Design of an On-machine Measurement System Based on GNC62

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Abstract: Parts with high precision requirements in CNC machining often require manual intervention for repeated checking of critical dimensions and dimension compensation to meet machining accuracy requirements. This makes it difficult to establish a standardized inspection process. This paper proposes a design scheme for an on-machine measurement system based on domestically produced machine tools. Firstly, design measurement features are created through CAD model feature recognition and information extraction, establishing the foundation for measurement data. Next, a method is developed for creating measurement programs for the GNC62 numerical control system based on measurement features. Then, measurement accuracy is enhanced through the design of pre-travel error and probe radius compensation procedures. Finally, on-machine measurement experiments are conducted on typical parts processed with the KEDE GNC62 numerical control system, achieving measurement and calculation of machining dimensions and positional tolerances, and implementing numerical control system alarms based on measurement results. Experimental results demonstrate the successful implementation of on-machine measurement functionality on the GNC62 numerical control system, with measurement accuracy within 0.02mm.

Keywords: On-machine Measurement; Pre-travel Error; Dimensional Tolerance; Tolerance Alarm

1. Introduction

The on-machine measurement technology of adding probes and other equipment to the existing CNC machine tools can reduce the time of parts transfer and re-clamping, decrease the positioning error of re-clamping, confirm the dimensional conformity before and during processing, and monitor the changing trend of key dimensions. On-machine measurement technology can improve production efficiency and machining accuracy, and meet the urgent needs of the modern manufacturing industry for integrated production and measurement.

Although foreign CNC machinery (computerized numerical control machinery) manufacturers have integrated in-machine measurement technology in some machine tools, the development of domestic CNC equipment manufacturers in this field still needs to be strengthened. It is urgent to solve a series of problems, such as low accuracy of measurement results, inconvenient generation of measurement procedures, and immature integration of in-machine measurement and processing. This paper aims to design an on-machine measurement system based on the GNC62 CNC system to automatically generate relevant measurement programs according to different characteristics and complete the integration of in-machine measurement and processing, thereby realizing the on-machine measurement function of domestic CNC machine tools.

2. Overall Design Scheme of On-Machine Measurement System

The on-machine measurement technology based on domestic CNC machine tools establishes the correlation between measurement objects, measurement data, and GNC CNC systemsmainly based on the hardware of machine tools, CNC systems, probes, etc., aiming to realize the application of on-machine measurement of parts. Fig. 1 shows the overall process design of on-machine measurement.

The on-machine measurement system includes three key modules: measurement program creation, error compensation, and data management, as shown in Fig. 2. The measurement program generation module allows users to select features and configure measurement parameters to generate measurement programs suitable for different measurement tasks. The data management module is responsible for saving measurement coordinate points andgeometric dimensiondata and generating measurement reports. The error compensation module realizes real-time measurement error and machine tool error compensation in the CNC system. After analyzing the measurement data, the processing can be compensated.

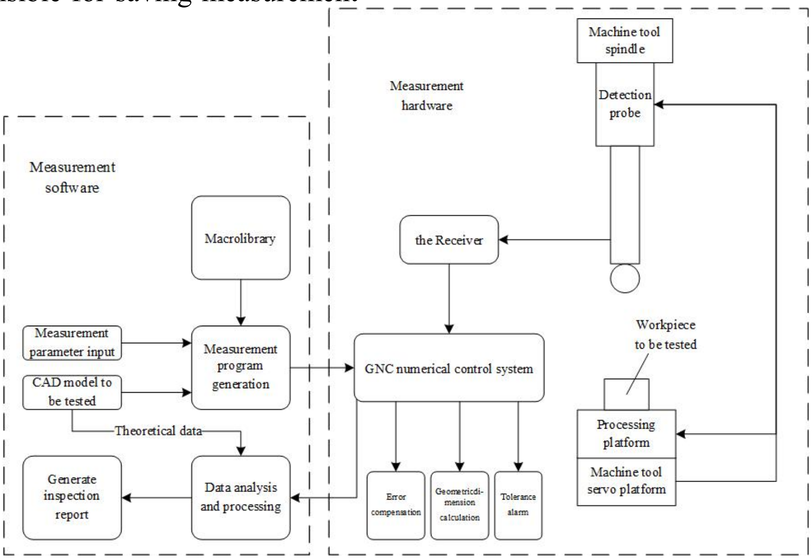

Figure 1. Overall Process Design

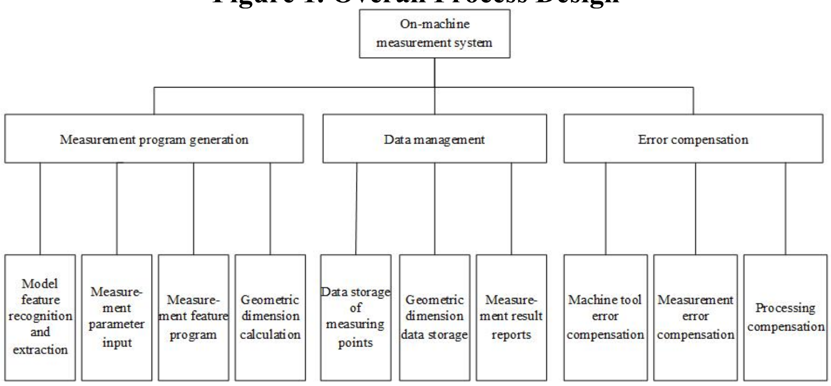

Figure 2. Overall Module Division

3. Key Technology of On-Machine Measurement

3.1 On-Machine Measurement Error Compensation

In the machiningprocess, the clamping method of the workpiece may result inits clamping error. In addition, the machine tool may also produce motion errors during the movement, which is caused by the positioning error of the machine tool itself. Similarly, the detection probe may also have radius error and pre-travel error. Finally, when the machine tool runs at different temperatures, there may be temperature errors. The research shows that[1] the pre-travel error of the measuring ball accounts for about 60% of the error of the whole measurement system. In this paper, the pre-travel error and the radius of the measuring ball are mainly compensated.

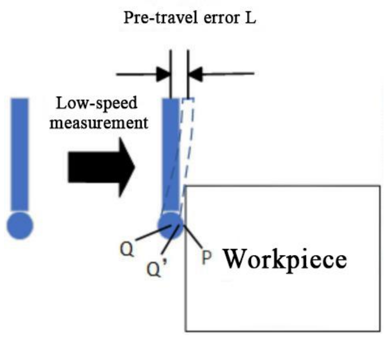

Figure 3. Diagram of Pre-Travel Error

When the contact trigger probe gets close to the workpiece along different contact measurement directions, the elastic deformation of the spring inside the probe is different, resulting in different forces generating the trigger signal, so the pre-travel error value will also be different. As shown in Fig. 3, the measuring ball gets close to the measured surface along the normal vector direction of a point P on the plane. When the measuring ball just touches the measured point P, its center is Q. Influenced by trigger delay and other factors, the measuring ball will continue to move forward with the machine tool for a small distance. The position of the measuring ball is shown as the virtual coil. At this time, the center of the measuring ball is Q', and L is the pre-travel error generated.After the trigger signal is emitted, the coordinates recorded by the CNC system of the machine tool are the coordinates Q'after a small distance of the ball movement, rather than just touching the coordinates Q on the measured surface. According to the geometric relationship of Q, Q'(x',y',z') and P (x, y, z), which are collinear and parallel to the normal vector of the touched measurement point, the calculation formula of the pre-travel error L in this direction can be obtained, that is:

$$L = |PQ| - |PQ'| = R - \sqrt{(x-x')^2 + (y-y')^2 + (z-z')^2}$$

By carrying out a calibration experiment on the master ball, the pre-travel error in different touch measurement directions can be obtained. In the experiment, 12 directions on the Z-axis and the equator of the standard sphere (measured every 30 degrees) are selected as sampling points. To ensure the reliability of the results when measuring the workpiece, the stability of the measurement conditions must be maintained. Specifically, the touch speed should be consistent with the speed when the workpiece is actually measured, such as a fixed speed of 30 mm per minute. Besides, it is necessary to keep the length of the measuring rod and other influencing factors constant. According to the formula, the pre-travel error of 13 measuring points is calculated, and Fig.3 shows the polar coordinate diagram of the pre-travel error.

In the measurement, the obtained pre-travel error data is stored in variables # 0 to # 12. For the measurement points located at the North Pole, only the measurement value of the Z-axis is subtracted from the pre-travel error value of the Z-axis (stored in variable # 0). For the measurement points located on the equator, the normal vector information (i, j, k) of the measurement points is first extracted from the CAD model of the workpiece, and then the angle between it and the X axis is calculated. Later, the area is judged according to the angle, the pre-travel error value of the point is calculated in proportion, and the error compensation of the radius and pre-travel is carried out. This process is implemented in the G872 subprogram, as shown in Fig. 5.

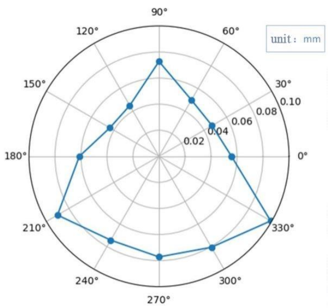

Figure 4. Polar Coordinate Diagram of Pre-Travel Error

Figure 5. G872 Subprogram

3.2 On-Machine Measurement Method based on Measurement Features

The measurement features of the workpiece can be divided into three categories: basic measurement features, geometric dimension features, and distance features, as shown in Fig. 6.

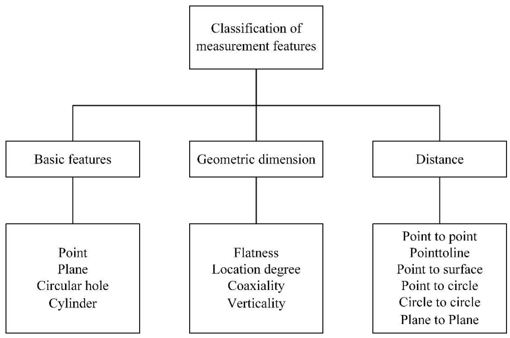

Figure 6. Classification of Measurement Features

The measurement process of a single basic feature is as follows: Firstly, extract or manually select several measurement points from the model information. Secondly, the probe is positioned to the positioning position of the first measurement point, and the calculation of the positioning point is based on the normal vector and positioning distance of the measurement point. At the beginning of the measurement, the test touch is performed at a relatively fast speed for the first time, then the rollback operation is performed, and the formal touch is performed at the same slow speed as the master ball calibration (usually consistent with the master ball measurement) to obtain the coordinate information of the measurement point. Later, the probe moves to the positioning position of the next measurement point and repeats the above steps until completing the measurement of all measurement points of the feature.Fig.7 shows the measurement trajectory of the four-point measuring circle (inner hole). After the measurement is completed, the center coordinates and diameters are calculated using the CALCIR [ ] function of the GNC62 system.

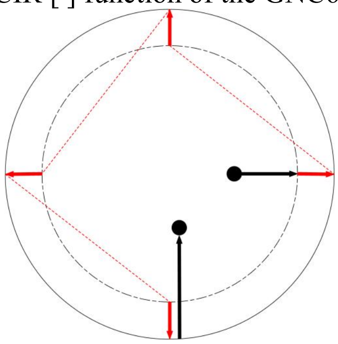

Figure 7. Measurement Trajectory of Circle

The measurement of geometric dimension features and distance features usually involves the measurement of multiple basic features. To ensure the safety of the measurement process, it is necessary to set a safety plane whose height should be much higher than that of the workpiece and fixture to avoid potential collision risks. Before each measurement feature, the probe is first moved to the projection position of the first measurement point on the safety plane and then moved to the positioning position of the measurement point. After completing the measurement of a single feature, the positioning position of the last measurement point is returned to the safety plane and then moved to the projection position of the first measurement point of the next measurement feature on the safety plane, and so on, until the measurement of all features is completed.

The calculation of geometric dimension features is usually achieved through cyclic subprograms, which are stored in the folder “GNC62/Subprgs” and named G800.nc ~ G999.nc. The format of calling the subprogram for calculating the position degree of the circle is shown in Fig.8. They need to receive the actual measured coordinate points (A, B, C) of the circle and the theoretical center coordinates (x, y, z) of the circle to calculate the position degree of the circle. In the subprogram, the incoming data is received and the following variables are saved: # 800=10, # 801=20, # 802=30, # 823=11, # 824=19, #825=32.

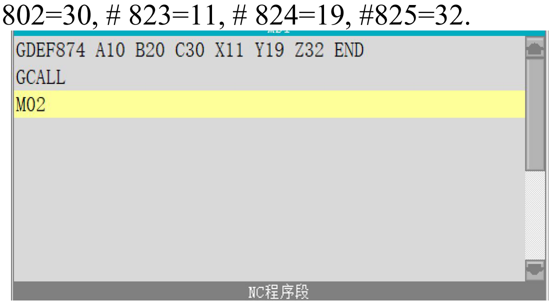

Figure 8. Geometric Dimensionsubprogram Call

After completing the calculation of the geometric dimension features, the main program will make a logical judgment on the calculated geometric dimension. If the set tolerance limit is exceeded, the system will trigger an alarm as shown in Fig. 9. This function can be set in the software, including opening the alarm and setting the tolerance limit, which will be generated into the main program.

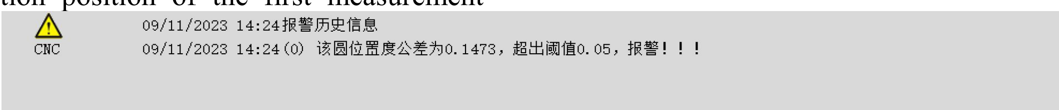

Figure 9. Tolerance Alarm

4. Application Examples of On-Machine Measurement

This experiment is carried out on the KMC800 S U five-axis vertical machining center equipped with a GNC62 CNC system and Renishaw RMP60 electric trigger probe module. The positioning accuracy of the XYZ axis of the machining center is 0.008 mm, and the repeated positioning accuracy is 0.005 mm.

The measured object is a typical part, as shown in Fig. 10.

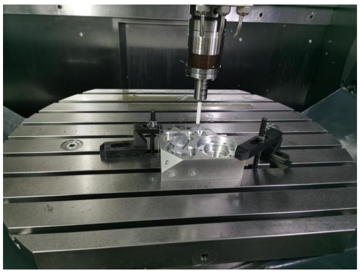

Figure 10. Measuring Typical Parts

Before measuring the workpiece, the pre-travel error is calibrated first. Then the machine model, the radius of the master ball, and the radius of the probe ruby ball are set in the software, and the calibration program is generated to calibrate the master ball, as shown in Fig. 11.

Figure 11. Master Ball Calibration

Then the parts are measured. Firstly, the CAD model of the part is imported. As shown in Fig. 12, the user needs to select the measurement features and set the parameters, and generate the main measurement program. Meanwhile, the measurement subprogram is sent to the CNC machining center. In this experiment, the three features including circle diameter (hole feature 1), flatness (plane feature 1) and perpendicularity (plane feature 1 and cylindrical feature 1) are taken as examples for measurement. The results obtained are compared with the three coordinates, and the results are shown in Table 1.

Table 1. Measurement Results

	1	2	3	Three-coordinate
Diameter (mm)	30.07023	30.06587	30.06061	30.063
Flatness (mm)	0.02417	0.02356	0.02498	0.023
Perpendicularity (mm)	0.01627	0.01739	0.01689	**0.017**

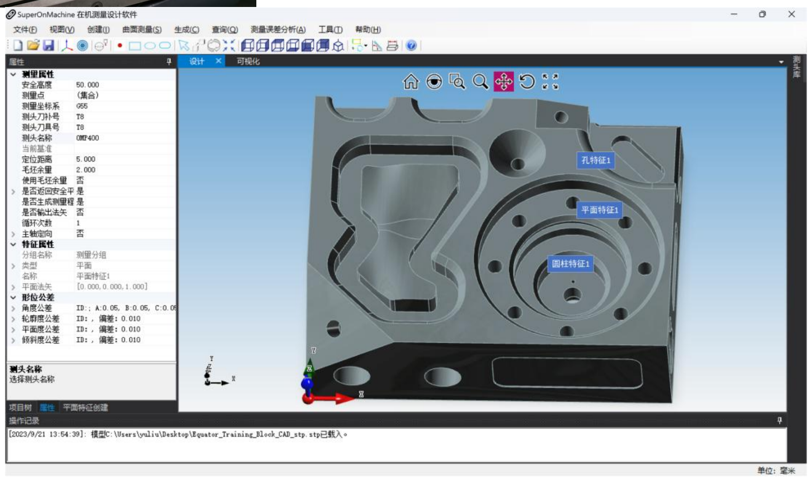

Figure 12. Select Features and Set Parameters

The experimental results show that the on-machine measurement system successfully realizes the measurement function of the main features, and the error of multiple measurements remains within 0.02 mm, showing good consistency and measurement accuracy.

5. Conclusion

In this paper, based on the GNC62 CNC system, a design scheme of on-machine measurement system is proposed. The experimental results show that: 1) the measurement accuracy meets the processing requirements; 2) Dimension measurement and geometric tolerance measurement meet the processing requirements; 3) The on-machine measurement system of machining and measurement integration based on domestic CNC system is feasible and has the function of on-machine measurement covering typical parts.

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