Thermal Stability and Geometric Error Assessment of A Hydrostatic Bearing Guided Machine

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Abstract

Recent machine tools require more and more high precision capability especially for the ultraprecision machining machines. In order to satisfy those requirements, the machine's positioning stability by the thermal effects and the machine geometric error between motional axes should be assessed and analyzed. In this paper the positioning stability experiment result and the analysis for finding the cause of deteriorated stability performance is presented. The geometric error identification result between linear and rotational axes will also be shown.

1 Machine tool desciption for experiments

An ultraprecision multi-axis machine tool has been designed and developed in our laboratory and the machine tool has four moving axes which are comprised of three linear axes and one rotational axis (c-axis). It has a gantry type structure and the z-axis is on the x-axis and the c-axis, on which a workpiece is located, is inside the y-axis. This machine was designed for manufacturing micro-patterns on large surface area and it can manufacture micro-patterned mold for LCD (Liquid Crystal Display) diffusion film, light guide plates, fuel cell membranes and anti-reflection film for solar cell panels. Each x and y axis has 500 mm travel and z axis has 110 mm travel. All the three linear axes and c-axis adopt hydrostatic bearing and the feeding oil temperature controlled using chillers. The whole machine components are in the environmentally controlled room.

2 Positioning stability experiments and analyses

In order to analyze the positioning stability of our machine, the repeatability experiment has been done by a laser interferometer for the y-axis with 400 mm travel. The ambient and supplying oil temperature was controlled within about 0.1 deg

Celsius and the obtained repeatability performance of the machine was 0.18 µm / 400 mm.

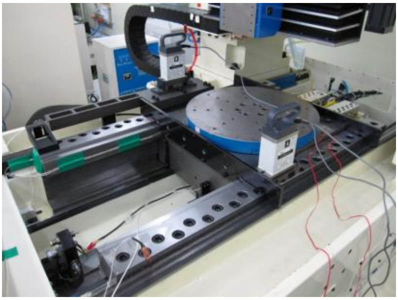
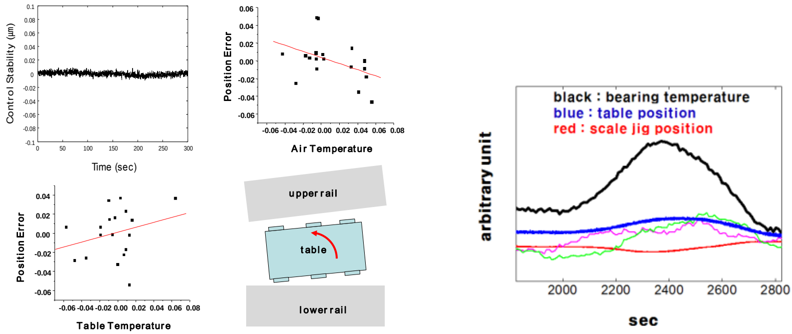


Figure 1: Hydrostatic bearing guided ultraprecision 4-axis machine in a thermal stability experiment.

By analyzing the repeatability experiment data, the dominant error source is considered as the temperature effect which is dependent on the table position. From the control stability result the laser interferometer measured the positioning stability within 10 nm and this result excludes many candidates for a positioning stability deterioration cause. By the repeatability experiment data we could not find a definite relationship between the positioning error and the temperature data (environment air and moving table) and by calculation from the temperature data and Edlen’s formula the environmental effects are much smaller than the measured repeatability data. With the above results the temperature difference between the guide rail and the hydrostatic bearing pocket oil is considered as the dominant cause of thermal stability which affects the positioning repeatability. In order to investigate the temperature difference effect between the guide rail and the bearing pocket oil, an experiment was performed and the experiment used many sensors such as capacitive position sensors, precision level sensors, a laser interferometer and many thermocouple type temperature sensors. The experiment shows that the temperature difference between the guide rail and the bearing pocket oil makes the feeding table rotate and therefore linear scale move through a rotational motion.



(a) (b)

Figure 2: (a) Control stability and positioning repeatability experiment result (b) table and scale jig displacement experiment result by varying bearing oil temperature.

3 Geometric error assessment bewteen c-axis and xy-axes

The R-test method was proposed for measuring geometric errors of a rotary table, it can measure directly three Cartesian axes errors with a submicron measurement resolution. And in order to measure geometric errors between the linear axis and the rotary axis the R-test equipment has been designed in our laboratory with three capacitive position sensors. A datum ball has been used for measuring the relative displacement. In order to analyze measured data and identify machine errors, a geometric model of the machine has been created. To identify machine errors from the measured data a kind of the inverse identification algorithm was used. The HTM (Homogeneous Transformation Matrix) method was used for the equation formulation and the coordinate transformation is made from the datum ball coordinate to the translational table coordinate (to the TCP (Tool Center Point)). Including measurement device set up errors and geometric errors, the forward simulation calculates a datum ball center trajectory and by the least-squares-method the geometric error backward identification was accomplished. The identified error was below 10 % for each unknown error. The R-test experiment has been performed with our lab-built measuring device for the 4-axis ultraprecision machine tool. The x and y axes are controlled simultaneously with the c-axis table for the measuring device to follow a circular trajectory. The experimental result and backward identified result are shown in Fig. 3. With the raw experimental data from the measuring device, x, y and z direction error values can be obtained through a calculation. With the converted x, y, and z directional error data the backward identification has been performed and those identified angular and positional error values are shown. The angle alpha means the angle error between the c-axis and x-axis and the angle beta is the error between the c-axis and y-axis. The offset error means that the center position error of the c-axis from the origin of the xy-axes.

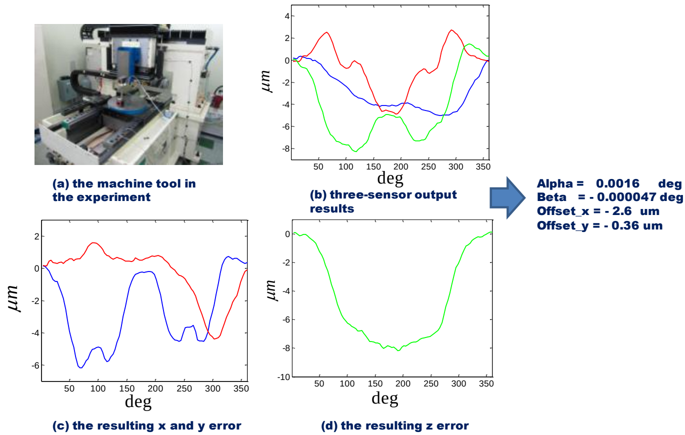


Figure 3: Geometric error experimental result for rotary and linear axes by the R-test.

4 Conclusion

The thermal stability and the geometric error assessment of a hydrostatic bearing guided machine has been done. The main cause of stability was analyzed and the R-test was performed for the geometric error measurement.

References:

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