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THERMAL INFLUENCE ON POSITIONING ERROR AND POSITION REPEATABILITY OF A MACHINING CENTER AXES

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The development of the aerospace, automotive, medical and other industries require a continuous improvement of fabrication technologies, including computer numerical controlled machine tools. Currently, the 5-axis CNC machine tools can reach machining precisions of a micrometer, but this characteristic depends on the multitude of fabrication and environmental conditions. In this paper, a general approach and the thermic influence on positioning error and positioning repeatability are presented. The experimental tests have been performed using a Renishaw XL-80 interferometer on a 5-axis CNC vertical machining center Makino D200Z.

Keywords: interferometry, computer numerical control machine, kinematic errors, positioning error, positioning repeatability

1. Introduction

Following the technological development in the materials processing industries, new technologies, processes, and systems have been embraced in order to increase precision, repeatability and reliability, which have made possible some characteristics unattainable in the past.

In this matter, the CNC (computer numerical control) machine tools are advanced elements in any high precision technological systems. The concept of NC (numerically controlled) machine tools started in the 1940s and was developed at the Massachusetts Institute of Technology between 1950 and 1970 under Air Force contracts [1], being intended for the needs of the aeronautical industry. Over time, the CNC machine tools were improved, leading to even higher accuracy of fabrication.

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The ideal CNC would have no machining errors, but reality shows different types of errors [2] derived from the machine that affects its accuracy:

- geometric errors – based on the machines design, the errors coming from the assembly and the errors of each part of the machine's assembly [3];
- thermal errors – produced between the workpiece and the tool by the different coefficients of thermal expansion according to the material of the machine's elements [4];
- cutting force induced errors;
- tool wear errors;
- fixture-dependent errors;
- servo errors.

The machining accuracy of CNC machines and, especially, of the five axis machining centers, relies on the geometric accuracy of the linear axes [5] and of the circular axes. The geometric errors consist of kinematic errors and location errors [6]. The location errors may affect the verticality or the parallelism of the machine's components [6]. Furthermore, it is considered that location errors can be neglected [2]. Those location errors are also named installation or assembly errors and are produced in the machine assembly procedure during fabrication. The kinematic error comprises of positioning error, straightness error and angular error (pitch, yaw and roll) [7].

In this paper, two characteristics are analyzed, namely the positioning error and positioning repeatability. ISO 230-2 [8] offers a detailed method of positioning error and repeatability determination for numerically controlled axis machine tools.

In the literature, it has been shown that there are several errors that occur during measurement procedures, such as positioning errors, backlash, errors resulting from acceleration and deceleration strategy, vibrations that occur in the measured object or in the optical components of the measurement equipment, servo errors and other [9]. In previous studies [10] different procedures of non-contact calibration were detailed but the one using the interferometer is suggested by standards for this type of calibration. The aim of this paper is to perform the measurement using an interferometer at different temperatures.

2. Set-up and experimental procedure

As ISO 230-2 recommends, the machine to be tested is to be thermally stabilized according to the manufacturer's specifications, the environment temperature should be at 20° C [11] and the measurement instruments should be in the same environment with the machine for sufficiently time in order to reach thermal stability. If any of the conditions are different, it should be noted in the measurement report.

The measurement device that has been used is a Renishaw XL-80 laser system, developed from Michelson's principle of interferometry.

The laser source is fixed on an adjustable tripod and the optics system is oriented and connected to a computer dedicated software package. The interferometer is connected, through the computer, to a compensator unit, crucial for the measurement accuracy.

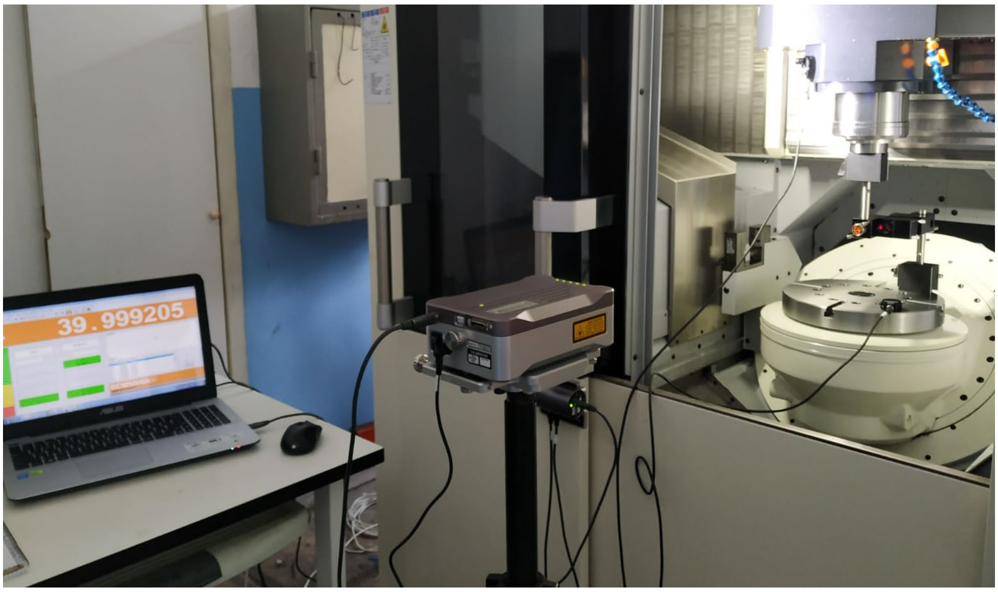

Fig. 1. Experimental set-up for interferometer linear measurement

The machine that has been inspected is a five-axis vertical machining center type Makino D200Z (Fig. 2). Each machine tool can be considered as a serial or parallel set-up of linear and rotary axes [12].

The elements to be evaluated are the rotary-worktable's Y axis and the spindle's Z axis positioning and repeatability. For Y-axis, the interferometer has the beam splitter on the spindle and the optical mirror is fixed on the worktable and for the Z-axis the optical devices are inversed.

The rotary axes B and C are fixed at 0°, while the other two axes are used in order to align the measuring device optics elements. The maximum travel on the Y axis is 300 mm and the maximum travel on the Z axis is 250 mm. After the optical devices were mounted, a maximum measurement length of 120 mm has been chosen, in order to avoid collision with other components. Taking this into consideration, the interferometer's test cycles had the following structure:

- 13 different positions;
- 5 cycles;
- 65 target points.

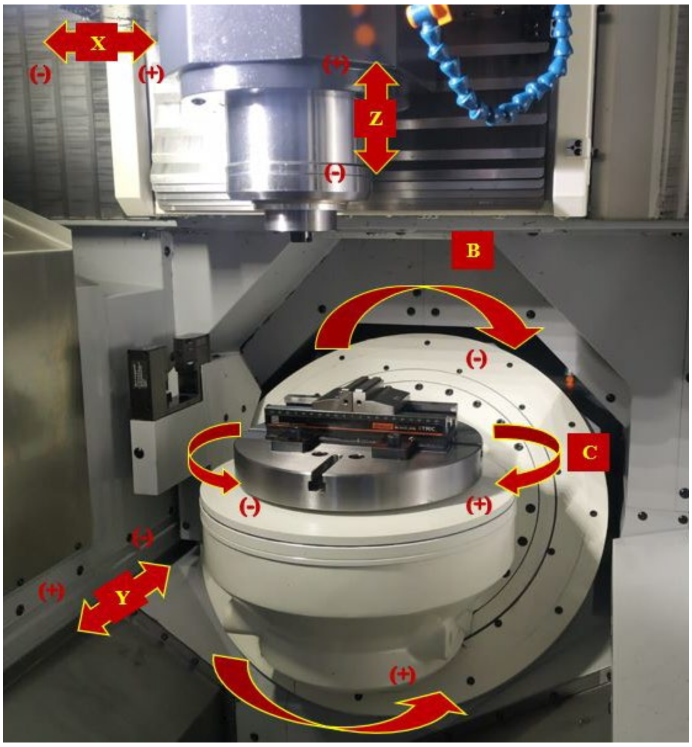

Fig. 2. Axis configuration of a 5 axis vertical machining center type Makino D200Z

The two temperatures chosen for the interferometer's measurements were 20°C as recommended [8,10], and 24°C.

3. Test results

For the Y axis, the interferometer's 20°C measurement (65 target points) was repeated 3 times.

Table 1

Tests environment conditions for Y-axis measurements

	Sensor	Unit	Start	End	CV
1st temperature	Air temp	[°C]	20,29	20,22	0,244%
	Air pressure	[mbar]	1012,26	1012,40	0,009%
	Air humidity	[% RH]	49,02	48,82	0,289%
	Material temp	[°C]	20,40	20,41	0,034%
2nd temperature	Air temp	[°C]	24,15	24,30	0,437%
	Air pressure	[mbar]	1011,80	1011,80	0
	Air humidity	[% RH]	48,11	47,15	1,425%
	Material temp	[°C]	23,92	24,10	0,53%

Table 2

Tests environment conditions for Z-axis measurements

	Sensor	Unit	Start	End	CV
1st temperature	Air temp	[° C]	20,70	20,71	0,034%
	Air pressure	[mbar]	1020,80	1020,60	0,013%
	Air humidity	[% RH]	54,75	54,78	0,038%
	Material temp	[° C]	20,19	20,40	0,731%
2nd temperature	Air temp	[° C]	24,46	24,55	0,259%
	Air pressure	[mbar]	1020,60	1020,80	0,013%
	Air humidity	[% RH]	49,23	49,06	0,244%
	Material temp	[° C]	24,18	24,38	0,582%

The results were extremely similar thus only one of the tests was considered. Considering this aspect, for the second temperature and for the second axis, only one cyclical measurement was performed. The environmental conditions and the coefficients of variation (CV) are presented in Table 1 and Table 2.

The manufacturer provides a ± 1,5 μm positioning accuracy limit deviations of linear motion and a ± 1,0 μm positioning repeatability limit deviations on all linear axes. The measurement's results are as presented in Fig. 3, Fig. 4, Table 3 and Table 4.

It can be determined that the positioning repeatability does not considerably vary from one temperature to another and from one axis to another and it is close to the manufacturer's values. On the other hand, the positioning accuracy of the axis doubles in value from one temperature to the other for both axes.

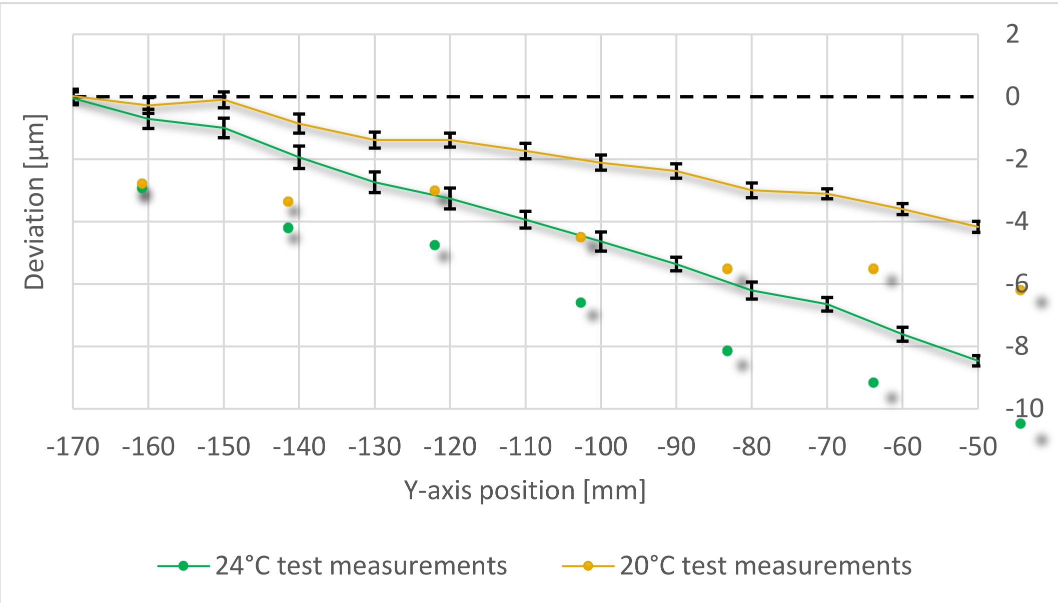

Fig. 3. Positioning accuracy and repeatability test results for two different temperatures on Y-axis

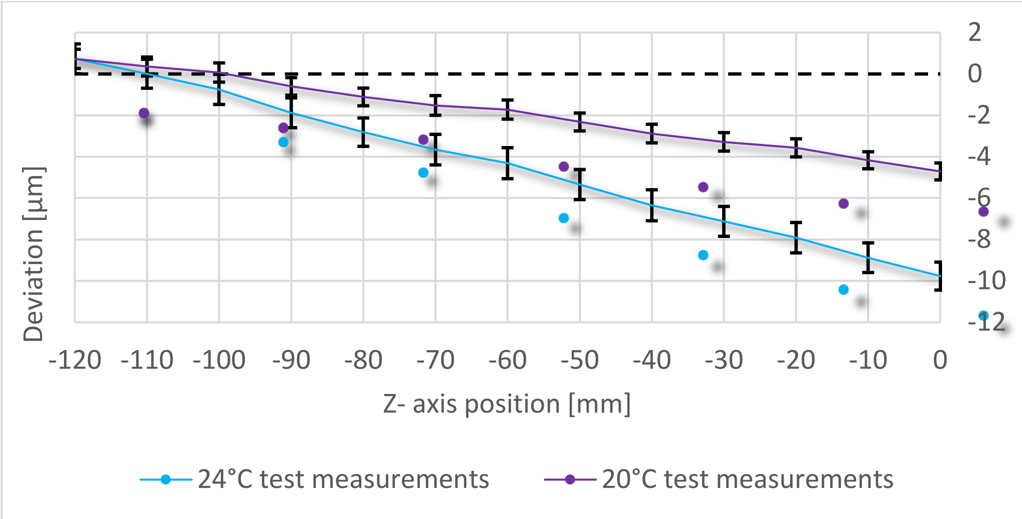

Fig. 4. Positioning accuracy and repeatability test results for two different temperatures on Z-axis

Table 3

Y-axis measurement results

Test	20° C			24° C		
	Unidir. (+)	Unidir. (-)	Bidir.	Unidir. (+)	Unidir. (-)	Bidir.
Unit	[µm]	[µm]	[µm]	[µm]	[µm]	[µm]
Positioning error	5,0	5,1	5,1	9	9,2	9,2
Positioning repeatability	1,3	1,0	1,4	1,4	1,1	1,5
Systematic positioning error	4,2	4,2	4,2	8,3	8,5	8,5
Reversal			0,4			0,6
Mean reversal			0,2			0,3
Range of mean bidirectional positioning error			4,2			8,4

Table 4

Z-axis measurement results

Test	20° C			24° C		
	Unidir. (+)	Unidir. (-)	Bidir.	Unidir. (+)	Unidir. (-)	Bidir.
Unit	[µm]	[µm]	[µm]	[µm]	[µm]	[µm]
Positioning error	7,1	7,3	7,3	13,2	13,7	13,7
Positioning repeatability	2,2	1,9	2,2	3,1	3,3	3,4
Systematic positioning error	5,3	5,5	5,5	10,3	10,7	10,7
Reversal			0,3			0,4
Mean reversal			0,1			0,1
Range of mean bidirectional positioning error			5,4			10,5

ISO 230-2 provides a procedure to determine the measurement uncertainty according to temperature compensation. Determining the real source of the error is however extremely difficult. The newest CNC machine tools have the capacity of thermal autocorrecting through an expansion coefficient. Throughout these measurements, the expansion coefficient used by the machine tool soft was 11,7 ppm/°C. Even so, the results were significantly different from one temperature to another.

3. Conclusion

The kinematic errors are one of the most important sources of errors for a 5-axis machine tool. The measurement test presented in this paper indicates the temperature's influence in measurements even in short axis positioning tests. It has been noticed that a variation in temperature of four degrees, while not influencing significant the repeatability, it affects the positioning accuracy. Further on, new studies on environmental influences on each axis must be studied.

Acknowledgments

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