Measurement set-ups and cycles for thermal characterization of axes of rotation of 5-axis machine tools

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Abstract

Up to 80% of all deviations on machine tools are caused by thermal effects [1]. To investigate the influence of thermal caused location errors of rotating and swiveling axes, different measurement set-ups (e.g. R-test) are examined. Thermal errors caused by rotary axes are compared to thermal errors caused by the environment, linear axes and spindles. It is shown that rotary axes can have a significant share in the total thermal distortions of 5-axis machine tools.

1 Introduction

High accuracy is a very important issue in manufacturing technology and becomes more and more essential for 5-axis machine tools. Beside geometrical precision, thermal effects are significant for high machine accuracy [1]. While the influence of the environment of a machine tool and also machine components like linear axes or the spindle are observed concerning thermal distortions in ISO [2], rotary axes haven't been examined yet. For this purpose, different measuring set-ups as well as corresponding measurement results are presented in this paper.

2 Mesurement set-ups

As possible measuring set-ups for thermal characterization of rotary axes, the *"continuous R-test"* and the *"discrete R-test"* are compared [3]. As an alternative, the "e*nhanced ISO set-up"* is presented as an extension of the measuring set-up for ETVE-tests (ETVE=Environmental Temperature Variation Error) in ISO 230-3 [2].

2.1 R-test

The R-test set-up consists of three or four probes measuring a high precision sphere at the TCP (TCP = Tool Center Point). During the continuous R-test, the rotary axes and the corresponding linear axes perform a synchronous circular movement. For the period of this movement, the relative displacements at the TCP can be measured, so that all location errors, except the change of the zero angle position (e.g. C0C with a C-axes), can be identified. In difference to the continuous R-test, the discrete R-test measures the displacements only at certain points. The example in Figure 1 shows a measurement with 5 points at 0, 90, 180, 270 and 360°. By repeating the measurement, once at point 0° and once at point 360°, a statement concerning the repeatability can be made. It is also possible to identify any change in C0C.

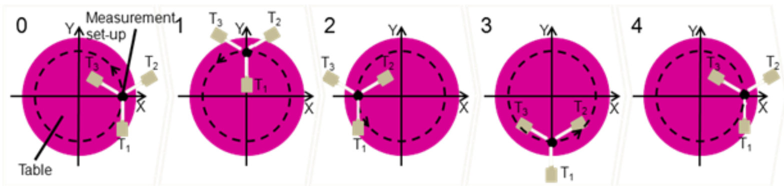

Figure 1: Measurement process for discrete R-test

A disadvantage compared to the continuous R-test is the higher measurement uncertainty, due to the small number of measuring points.

2.2 Enhanced ISO Set-up

As an alternative, the set-up proposed in ISO 230-3 for ETVE - tests and for spindle tests has been enhanced.

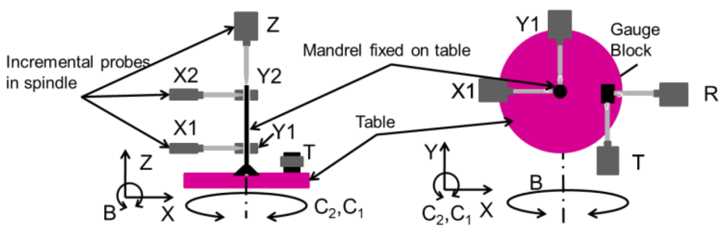

Figure 2: Enhanced ISO set-up (ISOe)

Five probes measure the five displacements X, Y, Z, A and B analog to ISO 230-3. With two additional probes (T & R), the zero angle position and the radial table growth can be measured.

3. Comparative measurements

To compare the three different set-ups, the C-axis of a 5-axis machine tool (C-axis with turning option) was analyzed. The test cycle for the comparative measurements is shown in Figure 3.

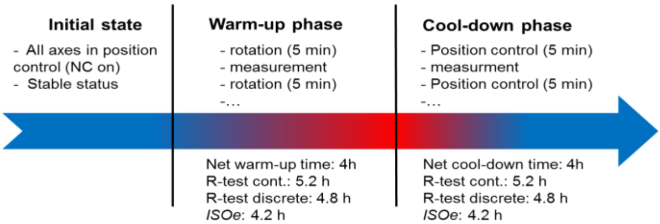

Figure 3: Test cycle for thermal measurements

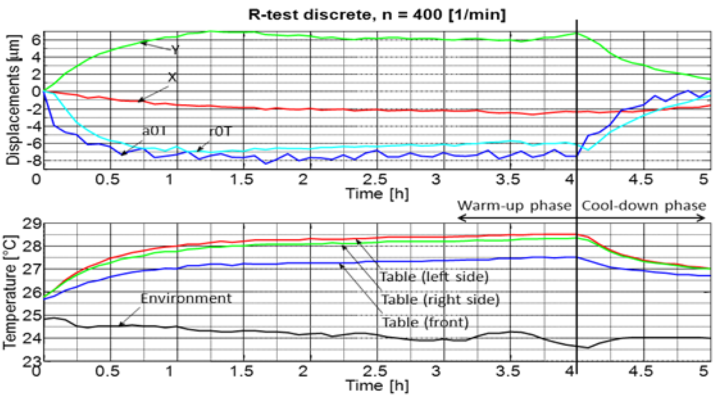

Figure 4: Results of discrete R-test (4 of 20 temperature records)

For every measurement set-up, displacements and corresponding temperatures were recorded. (Example: R-test discrete, Figure 4)

The measured displacements shows a quite good PT1-characteristic in direction of *a0T* (axial table growth), *r0T* (radial table growth) and *Y*. In *X*-direction the deviations are clearly smaller. Same measurement cycles were performed with the other set-ups with similar results. Radial table growth could not be measured with the extended ISO set-up because of the temperature dependency of the set-up. This has to be analyzed in further steps.

4 Quantification of results

To classify the influence of the thermal behavior of the rotary axis regarding thermal caused deviations in form and position of a machine tool, the other influences (linear axis, spindle, environment) were measured according to ISO 230-3. Table 1 shows the range of maximum deviations that have occurred on the machine tool under test.

Table 1: Summary of the different influences

		X-Axis	Y-Axis	Z-Axis	B-Axis	C-Axis	Spindle	ETVE
Testing parameter		500 mm/min	500 mm/min	500 mm/min	3000 °/min	400 U/min	3000 U/min	Max. in 7x24h
Error	**X** [µm]	2	4	6	4	3	1	2
	Y [µm]	4	10	10	4	7	3	6
	Z [µm]	7	5	5	6	8	8	7
	A [µm/m]	12	8	4	10	4	7	40
	B [µm/m]	5	6	12	30	8	5	25

5 Conclusion

Three different measuring set-ups to identify thermal caused location errors of rotary axis were presented. Comparative measurements showed that the 1st version of the extended ISO set-up has to be improved to measure radial table growth. Location errors caused by thermal effects showed a PT1 characteristic.

To identify the share of rotary axis of the total thermally caused location errors, the influence of all other axes, the spindle and the environment was measured. The individual contributions are of similar size, i.e. up to 10 µm in X-, Y-, Z- and up to 40 µm/m in B-,and C-direction. So, it could be shown that it is important to test rotary axes for thermal influences.

References:

[1] Bryan J (1990) International Status of Thermal Error Research. Annals of the CIRP, 39/2:645-656

[2] ISO-230-3:2007, Test code for machine tools- Part 3: Determination of thermal effects, Geneva, Switzerland, 2007

[3] Weikert S (2004) R-Test, a New Device for Accuracy Measurements on Five Axis Machine Tools. Annals of the CIRP 53/1: 429-432.