expansion and modulus of elasticity. These parameters often change with the change of temperature. In the process of 3D modeling, the smaller fillets and grooves in the machine tool are ignored, so as to reduce the calculation time and ensure the accuracy of analysis. The modelled machine spindle is shown in figure 4.

**Figure 4.** Modelled machine spindle.

#### 4.2. Temperature field and thermal deformation analysis of the CNC spindle

It can be seen from the curve of temperature change with time of front bearing and front two points of main shaft in Figure5 that the temperature rise of main shaft and bearing increases with time.
According to the simulation results, it can be seen that there are many factors affecting the deformation of the machine tool spindle, and the temperature field is only one aspect. In addition, through the analysis of the thermal deformation under the temperature field, it provides the basis for reducing the thermal deformation of the motorized spindle of the numerical control machine tool.

5. Conclusion
Because the heating of the electric spindle of CNC machine tool is more serious than that of the traditional spindle, the main heat sources are the internal heat sources which are mainly motor bearings, internal motors and bearing thermal friction, and the external heat sources which are mainly environmental temperature and thermal radiation. The thermal characteristics become the main factor affecting the working performance of the electric spindle. Through the establishment of the finite element thermal analysis model of the electric spindle of the CNC machine tool, and the use of computer ANSYS software to compare and study the thermal characteristics of the high-speed electric spindle, this paper obtains the distribution of its temperature field and the deformation of the bearing, which provides the basis for reducing the thermal deformation of the electric spindle of the CNC machine tool in the future.

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