Overview of Machine Tool Error Detection Technology

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Abstract. With the rapid development of modern mechanical manufacturing technology, precision and ultra-precision processing technology has become the main trend of the development of modern mechanical manufacturing industry. As a basic tool in mechanical manufacturing, the accuracy of CNC machine tools is an important index affecting the accuracy of workpiece processing. Therefore, the research on improving the accuracy of CNC machine tools has received great attention. In all kinds of high-speed and precision machine tools, the problem of the decline of machining accuracy caused by machine tool errors has become increasingly prominent. How to identify and eliminate machine tool errors quickly and efficiently has become an increasingly urgent task. In this paper, the research status of machine tool error detection technology at home and abroad is analyzed, in order to provide a reference for the development of machine tool error detection technology.

1. Introduction
Because of its high flexibility, high efficiency and high precision, CNC machining system has become the preferred method for machining high-performance parts. For example, a five-axis machine tool has not only three linear axes, but also two rotating axes. Compared with common numerical control machine tools, a five-axis machine tool is more convenient to adjust the relative positions of the tool tip and the blank, thus avoiding interference between the blank and the tool, station influence, and improving processing precision and processing efficiency. However, the number of axes directly affects the control precision and quality of products to a certain extent. Therefore, it is of great significance for the quality of products to detect and compensate the errors of NC machines [1-5].

Geometrical error, as the main error factor, is caused by machine tool parts, manufacturing defects of parts and poor assembly precision. It is a kind of error related to the shape and position of machine tool parts. When the machine tool moves or rotates, these shape errors or position errors are directly reflected on the machined workpiece, reducing the machining accuracy of the workpiece. There are mainly two methods to improve the accuracy of machine tools: error prevention method and error compensation method [6]. The former is to improve the machining accuracy and installation accuracy of machine parts and components. This method has higher economic cost and greater limitations. The error compensation rule is to offset the machine tool error by artificially manufacturing new errors. This method is simple and flexible, and is an economical and effective means to improve the machine tool performance. Therefore, the error compensation method has received extensive attention and has been studied extensively [7-8].

2. Research Status of Measurement Methods of Laser Interferometer
Laser has four characteristics of high intensity, high directivity, high monochromaticity and high coherence [9-10]. At present, the interferometers commonly used to measure length are mainly
Michelson interferometers, and a measuring system with interference function is formed by using frequency-stabilized nitrogen atmosphere laser as a light source. The laser interferometer can cooperate with various refracting mirrors, reflecting mirrors, etc. to measure linear position, velocity, angle, flatness, straightness, parallelism and verticality, etc., and can be used as a calibration work for precision tools or measuring instruments.

There are two types of laser interferometers: single frequency and double frequency. Single frequency appeared in the mid 1960s. It was first used to check the baseline ruler and then used to measure the length accurately in the measuring room. The dual-frequency laser interferometer appeared in 1970. It is widely used in the field of machine tool detection.

Common optical interferometry techniques include holographic, speckle and Michelson interference. Typical instruments include Michelson interferometer, Twyman Green interferometer, Mach-Zender interferometer, Fizeau interferometer, HP interferometer (as shown in fig. 1) and Renishaw interferometer (as shown in fig. 2), etc.

Doppler dual-frequency laser meter (LDDM) is a heterodyne interferometer developed on the basis of single-frequency laser meter (Figure 3). Two circularly polarized lights with different frequencies are used as light sources, and the emitted light is orthogonally separated by a polarization beam splitter. When the measuring mirror moves, due to the Doppler effect, the return light generates Doppler shift, which includes displacement information of the measuring mirror [11-13]. Therefore, the measurement information is superimposed on a fixed frequency difference and belongs to an alternating current signal. It has great gain and high signal-to-noise ratio, and completely overcomes the defect that the single frequency laser measuring instrument cannot work normally due to the DC level drift caused by light intensity variation. Even if the light intensity decays by 90%, the dual-frequency laser measuring instrument can still work normally. Because of its strong anti-interference ability, it is especially suitable for field operation. The instrument is combined with different optical components to measure distance (position accuracy), straightness, verticality, diagonal, parallelism, planeness, turntable accuracy, speed, acceleration, etc. at the same time, the vibration of the machine tool can be analyzed. These detection items include almost all the main indexes of machine tool accuracy verification, as shown in fig. 4.
3. Research Status of Measurement Methods for Ball Rod Instruments

The measuring method of the club instrument was born in 1982 and invented by J. B. Bryan. The method is easy to operate, fast in measuring speed and large in information, and can complete the "one-day test" of the machine tool. Therefore, it has received extensive attention. Scholars at home and abroad have done a great deal of work in the research of the club instrument. At present, there are mainly two ways to use the club instrument to carry out the round measurement test, i.e. directly using the existing club instrument and using the improved club instrument to carry out the round side method test [14-18].

Japan's M. Tsutsumz and others have successfully identified and separated 8 errors (1 linearity, 2 straightness and 3 rotation errors of Axis A, verticality error of Axis A and C and axis deviation in Y) of the rotating shaft of a 5-axis numerical control machine tool by using a club instrument to carry out linkage tests of 3 axes (2 linear axes and 1 rotation axis) and 4 axes (2 linear axes and 2 rotation axes). Canadian S. H. H. Zarraghbashi et al [13] proposed a five-step measurement method for the rotation axis based on a club instrument, which can measure five errors (2 straightness and 3 rotation errors of axis A).

There is also a lot of research on this method in China. W. T. Lel of Taiwan National Tsinghua University and others have developed a novel measuring device-3D Probe-Ball and a geometric error calibration method for machine tools to identify the feed axis error and compensate it. The experimental results show that the accuracy of machine tools has been improved by 90%. Liu Huanlao et al. [19] of Huazhong University of Science and Technology developed a new geometric error measuring instrument: two-dimensional club instrument, aiming at the defect that the existing club instrument cannot measure the angle error. Wang Wen [20-21] of Hangzhou University of Electronic Science and Technology proposed and designed a new type of spatial two-link club instrument (J-DBB) which can move in three-dimensional space and has a larger detection range.

Since the existing club instrument is only suitable for the test results of planar circular tracks linked by two axes, if you want to obtain the three-dimensional variation in space, you need to implement it through a special experimental design scheme, which introduces intermediate errors and makes the results unsatisfactory. In response to the above problems, Renishaw Company has introduced a new generation of products with space testing capability: QC20-W club instrument.

4. Research status of R-test measurement method

Weikert and Knapp invented the r-test measuring device, which measures the three-dimensional displacement of the spindle relative to the worktable through three displacement sensors. ISO 230-1:2012 describes the R-test measuring device. ISO 10791-6 standardizes the synchronization error measurement process of R-test equipment on the rotating shaft and linear shaft of the machine tool.
Recently, IB S precision engineering and Fidia group commercialized the R-test device for calibration of numerical control machine tools. Bringmann and Knapp use this device to detect the positioning error of the rotating shaft of the five-axis numerical control machine tool, that is, the deviation of the average axis position of the rotating shaft from the reference axis, which is the main error source of the five-axis numerical control equipment and cannot be ignored [22].

Ibaraki et al. of Kyoto University in Japan extended the application of R-test and proposed a method to detect the error of rotating shaft assembly. That is, when the machine tool makes rotary motion, the three-dimensional displacement change of the sphere installed on the main shaft and the workbench is detected. This method can not only identify the installation error of the rotary shaft, but also identify the movement error of the rotary shaft.

5. Summary and Prospect
In this paper, the commonly used testing methods of machine tools are summarized, including laser testing, ball bar measurement, r-test measurement, etc., and the research progress in this field at home and abroad is summarized. In the future research of numerical control technology, I think it can be further strengthened in the following aspects:

(1) In future tests, it is also necessary to analyze the vibration of the machine tool and find a simpler and more accurate detection scheme. In error compensation, the vibration attribute should be added.

(2) There are still some limitations in the measurement of machine tools for dual-frequency laser interferometers and club instruments. With the continuous development and progress of testing instruments, new testing instruments should be introduced in future tests.

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