A Mechanical Structure Design for Miniaturized CNC Milling Machine

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Abstract

In order to enhance the convenience of milling parts, lowering production costs and shrinking sizes of CNC milling machine, a design plan for miniaturized CNC milling machine was presented. Firstly, the research significance and current research status were discussed and analyzed. Secondly, the overall mechanical configuration was illustrated and the schematic design plans were made. Through detailed calculating and analyzing, the spindle system and the guide rail system were designed subsequently. The model number of ball screw was chosen and its strength was checked. Next, the sizes of plain shafts were decided. The material and structural number of portal frame were proposed. Additionally, the 3-dimensional assemble modeling was built in SolidWorks, and the engineering graphics were drawn by using AutoCAD. Compared with the traditional ones, this new type CNC milling machine has occupied less space with high productivity in milling works, and lowered the production costs.

Keywords

Miniaturized CNC milling machine, structure design, ball screw, portal frame.

1. Introduction

A large number of CNC machine tools change the traditional production mode, speeding up product transformation [1]. However, in the practical application, the process control and human-computer interaction of the traditional CNC milling machine are more complex, which reduces the processing efficiency and increases the loss of power and equipment [2]. In view of this situation, it is urgent to design a small CNC milling machine with space saving, easy to operate [3,4] and low cost. As a new field of CNC milling machine, small CNC milling machine enriches the application range of CNC milling machine, enhances the usability of CNC milling machine, and has a certain development significance [5].

The five axis super precision micro CNC milling machine, which is studied by [6] in Brunel University, uses the technology of modeling and simulation, and designs a method of dynamic performance analysis. In his thesis, Wu Longyuan of South China University of Technology mentioned the method [7] using Modelica language and Dymola simulation platform to simulate mechanical systems. Ma Hongguang of Tianjin University proposed the concept of parameterized module design in his paper, so as to quickly generate the design scheme of product. In his paper, Wang Lijun of Dalian University of Technology mentioned the method of static analysis and dynamic characteristic analysis to analyze the design result [9].

2. Technical requirements and overall design

2.1 Technical requirements

Through optimizing the structure of machine tools, rational layout, improving the stability of machining, improving the efficiency of motion and ensuring the processing performance. The main technical indicators are shown in table 1.

Table 1 Technical indexes of small numerical control milling machine

Technical indicators	Data
Spindle speed n/r·min^{-1}	24000r·min^{-1}
Maximum processing speed v/mm·min^{-1}	3500mm·min^{-1}
Machining precision mm	0.03-0.05mm
Repetition precision mm	0.02-0.03mm
transmission efficiency	0.95

2.2 Overall design of mechanical structure

The CNC machine tools should have the characteristics of steady movement of each axis, good stiffness and stability, and certain machining precision. The structure layout of the CNC milling machine should meet the requirements above. In comprehensive consideration, Longmen type supporting structure is selected. The guide rail system adopts a double coordinate cross slide, and the transmission unit is a ball screw. Fig.1 shows the system structure layout of a small CNC milling machine.

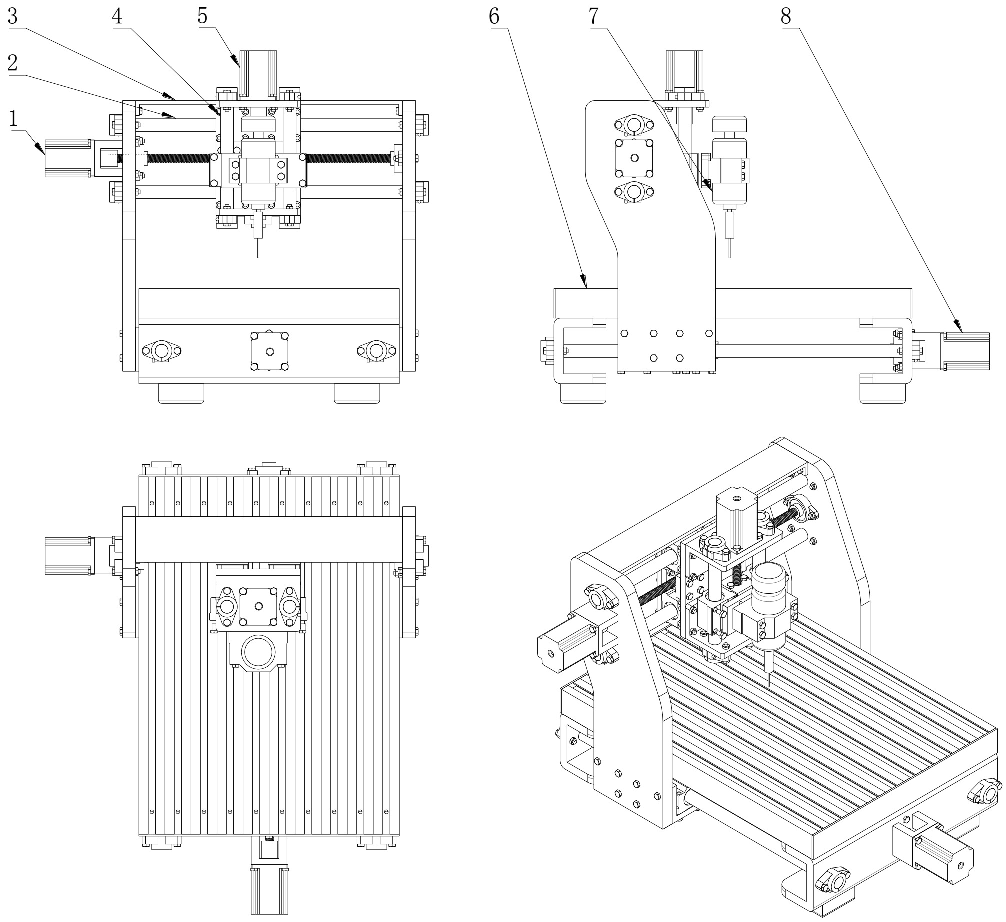

Fig. 1 Structure layout of small numerical control milling machine

3. Design of key components of small numerical control milling machine

3.1 Design of spindle system

3.1.1 Selection of spindle motor

In order to realize the basic requirements of cutting tools and ensuring the precision of machining, there are two kinds of main spindle motors, one is servo motor and the other is step motor. The servo motor is applied to the closed loop system. Because of the feedback mechanism, the accuracy of the servo motor is higher than that of the stepper motor. However, as a stepper motor, which is widely used in open loop system, its control mode and installation way is simpler, and the inertia is low, no cumulative error, and the situation of low speed is satisfied. In addition, stepping motors are cheaper than servo motors, effectively reducing costs.

3.1.2 Selection of stepper motor

Refer to stepper motor related information [10], choose 57BYG250B type stepper motor. Its specific technical indicators are shown in table 2.

Table 2 Technical index of stepping motor

Model	Torque N·m	Rated current A	rotor inertia kg·cm3	Motor weight kg	Adapter driver
57BYG250B	0.8	2.5	0.28	0.7	F258

3.2 Selection calculation of ball screw

The X, Y and Z axis of small numerical control milling machine use ball screw as transmission unit. Its precision directly affects the accuracy of the machine tool, the size of the load and the sensitivity. Therefore, the selection of ball screws should be chosen strictly according to the principles of mechanical design.

1）The guide of the initial ball screw pair

$$P_{\mathrm{h}} = \frac{v_{\max}}{n_{\max}} = \frac{2000}{500} = 4\,\mathrm{mm}$$

In the form of： P_{h} ——Guide of ball screw；

$v_{\max}$ ——Maximum moving speed of wire rod；

$n_{\max}$ ——Maximum relative rotational speed of wire rod。

2）Determination of equivalent speed and equivalent load

$$n_i = \frac{v_i}{P_{\mathrm{h}}} \times 10^3$$

Table 3 Working condition of X axle ball screw

Cutting mode	Axial cutting force $P_{\mathrm{Xi}}/\mathrm{N}$	Vertical cutting force $P_{\mathrm{Yi}}/\mathrm{N}$	Feed speed $v_{\mathrm{i}}/\mathrm{m\cdot min^{-1}}$	Working time percentage $t_{\mathrm{i}}/\%$	Screw speed $n_{\mathrm{i}}/\mathrm{r\cdot min^{-1}}$
General cutting	500	450	0.8	30	80
Strong cutting	750	600	0.6	10	60

Fine cutting	300	200	1	50	100
Fast feed	0	0	15	10	1500

The working conditions of table 3 X axle ball screw are:

$$n_1 = \frac{0.8}{4} \times 10^3 = 200\,\mathrm{r/min}$$

$$n_2 = \frac{0.6}{4} \times 10^3 = 150\,\mathrm{r/min}$$

$$n_3 = \frac{1}{4} \times 10^3 = 250\,\mathrm{r/min}$$

$$n_4 = \frac{15}{4} \times 10^3 = 3750\,\mathrm{r/min}$$

$$F_\mathrm{i} = P_\mathrm{xi} + \mu \cdot (W_1 + W_2 + P_\mathrm{zi})$$

In the form of: F_i ——Axial load of wire rod;

P_xi ——Longitudinal cutting force;

P_zi ——Vertical cutting force;

W_1 ——Workbench weight;

W_2 ——Maximum weight of workpiece and fixture。

Obtain:

$$F_1 = 500 + 0.1 \times (5000 + 3000 + 450) = 1345\ \mathrm{N},\ F_2 = 750 + 0.1 \times (5000 + 3000 + 600) = 1610\ \mathrm{N}$$

$$F_3 = 300 + 0.1 \times (5000 + 3000 + 200) = 1120\ \mathrm{N},\ F_4 = 0 + 0.1 \times (5000 + 3000 + 0) = 800\ \mathrm{N}$$

$$n_m = \frac{n_1 t_1 + n_2 t_2 + n_3 t_3 + n_4 t_4}{t_1 + t_2 + t_3 + t_4} = 4750\,\mathrm{r/min}$$

$$F_m = \sqrt[3]{\frac{F_1^3 n_1 t_1 + F_2^3 n_2 t_2 + F_3^3 n_3 t_3 + F_4^3 n_4 t_4}{n_1 t_1 + n_2 t_2 + n_3 t_3 + n_4 t_4}} = 1000\mathrm{N}$$

3）Expected rated dynamic load

$$C_{am} = \sqrt[3]{60 n_m L_h}\ \frac{F_m f_w}{100 f_a f_c} = 52.8\mathrm{kN}$$

In the form of: C_{am} ——Expected rated dynamic load;

f_w ——Load property coefficient, use 1.3;

f_c ——Reliability coefficient, use 0.44;

f_a ——Precision coefficient 1;

L_h ——Rated working life, use 20000h.

$$C_{am} = f_e f_{\max} = 7.2\mathrm{kN}$$

In the form of: f_e ——Preloading coefficient, use 4.5;

$f_{\max}$ ——Maximum axial load.

Take the above two maximum values as the expected rated dynamic load values,so $C_{am} = 52.8\text{kN}$ 。

4）Determine the minimum thread bottom diameter of ball screw

$$d_{2m} = 10\sqrt{\frac{10F_0L}{\pi\delta_m E}} = 17.44\text{mm}$$

$$L \approx (1.1\sim1.2) + (10\sim14)\ P_h \approx 600\text{mm}$$

5）Determine the size of the ball screw

The use of the internal circulation screw thread pretightening flange nut FFZL 1604-3, fixed method for two segments fixed, while considering the angular contact ball bearing axial stiffness, simple installation, no need for pre load adjustment, small friction torque, so the selection of one to 760201 bearings,nominal contact angle $a = 60°$.

3.3 Strength checking of ball screw

1）Calculation of the pre tightening force of ball screw F_p

$$F_p = \frac{1}{3}F_{\max} = \frac{1}{3}\times1610 = 536.7\text{N}$$

2）Calculation of travel compensation value

$$C = 11.8\Delta t l_u \times 10^{-3} = 11.8\times2.5\times32\times10^{-3} = 17.28\mu\text{m}$$

In the form of： Δt ——Temperature change value,2~3℃;

l_u ——Effective stroke of ball screw.

3）Critical speed of calculation

$$n_c = \frac{10^7 f d_2}{L_{c2}^2} = \frac{10^7\times21.9\times13.1}{577^2} = 8617\text{r/min}$$

4）The pretension of the ball screw

$$F_t = 1.95\Delta t d_2^2 = 1.95\times2.5\times13.1^2 = 823.7\text{N}$$

5）Stability of ball screw press rod

$$F_c = \frac{10^5 K_1 K_2 d_2^4}{L_{c1}^2} \geqslant F'_{a\max}$$

$$L_{c1} = L_{c2} = L - \frac{L - L_K}{2} = 600 - \frac{600-554}{2} = 577\text{mm}$$

Maximum axial load $P_{Xi} = 750\text{N}$ Less than the pre stretching force of the lead screw, the leading screw will not be unstable under pressure.

6）The allowable tensile stress of the shaft shaft

$$\sigma_p = \frac{F_t}{\frac{\pi}{4}d_2^2} = \frac{823.7}{\frac{\pi}{4}\times13.1^2} = 6.12\text{MPa}$$

σ_p Far below the allowable tensile stress, the tensile strength is acceptable.

4. Conclusion

This paper puts forward the design scheme of the mechanical structure of the small numerical control milling machine. From the significance of the analysis, the problems and the aspects that need to be developed are summed up, and the design emphasis is put on two aspects of the efficient use of space and the cost reduction. Starting from theoretical design and calculation, the spindle system, guide rail system and auxiliary system of the milling machine are selected and designed one by one. The selection of the spindle motor, the selection of the coupling, the calculation and checking of the ball screw, the design and calculation of the dimension of the optical axis, the material selection and the structure type design of the Longmen frame. The design was modeled by SolidWorks and 2D engineering drawings were produced by Auto CAD.

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