Determining the 5-axes machine tool contouring performance with dynamic R-test measurements

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Abstract

Current state-of-the-art methods use a tactile (i.e. touch-trigger) probe in combination with a masterball to calibrate 5-axes machine tools. However, they cannot measure dynamically and are unable to detect or capture the observed dynamic machine tool behaviour as described in this paper; for this the R-test is required.

In this paper a “directional rotary table following error” is addressed. This is an error for which the CW measurement significantly differs from a CCW measurement. This effect is proven to be caused by the dynamic performance of the rotary table.

1 Introduction

Currently tactile (i.e. touch-trigger) probes are used in combination with a masterball to allocate a rotary axis (i.e. the Siemens 996 cycle). This method however is static and time consuming: such a probe cannot measure dynamically and it needs multiple probing points (i.e. 5 points: 4 on equator and 1 on top of the masterball) to obtain the X, Y and Z-coordinates of the centre point of the masterball for each measuring position.

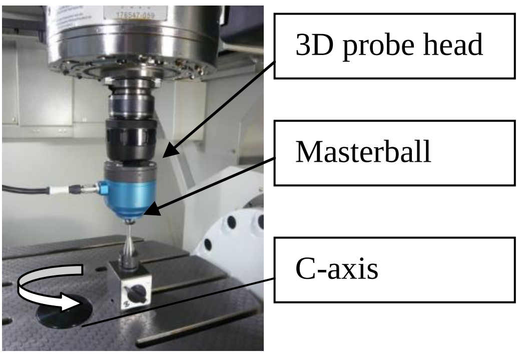

Figure 1: Typical measurement setup R-test

The innovative R-test can be applied for both static and dynamic measurements. When applied static the location (i.e. XOC, YOC for a C-axis) and squareness error (i.e. AOC, BOC for a C-axis) of a rotary axis is determined accurately relative to the machine's linear axes, see Figure 1 [1,2,3].

The measurement consists of a sequence of discrete angles of the rotary table. When moving to the next measurement point the linear axes follow the rotation of the rotary table. At each position the probe head measures the relative displacement of the masterball in X, Y and Z direction simultaneously. By analysing the data in the XY-plane the location and squareness errors of the C-axis are determined, see Figure 2.

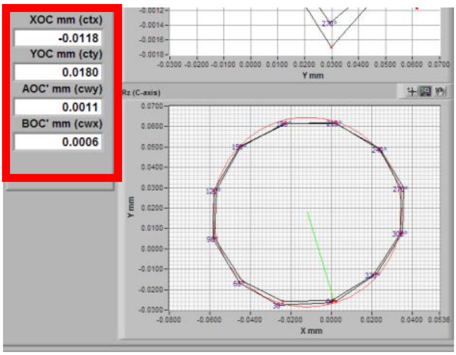

Figure 2: Static R-test measurement result of a C-axis. One revolution CW and one revolution CCW, step-angle is 30^o degrees (location errors displayed in the red box).

The location error XOC is -11.8 μm and YOC equals 18.0 μm. The squareness errors AOC (2.0 μm) and BOC (3.6 μm). The repeatability of this test is better than 1 μm from the CW and CCW results. Typically the location errors can be corrected for by the kinematic settings in the controller.

In this paper a case study is presented dealing with dynamical R-test measurements to highlight the importance of measuring a machine tool dynamically (like its use in normal operation). For this a dynamic R-test measurement is performed on the same machine as figure 2. In addition a dynamic ball bar measurement is performed to verify the dynamic behaviour of the linear axis. As a result the "directional rotary table following error" or "dynamical backlash" [5] is determined: the machine's rotary table dynamic behaviour in CW direction differs significantly from its behaviour in CCW direction.

2 Dynamic R-test

With the R-test dynamic measurements are executed on the same machine. Instead of stopping for each measuring point, the 3D displacement of the masterball relative to the probe head is captured at 6.5 kHz. Such measurements reveal the machine's 3D contouring accuracy one can expect when making a workpiece [3,4]. In Figure 3 such a dynamic R-test result is shown. Here the machine is commanded to execute 3 complete revolutions CW and CCW with a 2 second delay in between.

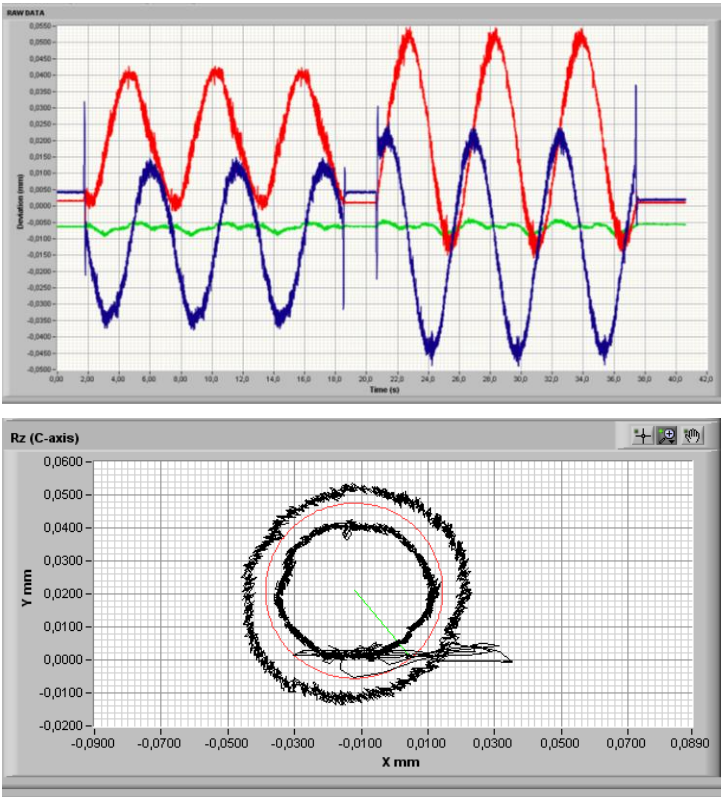

Figure 3: Dynamic R-test result: 3 revolutions CW and 3 revolutions CCW. The results are shown in time (upper figure) as well as in the XY-plane (lower figure).

The masterball is placed about 125 mm from the C-axis centreline for this measurement. In Figure 3 the displacement of the masterball relative to the probe in X (blue), Y (red) and Z (green) direction is displayed in time (upper figure) and also in the XY-plane (lower figure). Here 2 concentric circles are observed with a difference in radius of 12 µm. The straight green line marks the starting point of the measurement and the typical start-stop spikes are present at this point. For a static measurement on this machine these circles coincide, see Figure 2. The measured difference is caused by the machine tool's dynamic behaviour.

2 Dynamic ball bar measurement of linear X- and Y-axis.

In ISO230-4 circular ball bar tests are described for which the X- and Y-axis execute a circular path [6]. In Figure 4 the results of such a ball bar test is shown, executed on the same machine with comparable radius (100 mm) resulting in a similar trajectory as during the R-test measurement.

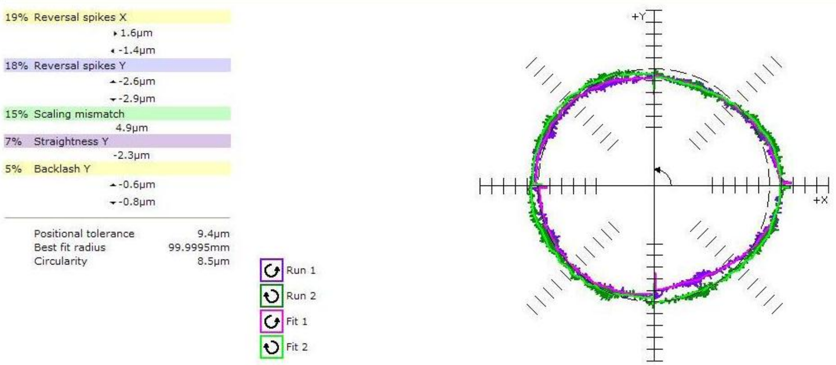

Figure 4: Ball bar test CW (purple) and CCW (green) result.

Here the difference between the CW and CCW result is 1.3 µm only. This means that the following error between the X- and Y-axis is small, negligible for this machine and the result shown in figure 3 is caused by the 'directional rotary table following error'.

3 Conclusion

Apparently a difference in radius of 12 μm has been observed which cannot be explained by a following error between the X- and Y-axis. This difference must therefore be caused by the rotary axis and can be described as a “directional rotary table following error”. The dynamic performance of a 5-axes machining centre in CW direction significantly differs from its performance in CCW direction.

Acknowledgements

The authors are grateful to S. Moylan (NIST) for providing measurement data and his contribution to this paper.

References:

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