A Design of Camera Adjustment Mechanism Based on Automatic Visual NC tool Detector

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***Abstract*—Aiming at the camera adjustment mechanism of the automatic NC tool detector based on automatic vision affects the measurement accuracy of the tool parameters, the camera adjustment mechanism is designed. The geometric nature of the camera adjustment mechanism is studied, and the camera rotation and its linear motion in the XZ direction are given; analyzes and contrast the accuracy, structure and cost, the structural scheme is obtained; according to the requirements of the itinerary and accuracy requirements, the selection and design of related components were carried out; finally, the strength and stiffness analysis of the main components was carried out. It provides hardware guarantee for improving the detection accuracy of the vision system's tool parameters.**

Keywords-Visual Inspection; Camera Adjustment; Tool Parameter; Structural Design

I. INTRODUCTION

In industrial production, the parameters of the cutter directly affect the manufacturing efficiency and manufacturing accuracy of the processed parts, as well as the processing cost of the overall production[1-3].Tool detector is mainly used to measure the cutting edge coordinated position of CNC tools. Therefore, the development of the tool detectors restricts the level of industrial production.

The development of foreign tool detector started earlier. In the 1970s, sensors and equipment for tool wear and damage were produced. In the early 1980s, Japan and Germany successfully developed CNC machine tools with tool detection sensors, while in the 1990s machined vision are booming, and its automation and high-precision features have driven the development of tool detectors. At present, many developed countries have introduced high-quality and high-precision digital tool detectors. Among them, the high precision and high market share are the products of *ZOLLER* in Germany, accounting for 60% of the sales in the world market, accounting for 80% of the sales of the Chinese market. The camera adjustment mechanism of their smile series products is a two-axis linkage with a positional accuracy of 1 μm and a repeatability of 2 μm[4,5].

China's digital tool detectors have also begun to develop rapidly in recent years.[6,7]. In 2005, Tianjin Tianmen Precision Machinery Co., Ltd. launched the CCD digital tool measuring instrument, which first appeared at the exhibition. In 2007, Xiamen University developed its own digital image measuring instrument. In 2012, Suzhou Huliang Precision Instrument Co., Ltd. CX15 tool detector, coordinate positioning accuracy (8+L/20) μm[8, 9]. Although China has made great progress in tool detectors, there is still a large gap in the level of technology in the developed countries, and it is necessary to continue to accelerate development and improvement[10].

Although the accuracy of the current tool tester has reached a very high level, the modern CNC tool tester still has the following problems: currently, the tool testing equipment on the market is not free from offline testing, and can not realize product production automation; In China, the high-precision testing equipment is monopolized. Most tool detectors on the market are still operated manually[11-15]. The main content of this thesis is that the vision-based CNC tool detector uses machine vision to detect various parameters of the tool, and adjusts the correctness and measurement accuracy through camera and tool attitude adjustment. The reliability of the inspection accuracy is ensured by designing the mechanical design and electrical system design of the tool detector. The reliability of the inspection accuracy is ensured by designing the mechanical design and electrical system design of the tool detector. Based on the original manual vision tool detector, research and development of automatic, higher precision, more stable and reliable, low cost tool detector products[16-20].

II. Analysis of the Overall Structure of the Detector

A. *Overall* program analysis

Through the visual system to achieve comprehensive measurement of CNC tool parameters, the main task is to achieve full-scale photography of the tool, obtain images of various directions and parts, and then process the tool parameters through subsequent image acquisition circuits and image processing software. The key to capturing the image of all directions of the tool for the mechanical structure is to properly distribute the freedom of the camera and the tool. The degrees of freedom between the camera and the tool are: the linear freedom of movement away the camera and the tool; the linear freedom of movement of the camera and the tool; the circumferential freedom of rotation of the camera and the tool; rotational freedom of camera and tool axial transformation along the tool axis.

A variety of overall layouts can be obtained by assigning degrees of freedom. When the tool has only one direction of freedom, the camera has three degrees of freedom: focusing motion in the Z direction, linear motion in the X direction, and rotational motion in the axial and radial directions of the tool. This kind of scheme is relatively simple compared to other schemes based on camera function that can achieve the required camera function. It is required that the X and Z axes are connected with series, and the camera realizes a 90° rotation. The structure is small, the implementation is convenient, and the precision is easy to ensure. Therefore, choose option one as the overall design scheme, and the schematic diagram is shown in Figure 1.

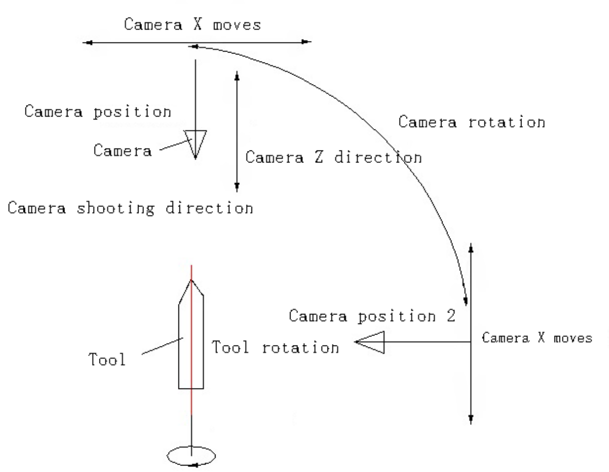

Figure 1. Overall plan one schematic

B. *Structural analysis*

The main structure of the CNC tool detector is shown in Figure 2. It is divided into four parts: the base, the column, the beam and the rotary shaft. A slewing mechanism is arranged at the left end of the base, and an X-axis horizontal moving guide is mounted thereon. The industrial camera is placed on the beam of the tool detector, and the motor is used as a power component, and in order to obtain the best imaging point of the CNC tool, the screw is used as a moving component to control the movement of the camera in the direction of the optical axis.

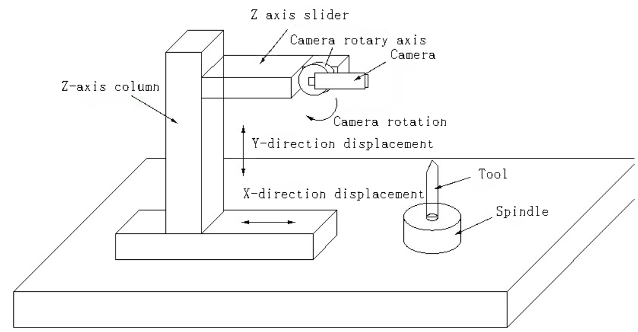

Figure 2. Structure of CNC tool detector

The base is the basic part of the tool tester, on the basis of meeting the requirements of 20μm positioning precision, from the perspective of structural realization and cost, the scheme of “steppe motor drive + ball screw drive + rolling guide guidance + grating rule detection” is selected. The advantage is open loop control, high precision, fast response, high transmission efficiency and simple control.

III. Detailed Structural Analysis

A. *Z-axis structure design*

The Z-axis is designed to produce a linear motion in camera section and to accurately position it. According to the overall principle scheme, a steppe motor and a ball screw are used.

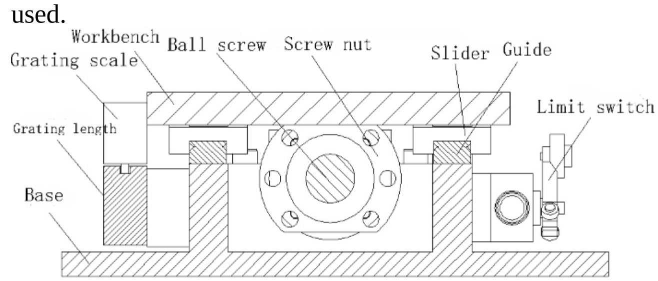

Figure 3. Z axis structure diagram

Figure 3 shows the basic structure of the Z-axis, and the position layout of each part is shown in the figure. The two guide rails are symmetrically distributed on the lead screw, and the load is evenly distributed on the four sliders to obtain a relatively smooth guiding motion. The ball screw nut pairs is in the middle of the two rails, ensuring that its radial load is at a minimum, and only axially Load, push the table movement. The left side of the workbench and the base are equipped with a linear scale, the movable ruler is mounted on the workbench, and the fixed ruler is mounted on the base for real-time detection of the position of the workbench, feedback to the control system To achieve the purpose of precise positioning. A pair of micro limit switches is installed on the right side to prevent the table from exceeding the stroke. Install a steppe motor along one end of the screw shaft to drive the lead screw to rotate, and finally push the table linearly. The other end of the screw is equipped with an electromagnetic brake. The accidental power failure can lock the screw and prevent the table from moving freely, destroy by colliding with other objects.

B. Ball screw component selection analysis

The workload comes from the gravity of the camera shaft component as a whole and the driving force of the camera part to accelerate the motion. According to the quality characteristics analysis in Solidworks software, the camera shaft components (including camera, light source, lens, camera mounting plate, light source connection plate, small The total mass of the shaft, key, motor base, housing, camera shaft connection plate, etc.) is 10.6 kg, set the table speed to $v = 60mm/s$, acceleration time $t = 0.1s$, So the screw workload is

$$F = mg + ma \quad (1)$$

Driving torque calculation formula:

$$M_{te} = \frac{FP}{2000\pi\eta} \quad (2)$$

Where: F is the workload; P is the lead of the screw; η= efficiency, generally take 0.9.

Preliminary selection of lead screw lead 5mm, according to the calculation and consulting data, choose *SFU2005-4* ball screw pair produced by *Shanghai Jinyun Machinery Equipment Co., Ltd.*, its dynamic load is 1130N, and the lead is 5mm.

The lead screw used in this design is relatively long (450 mm). The axial load mainly carries the measuring force and the friction of the probe. Therefore, we choose the simplest installation method of the screw mounting structure, fixed support at one end and simple support at one end. The fixed end bearing selects an angular contact ball bearing with a contact angle of 25°, model 7201AC; the simple support end uses a deep groove ball bearing, model 6001. Vertical installation, fixed end down, preloaded with a round nut, the simple support end is on, not preloaded.

IV. ANALYSIS OF STRENGTH AND STIFFNESS OF MAIN COMPONENTS

A. Ball screw stiffness check

The comprehensive tensile and compressive stiffness of the transmission system including the ball screw pair and the bearing supporting the screw is called the transmission rigidity of the ball screw pair. It mainly consists of three parts: the screw tension and compression stiffness K_C, and the contact stiffness between the screw and the nut K_N. , the support stiffness of the screw bearing and the bearing housing K_B. Since the torsional stiffness of the lead screw is generally less than 5% of the sum of the three parts, it is usually ignored. Insufficient transmission stiffness of the ball screw pair is the main factor affecting the transmission accuracy and positioning accuracy. Therefore, the transmission stiffness must be checked when designing the servo mechanical transmission system.

$$\frac{1}{K} = \frac{1}{K_C} + \frac{1}{K_N} + \frac{1}{K_B} \quad (3)$$

1) Screw tension and compression stiffness

The tension and compression stiffness of the lead screw is related to the support method. In this design, the support method of "fixed at one end and supported at one end" is adopted. The tension and compression stiffness of this case is:

$$K_C = 165 \cdot \frac{(d_0 - 0.71D_W)}{L_{S1}} \quad (4)$$

Where: d_0 is nominal diameter of lead screw(mm); D_w is ball diameter(mm); K_{S1} is bearing to nut distance(mm).

According to the parameters in the design of the ball screw, calculated $K_C = 7.83N/\mu m$.

2) Contact strength between screw and nut

Since the selected screw nut pair is preloaded with a single nut, the contact stiffness is:

$$K_N = 2667.7 \cdot \sqrt[3]{\frac{i^2 d_0^2}{D_W}} \cdot F^{\frac{1}{3}} \quad (5)$$

Where: *i is e*ffective number of turns; d_0 is nominal diameter of lead screw(mm); D_w *is b*all diameter(mm); F is axial maximum load(N).

Similarly, $K_N = 434664.4N/\mu m$.

3) Support stiffness of screw bearing and bearing housing

$$K_B = \frac{AE}{L \times 10^3} \quad (6)$$

Where: A is support cross-sectional area(mm^2); E is Elastic Modulus, E=2.1×10^5MPa; L is axial resultant force arm length(mm).

Similarly, $K_B = 231807.6N/\mu m$. So, $K = 7.8 \times 10^5 N/\mu m$. The allowable stiffness K_0=0.25×10^6 N/µm. Because K> K_0, the ball screw pair stiffness is acceptable.

B. Dangerous part strength check

Analyze the force of each component in the automatic vision tool detector and find that the four M2 screws installed on the industrial camera are dangerous parts. Now check the strength as follows:

When the camera shaft member rotates, the four screws are subjected to the shearing force, and the force diagram is shown in Figure 4.

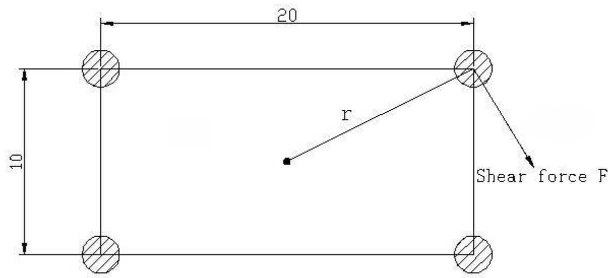

Figure 4. Screw force diagram

The single screw load in the figure is:

$$F = M / 4r \quad (7)$$

Then drive the torque meter to

$$\delta = \frac{4F}{\pi d} \quad (8)$$

The total load of four screws is M=0.389 N m, calculated $\delta = 1.41MPa$, the allowable shear stress of No. 45 is 55 Mpa, which is greater than the shear stress of the screw, so the screw strength is sufficient.

V. CONCLUSION

- Aiming at the movement mode of camera and the tool in the camera adjustment mechanism, the overall layout scheme is given; analyzing the precision guarantee, structural complexity and cost of the solution, the optimal structural scheme is given, thus realized the overall structure design of the camera adjustment mechanism.
- Through the selection and design of related components, the camera adjustment mechanism can cooperate with the control system to perform automatic tool parameter detection, higher precision, more stable and reliable functions, and improved economic efficiency.

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