Ultraprecision Control of A Hydrostatic Bearing Guided Machine with Position Stability Analysis

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Abstract

This paper shows a method and procedure of ultraprecision control of a hydrostatic bearing guided machine and also investigates the machine's positioning stability. Through improvements of electrical and mechanical components for the control system, control disturbing noise was decreased. Also with the frequency domain analysis of the control system those problem-making system components were identified. The controller was analyzed and designed from frequency domain data and system information. The long term stability of the machine was investigated and analyzed. With the machine operating environment of controlled temperature and humidity, those position stability contributing causes were analyzed from various sensors and measuring instruments.

1 Introduction

Recently, the requirement for ultraprecision machining machines goes beyond conventional machine performance especially in those industrial areas producing displays, mobile devices and semiconductors. Ultraprecision machining plays important roles in manufacturing precise molds, BLU (Back Light Unit) films and polishing semiconductor wafers and so on. Therefore, machining precision is important and positioning capability of ultraprecision machines plays an important role. The positioning capability can be assessed in those aspects of achievable positioning resolution and positioning stability (which can be thought of as positioning repeatability of a machine). An ultraprecision multi-axis machine tool has been designed and developed in our laboratory and the machine was used for those experiments. 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 the workpiece is located, is inside the

Y-axis. This machine is designed for manufacturing micro-patterns on a large surface area and it can manufacture micro-patterned molds for LCD (Liquid Crystal Display) diffusion film, light guide plate, fuel cell membrane and anti-reflection film for solar cell panel. Each X and Y axis has 500 mm travel and the Z axis has 110 mm travel. All the three linear axes and C-axis adopt hydrostatic bearings and the feeding oil temperature is controlled by a cooler and the whole machine components are in an environmentally controlled room.

Figure 1. The 4-axis machine tool which is adopting hydrostatic bearings.

2 Control system design and analysis

In order to enhance positioning capability of the machine, hydraulic and electric components have been redesigned and modified to decrease control disturbances and noise. Also from the frequency domain analysis of the control system and machine, those problem-making system components have been investigated and modified. One of the most influencing disturbing causes is the machine mechanical mode as shown in Fig. 3(a). When the hydraulic pressure for the bearings is applied and the controller is turned on, a broad band pressure induced vibration and 58 Hz mechanical mode can be observed (116 Hz mode is the harmonic of 58 Hz). By modal analysis and experiment the 58 Hz mode was identified as the mode frequency of scale jig frame and the scale jig frame was changed to have a higher mode frequency and higher damping capability.

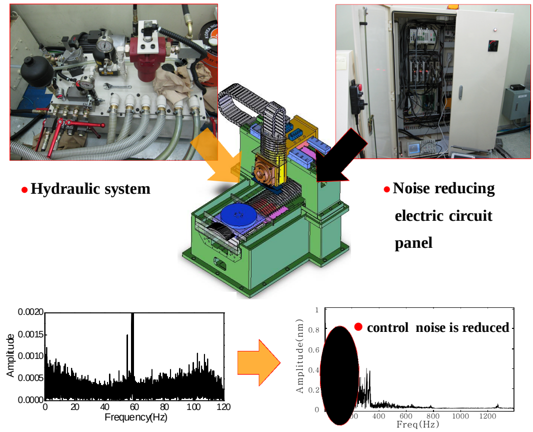

Figure 2. Control disturbance and noise improvement results

Before all of those improvements step responses were not clearly observed for a 5 nm multi-step input. However, as can be seen in the Fig. 3(d), with all improvements and changes, 3 nm step reponse can be observed.

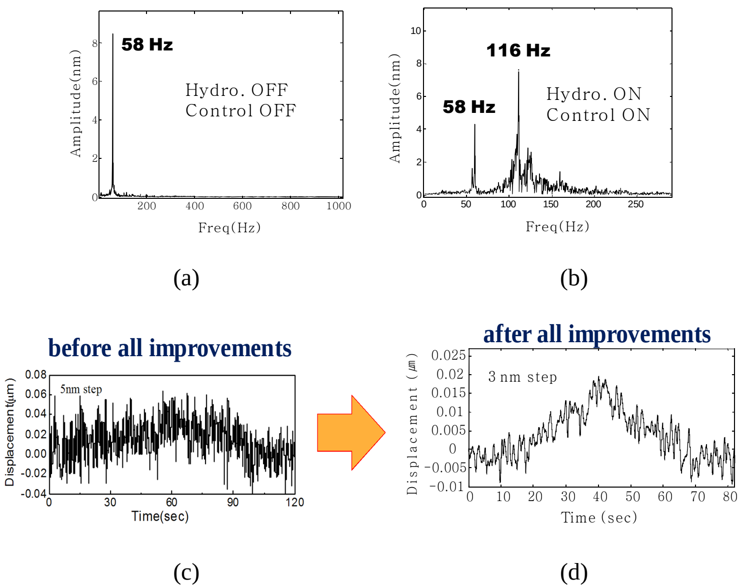

Figure 3. (a), (b) : FFT of position sensor, (c), (d) : multi-step control results

3 Positioning stability analysis

To analyze positioning stability of our machine repeatability experiments have been done for the Y-axis over a 400 mm stroke. The ambient and supplying oil temperature was controlled within about 0.1 deg Celsius and the obtained repeatability performance of the machine is 0.18 um / 400 mm. The dominant contributing factor is inferred as temperature difference between bearing pocket oil and guide rail (also machine body).

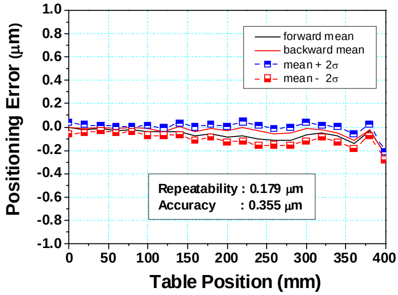

Figure 4. Repeatability experiment result. 0.18 μm / 400 mm repeatability and 0.36 μm accuracy.

4 Summary

The method and the procedure for improving ultraprecision positioning are presented and positioning stability analysis for a hydrostatic bearing machine is presented.

References:

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[2] J.Y. Shim, C.B. Bui, J.H. Hwang, C.K. Song, C.H. Park, Positioning repeatability evaluation of hydrostatic bearing guided precision machine, ASPE 2010 annual meeting, 2010, pp 317-320.