A simple yet comprehensive approach to the testing of machine tools with arbitrary axis configurations

C. Brecher[1], J. Flore[1], H. Schwenke[2], M. Wissmann[2], C. Wenzel[1]

[1]*Fraunhofer Institute for Production Technology (IPT), Germany*
[2]*Etalon AG, Germany*

Jakob.Flore@ipt.fraunhofer.de

Abstract

The standards for machine tool testing have developed historically with the advancement of machine tool technology. Due to the high number of machine types and possible configurations industry increasingly suffers from the complexity of the test procedures described. This paper introduces a concept of unified specifications and test procedures that can indicate the geometric accuracy of an individual machine to generate an accurate part, independent of the machine tool configuration. The paper presents the concept and verifies it by comparison measurements with different instruments.

1 Introduction

International standards have grown to be a powerful toolbox to build and test machine tools over the last decades. Many of the described test procedures go back to Schlesinger [1]. However, due to the rising number of axes as well as possible configurations within multi axis machines the complexity and number of these tests have increased dramatically. To harmonize the testing, this paper proposes, based on the “volumetric error” described in ISO DIS 230-1(2011) [2], a machine specification that states a maximum deviation from the nominal TCP path and tool orientation in the entire working volume, independent from the axes involved in the motion. Such a specification would make the prediction of achievable part accuracies possible. In the following the practical realization of such a testing is discussed.

2 Basic principle of the testing approach

High machining accuracy is achieved, when the deviations from the programmed motion (position and orientation) of the tool in relation to the work piece table are small. From the workpiece table to the tool the nominal vector N is programmed, whereas, due to inaccuracies of the machine axes, the vector M will be effective (Figure 1). As a universal and simple testing specification we propose the limiting value S > |M-N|. This specification has to be hold in the entire working volume and independent from the axis motions involved in the programmed path. Compliance of the machine with this specification would assure that deviations on the part resulting from machine geometry errors would not exceed 2·S.

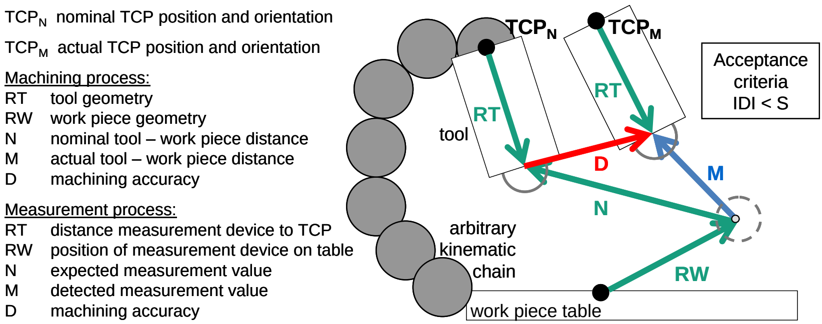

Figure 1: Basic principle of the testing approach

For an accurate and reliable testing, the vectors RT and RW have to be identified by means of the application setup or a measurement data fitting processes. It can be shown, that the maximum observed values with best-fitted RT or RW are equal or smaller in comparison to values measured with a defined RT and RW, thus an observed value S < |M-N| will necessarily mean, that the machine accuracy specification is violated. Intensified measurement effort with more M_i measured at arbitrary axis positions for each pair of RT, RW and many different setups RT, RW will test the machine increasingly rigorous. The following chapter discusses the practical use of existing metrology for testing against this specification S.

3 Application of the test principle with different metrology instruments

Ideal (yet not available) metrology to verify the specification would have a defined and flexible RT and RW and could measure the vector M directly and accurate. However, Table 1 presents an overview of the capabilities and limitations of available metrology. For most metrology instruments, only the deviation component in direction of the system sensitivity can be measured (1D). Figure 2 visualizes the testing principle on the R-Test, the long range double ball bar and a straightness standard.

Table 1: Capability of available metrology (list is not exhaustive)

Instrument	Single observation	Uncertainty	Restriction
Ideal Instrument	**M_i**	**0**	**none**
Laser tracker	M_i	50 µm	1 m < |N| < 50 m
R-Test	M_i	1 µm	|N| = 0
Probe and Sphere	M_i	5 µm	|N| = 0
Double ball bar	$\|M_i\|$	2 µm	|N| constant
Long range double ball bar	$\|M_i\|$	1 µm	260 mm < |N| < 1000 mm
Lasertracer	$\|M_i\|$	0.3 µm + l*0,3 µm/m	260 mm < |N| < 15 m
Linear interferometer	$\|M_i\|$	0.3 µm + l*0,3 µm/m	in beam direction
Straightness standard	$\|M_i\|$	2 µm	perpendicular to artefact

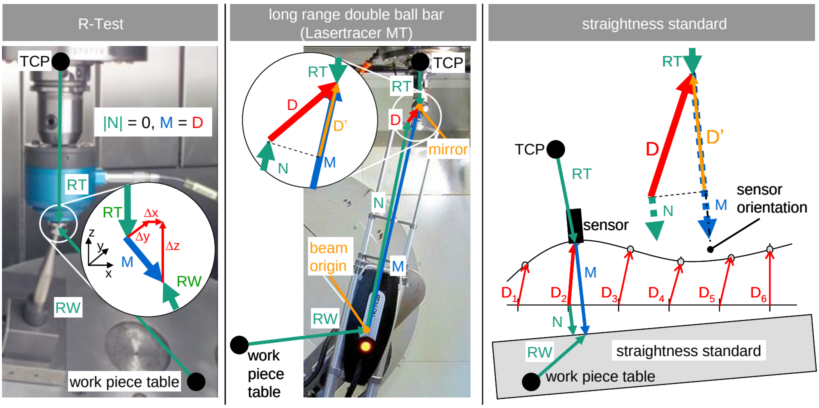

Figure 2: Testing principle visualized on different metrology instruments

4 First practical trials

First practical verification measurements with the R-Test and the long range double ball bar (represented by the Lasertracer MT) have been performed. Both systems were used on the same machine. The R-Test measured deviations between the master ball and the spindle while the master ball was moved by the C- and A-axis. The spindle head followed the motion by the linear axes, the nominal vector was N=0. For the Lasertracer MT measurements one end of the instrument was fixed to the table, the other to the spindle head. A measurement path was performed that involved all axes of the machine, varying also the nominal vector N_i. Figure 3 shows the absolute values of the deviations $|M_i|$ over the nominal length $|N_i|$. Due to the measuring principle, the R-Test values are limited to $|N_i| = 0$.

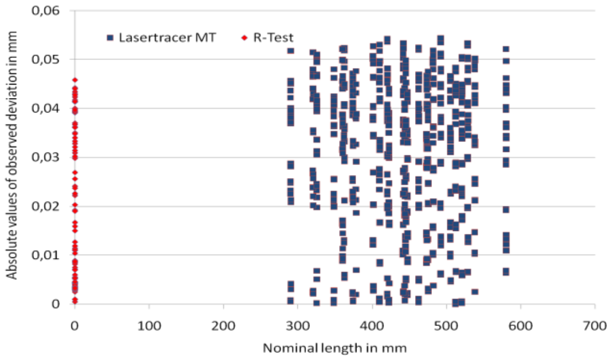

Figure 3: R-Test and Lasertracer MT measurement results of a 5-axis machine

The diagram shows that both instruments detected a comparable maximum deviation. The results would have proven a violation of a specification of S=40 µm. For the tested machine, the deviations were not dependent to the nominal measuring length |N|, since the dominant errors resulted from the location errors of the rotary axes.

4 Preliminary conclusions and outlook

The compliance with the specification of S > |M-N| for arbitrary axis motions in the entire working volume yields a maximum error of 2·S on the workpiece. Different metrology can be used for the testing against this specification, whereas different instruments have different sensitivities and limitations for the measurement of |M-N|. First practical verifications trials were performed by using the R-Test and a long range double ball bar. In our future work, we aim to develop optimized measurement strategies to reliable capture machine geometry errors. For this, simulations will be performed to analyze systematically the measurement processes. Furthermore, the specification system may be extended to allow lower specifications for certain tasks, where additional constraints regarding axis motion and machine volume are accepted.

References:

[1] Schlesinger, G.: Prüfbuch für Werkzeugmaschinen, edition 7, 1962, Middelburg: G.W. den Boer

[2] IS0 230-1 Draft international standard 2012, Test code for machine tools, Part 1: Geometric accuracy of machines operating under no-load or quasi-static conditions, to be published soon