Measurement 45 (2012) 1713–1722

Contents lists available at SciVerse ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

The detection of rotary axis of NC machine tool based on multi-station and time-sharing measurement

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ARTICLE INFO

Article history:
Received 24 September 2011
Received in revised form 2 April 2012
Accepted 21 April 2012
Available online 28 April 2012

Keywords:
Laser tracker
Rotary axis
Multi-station and time-sharing measurement
Error separation

ABSTRACT

At present, the detection of rotary axis is a difficult problem in the errors measurement of NC machine tool. In the paper, a method with laser tracker on the basis of multi-station and time-sharing measurement principle is proposed, and this method can rapidly and accurately detect the rotary axis. Taking the turntable measurement for example, the motion of turntable is measured by laser tracker at different base stations. The redundant equations can be established based on the large amount of measured data concerning the distance or distance variation between measuring point and base station. The coordinates of each measuring point during turntable rotation can be accurately determined by solving the equations with least square method. Then according to the error model of rotary axis, the motion error equations of each measuring point can be established, and each error of turntable can be identified. The algorithm of multi-station and time-sharing measurement is derived, and the error separation algorithm is also deduced and proved feasible by simulations. Results of experiment show that a laser tracker completes the accuracy detection of the turntable of gear grinding machine within 3 h, and each error of the turntable are identified. The simulations and experiments have verified the feasibility and accuracy of this method, and the method can satisfy the rapid and accurate detecting requirements for rotary axis of multi-axis NC machine tool.

1. Introduction

With the development of modern manufacturing, the demand of multi-axis NC machine tool is increasing. The multi-axis NC machine tool can achieve the efficient and accurate processing for large and complex parts, which has been widely used in the manufacturing of large wing, blade and other complex mechanical parts. The machining accuracy is an important index to evaluate the machine characteristics. Quick and accurate detecting the error of machine tool and making error compensation have become the important ways to improve the machining accuracy [1–4]. Currently, there are many methods for detecting the linear axes of machine tool, however, the methods for detecting rotary axis are relatively less [5–7]. Meanwhile, detecting the error of rotary axis is also a difficult problem. By using of the autocollimator and polygon can only evaluate the position error of rotary axis, and the other errors cannot be measured. Each error can be detected by using of the laser interferometer, Renishaw rotary measuring system RX10 and some assistant measurement tools, but the detecting period is long. When the ball bar is used to detect the rotary axis, the multi-axis movement is needed. Meanwhile, the measurement should also be carried out on different modes, and the measurement process is relatively complex. The error of rotary axis directly affect the machining accuracy of multi-axis NC machine tool, so how to quickly and accurately detect the error of rotary axis is

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http://dx.doi.org/10.1016/j.measurement.2012.04.015

particularly important. Taking the turntable measurement for example, a laser tracker is adopted the multi-station and time-sharing measurement principle to rapidly and accurately detect the error of turntable in the paper.

2. The principle for turntable measurement

Since 1980s, with the development of robot technology and large workpiece measurement [8], three-dimensional and dynamic tracking measurement has developed rapidly. Laser tracking measurement system has fast, high-precision features, and it satisfies the requirements of large-scale, field and no-guild measurement, so it has become an irreplaceable tool in many areas, such as: aerospace, shipbuilding, automotive and other fields. Currently, laser tracker has also been applied to the detection of errors in machine tool [9,10]. According to the number of laser tracker in the measurement, it can be divided into single station measurement and multi-station measurement [11]. Single station measurement adopts spherical coordinate measurement to calculate the space coordinates of moving target by means of measuring azimuth φ_i, elevation θ_i and length L_i. The distance measurement of laser tracker is based on the laser interference principle, and the measurement accuracy of distance is higher. The measurement accuracy of angle is generally limited, and the measurement uncertainty of angle will be larger with the distance increasing, which affects the overall accuracy of spatial coordinates. The distance measurement accuracy can be generally guaranteed within 1×10^{-6} mm, however, the measurement uncertainty of coordinate is $\pm 1 \times 10^{-5}$ considering the impact of angular error. So single station measurement is not suitable for the situations requiring high measurement accuracy. The multi-station measurement adopts the GPS principle. Only distance is involved in the measurement, therefore this method has high accuracy. However, the method requires multiple laser trackers to measure the target point simultaneously, so the cost is relatively high.

In order to save cost and maintain high measurement accuracy, a laser tracker measures the target points successively at different base stations, and only distance is involved in the measurement, which is called "multi-station and time-sharing measurement". The target mirror (cat eye) is installed in the vicinity of the cutter, and the position of cat eye's center is defined as the location of base station in the measurement. The position of base station can be changed by controlling the motion of cutter. The laser tracker is installed on the turntable, and follows the rotation of turntable. The rotating mirror's center in the laser tracker is defined as the target point. Fig. 1 shows the measurement principle of turntable by multi-station and time-sharing measurement, and Fig. 2 shows its mathematical model. P_1, P_2, P_3 and P_4 represent four positions of base station respectively. The measurement area is given by a circle, and A_0 is defined as the initial measuring point.

When the turntable rotates a preset angle, it is controlled to stop, and the distance reading of laser tracker will be recorded. When the turntable rotates through 360°, the measurement at the first base station is completed, and the cat eye is moved to the second base station by the motion of cutter. Then, repeat the above measurement process until the turntable measurement is finished at all base stations. Based on the GPS principle, the actual coordinates of each measuring point during the turntable rotation can be determine by the measured data at different base stations. Then the motion error of turntable at different rotational angle can be determined by comparing the actual coordinates of each measuring point with its theoretical coordinates.

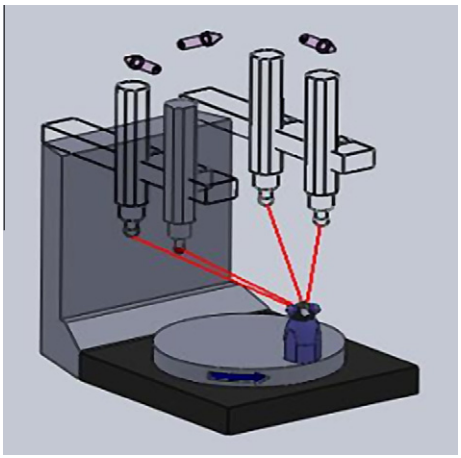

Fig. 1. The principle of multi-station and time-sharing measurement.

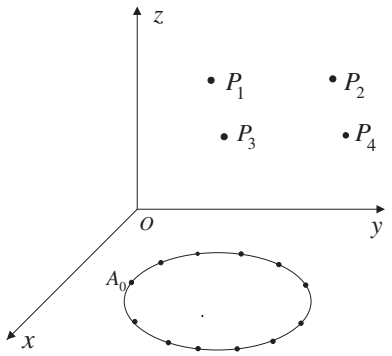

Fig. 2. The mathematical model.

3. The Algorithm for turntable measurement

Taking four stations and time-sharing measurement for example, the algorithm is derived as follows. The positions of four base stations in machine coordinate system are defined as: $P_1(x_{p1}, y_{p1}, z_{p1})$, $P_2(x_{p2}, y_{p2}, z_{p2})$, $P_3(x_{p3}, y_{p3}, z_{p3})$, $P_4(x_{p4}, y_{p4}, z_{p4})$, and these positions are known in practical measurement. Meanwhile, the coordinates of turntable center is defined as $O'(p_x, p_y, p_z)$ in machine coordinate system.

Currently, the laser trackers of Leica, FARO and other companies have used the bird nest technology, and the reference distance is known, so these laser trackers can