Investigations into Spindle Error Motions using a Modified Loading Device

Aditya K. Sharma
Manufacturing Research and Development
The Boeing Company, Seattle, WA 98124
and
Steven R. Patterson
Center for Precision Metrology
University of North Carolina at Charlotte, Charlotte, NC 28223

Keywords: CNC vertical machining center, Loading device, Spindle error analyzer, Axial and Asynchronous error motions

Introduction

Current measurement methods specified by ANSI/ASME B5.54-1993 and B89.3.4-1985 Standards[1, 2] for spindle error motions establish error motion characteristics of the spindle with no load applied to the spindle bearings. It is possible that the application of load to spindle bearings will result in either different error motions or a different response to the error motions, or both.

The objective of this study is to extend the application of a loading device designed and built in a previous study to investigate error motions of a Computer Numerically Controlled (CNC) machine tool spindle with tapered roller bearings and a constant preload mechanism.

Experimental Setup

The loading device is an external fixture that applies various axial loads to lower and upper bearings of a spindle. It combines traditional spindle testing with an artifact to study both spindle drift and error motions with the ability to conduct these tests under load while at speed. The details of loading device can be found in Reference [3].

In this study, design of the loading device has been modified for testing on a Monarch vertical machining center (VMC-75). A separate fixture was designed to mount the pair of magnets. To apply thrust load to the spindle bearing system, magnets are mounted to a collar that fits around the quill of the machine. The collar is made of Aluminum and has small clearance to fit onto the quill with various holes for mounting magnets that can be placed equal distance from the centerline of the spindle. Additionally, a new tool holder was modified by heat-shrinking a steel sleeve onto the straight dimension of the collet chuck. The sleeve allowed target plate to be mounted onto the tool holder. The spindle of this machine tool has tapered roller bearing and a constant preload throughout the range of speeds from 35 to 10,000 rpm.

Spindle error motion tests were conducted at various rpms using the modified loading device with an application of 140 lbs. of thrust load and under no load. The test set up for spindle error motions under load is shown in Figure 1. For tests under unloaded conditions, magnets are removed from the collar.

A commercially available, capacitance gauge based system is utilized to monitor spindle error motions under load and no load conditions. A calibrated load cell was used to monitor loads applied to the spindle at a given air gap. The range of axial loads that can be achieved using the modified loading device is from 0-140lbs (623N) at an air gap of 0.125 inch (3mm).

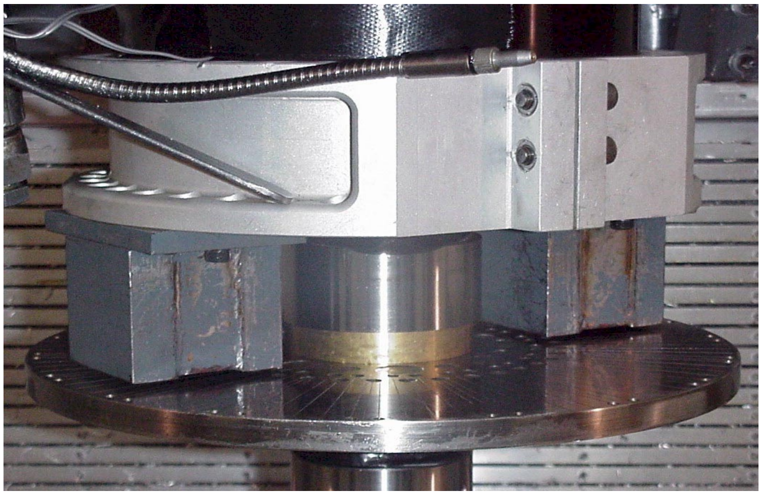
Figure 1 Setup for spindle error motions under load

To establish a relationship between unloaded and loaded spindle error motions, results of axial and radial error motions along with polar plots have been analyzed and reported.

Results of Spindle Error Motions under Loaded and Unloaded Conditions

Spindle error motions have been analyzed for Axial error motions and Asynchronous error motions. Tests at various loads and rpms were conducted according to the ANSI/ASME B5.54 standard specifically related to the axial and radial error motions for rotating sensitive direction.
In this study, tests conducted under the application of 140 lbs of axial load are reported. For radial error motion tests, only asynchronous error data have been analyzed and reported.

Axial Error Motions, Rotating Sensitive Direction

The axial error motion is defined as in and out motion of the spindle while it rotates. The data has been taken for 16 revolutions of spindle with 128 data points per revolutions. For axial error motion tests capacitance gage target eccentricity was minimized to avoid measurement errors. Figure 2 shows results of the axial error motion magnitudes under loaded and unloaded conditions and at various rpms.

Axial error motion was found to be higher at unloaded conditions of the spindle bearing system. The application of 140 lbs. of axial load reduced both the amounts of axial error and variations within

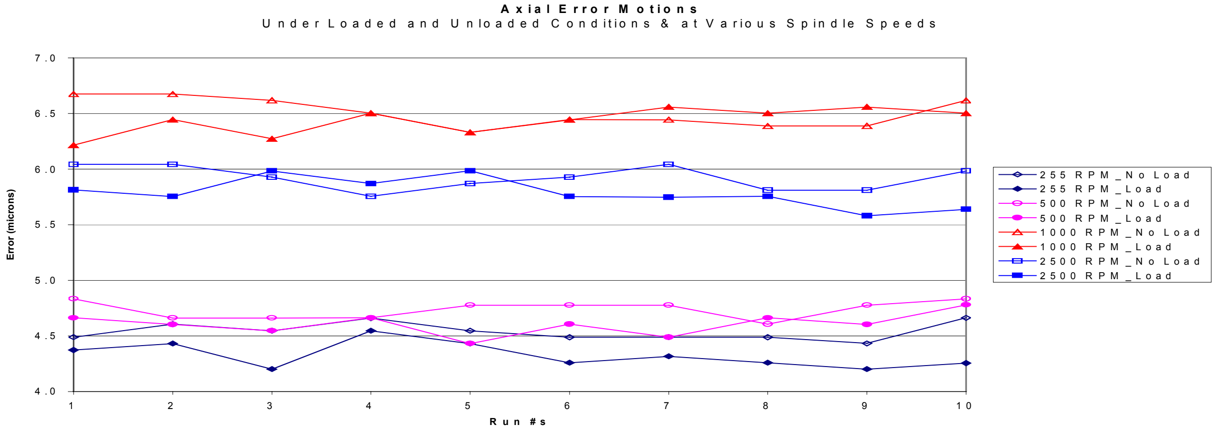

Figure 2 Axial error motions under loaded and unloaded conditions and at various spindle speeds

the measurements by approximately 0.25 and 0.15 micron respectively. It is possible that by increasing the amount of axial load may reduce either the magnitude of the axial error or the amount of variations within measurements or both.

At 500 rpm, the application of external load in this study did not affect spindle axial error motion. Similar results were obtained at spindle operating speeds of 1000 and 2500 rpm. However, the amount of axial error obtained was higher by approximately 0.60 micron at 1000 rpm than at 2500 rpm.

Radial Error Motion, Rotating Sensitive Direction

In capacitance gage measurement system data is acquired from the X and Y probes positioned 90 degrees to each other. The probes measure X and Y changes in position of the axis line of rotation and generates sine and cosine signals to produce a polar plot using Tlusty method [4,5]. For radial error measurements target eccentricity was maintained constant.

Figure 3 shows results of the asynchronous error motions recorded at various rpms, and under the applications of 140 lbs of axial load on spindle bearings and under unloaded conditions of the spindle.

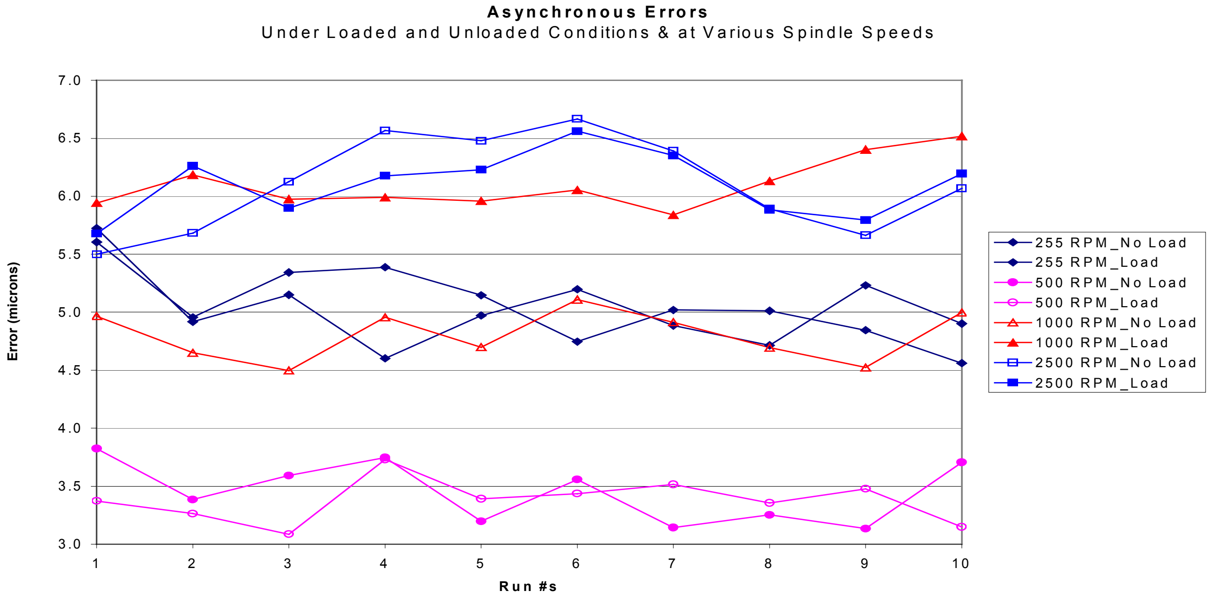

Figure 3 Asynchronous error motions under loaded and unloaded conditions and at various spindle speeds

For radial error motions at 255 rpm and 500 rpm, application of 140 lbs. of thrust load did not influence asynchronous error motions. However, variations in measurements obtained were approximately one and one-half times larger at 255 rpm than at 500 rpm.

At 1000 rpm, average asynchronous error motion increased by approximately 3 microns when axial load was applied to spindle bearing system. Further data analysis and measurements will be required to establish key factors that could cause spindle error motion to remain unchanged both under loaded and unloaded conditions at 1000 rpm. Asynchronous error magnitude remained unchanged at 2500 rpm.

Conclusions and Future Work

A loading device previously designed and built to study spindle thermal drift was modified and utilized to investigate error motions under loaded and unloaded conditions. The maximum load and spindle operating speed were limited to 140 lbs. and 2500 rpm.

The magnitude of axial error motions under the application of 140 lbs. of external load did not change significantly when compared with the axial error motion without the application of load. However, variations within the measurements were found to be larger than the difference in the magnitudes of axial errors obtained under loaded and unloaded conditions.

Similar characteristics were obtained for asynchronous errors accept for measurements at 1000 rpm. At this rpm, asynchronous error increased under the application of 140 lbs. of axial load. However, more measurements and data analyses are necessary to establish spindle behavior at this rpm.

Future work will include comprehensive analysis of the data obtained with the modified loading device, and study of spindle thermal stability under loaded and unloaded conditions.

References

1. ANSI/ASME B5.54-1993, “ Methods for Performance Evaluation of Computer Numerically Controlled Machining Centers,” American Society of Mechanical Engineers, NY, 1992.
2. ANSI/ASME B89.3.4, “Axes of Rotation, Methods for Specifying and Testing” American Society of Mechanical Engineers, NY, 1985.
3. Sharma, A.K., “An Experimental Investigation into Thermal Spindle Growth Under Load”, Masters Thesis, The University of North Carolina at Charlotte, 1997.
4. “Spindle Error Analyzer, Instructions Manual,” Lion Precision, Inc., St. Paul, MN., 1996.
5. Tlusty, J. “System and methods of testing machine tools,” Microtechnic, 13, 162-178, 1959.