Vibration analysis in reciprocating motion of ultra-precision machine tool using real-time position capturing method

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Abstract. This paper describes a development of a real-time position capturing method in which branched encoder signals are recorded in external data storage, to evaluate motion trajectories of the multi-axis simultaneous control on ultra-precision machine tool. We captured positions of the single axis (X, Y, and Z) control following the straight reciprocating motion trajectories to analyze vibration of machine tool movement in process. When the Y axis is moving in a straight direction trajectories, the movement deviation is close to 0.6 \(\mu m\) p-v, which is the largest than X and Z axis. In the result of vibration analysis, the amplitude on Y axis is also larger than X, Z axis at frequencies near 5 Hz.

Introduction

The optical elements with non-axisymmetric aspheric surface (Free form surface) have been widely used in high-end optical instruments, which greatly promoted the aerospace, astronomy, environmental and other cutting-edge technology development. For producing non-axisymmetric surfaces, conventional lathes are insufficient on the rotational asymmetry requires simultaneous control of multiple axes. Also the solution way to realize both the asymmetry and the high precision for optics is to use diamond tool together with an ultra-precision machine tool, However, even with the ultra-precision machinery, a straightforward approach often fails; The cause of the error is usually thermal deformation, rigidity, processing environment, etc. On this basis, the requirements by the multi-axis simultaneous control make it more difficult to achieve high processing accuracy verify the dynamic motion accuracy. With conventional methods, e.g. double ball bar (DBB) measurement [1] and non-contact measurement using laser displacement interferometers [2] are usually used for precision measurement. Thus, the necessity arises for simple and reliable means of motion accuracy evaluation on multi-axis simultaneous control which can be done during the machining. To solve this problem, we developed a method for evaluating trajectory accuracy using scale signal separator in an ultra-precision machine tool and evaluate accuracy of trajectory. The method cans capturing the real-time position data are recorded in external data storage.

In our previous work, we have demonstrated that quadrant protrusions: the error which was dominant in our non-axisymmetric lens prototyping can be correlated to the recorded positions from the encoders. Based on this result, we were able to modify a tool path for the multi-axis simultaneous control, and the quadrant protrusions were successfully reduced. The results proved the effectiveness of the proposed method for improving machining accuracy for non-axisymmetric optics. And we have demonstrated that the trajectory accuracy verification is carried out by 3 axes simultaneous control of the real-time position capturing system [3-8]. However, in the previous report, we have only validated the error incentives were caused by the quadrant protrusion, and did not further validate the frequency distribution of the trajectory accuracy of multi-axis simultaneous control. In this paper, we report further experimental results using the real-time position capturing method. Our
aim is to find a relationship between the trajectory parameters and the vibration distribution of the accuracy of axis. Thus, we captured positions of the single axis (X, Y, and Z) control following the straight reciprocating motion trajectories.

Real-time position capturing method

Fig.1 shows the system for real-time position capturing of ultra-precision machine tools. Signals of the interpolators for the encoders used in machine control are extracted using a signal separator circuit on XYZC axes. The position capturing interval is 1 ms at minimum. The greatest advantage of this system is in its adaptability: the only modification necessary is an addition of the encoder separator circuit.

Fig. 1 Configuration of real-time position capturing system (left) and Ultra-precision machine tool (right)

Experimental

In our previous work, we have only validated the error incentives were caused by the quadrant protrusion on 3-axis simultaneous control following the three-dimensional ellipse trajectories. At the same time in the measurement process we have found that the control axis in the movement of a small vibration was happen occurred to determine the vibration of the various system of the axis, we have done the single axis reciprocating motion test. For this type of test, the control axis performance as shown in Fig. 2 when the movement in the straight direction. The trajectory rage is ±50mm; the feed rate is 10 mm/min; the capturing interval at personal computer is 10 ms.

Fig. 2 Example of single-axis control (X, Y, Z) trajectory

Experimental Results

The result shows that the deviation distribution on Y axis is higher than X, Z axis. The deviation on Y axis is close to 0.6 μm p-v, the deviation of X and Z axis is close to 0.2 μm p-v. The reason for this result is that the y-axis is the motion axis structure on the vertical plane and the x-axis and the z-axis are the motion axis structures on the horizontal plane. This vibration will cause the machining error to become worse. To analyze the periodic behavior of the X, Y, Z axis, we have performed a
vibration analysis of that by FFT (Fast Fourier Transform). The result of the analysis shows in Fig. 3(c), the amplitude on Y axis is larger than X, Z axis when the frequency is near 5 Hz.

![Graph showing trajectory deviation and vibration analysis](image)

(a) Trajectory deviation (range: +50 mm ~ 0 mm)

![Graph showing trajectory deviation in one second](image)

(b) Trajectory deviation in one second

![Graph showing vibration analysis on X, Y, Z axis](image)

(c) Vibration analysis on X, Y, Z axis (range: +50 mm ~ 0 mm)

Fig. 3 Trajectory deviation and vibration analysis of X, Y, Z axis (Range: +50 mm ~ 0 mm, feed rate 10 mm/min)
Summary

In this paper, we captured positions of the single axis (X, Y, and Z) control following the straight reciprocating motion trajectories.

The characteristics of each axis are shown on the frequency distribution. We know that the deviation distribution on Y axis is higher than X, Z axis. The deviation on Y axis is close to $0.6\mu m$ p-v, the deviation of X and Z axis is close to $0.2\mu m$ p-v. In the future study, we will continue to study the characteristics of vibration on axis in future studies.

References


