R-Test Measuring System

System for the measurement of spatial displacements during swivelling motions

Problem Statement

Five-axis machines are frequently used for the machining of free-form surfaces in the molding industry. Here, the advantages of five-axis machining are the free-form surfaces are the improved surface finish, the higher material removal rate and finally the improved productivity.

On three-axis machines beside the component errors of the linear axes only the three perpendicularity errors influence the accuracy of a finished piece. In contrast to this on five-axis machines additionally the orientations and the locations of the rotational axes relative to the linear axes have to be known precisely. Unfortunately the determination of geometrical parameters of the rotational axes can be a quite time consuming task.

Beside the geometrical accuracy, for simultaneous five-axis machining requires a very good synchronisation of the required movements. Until now machining of test pieces was needed to assess the accuracy of simultaneous five-axis motions.

For the assessment of the spatial of five-axis machining centres and to measure the geometrical parameters with moderate effort the development of the R-Test was started and further carried-out in the KTI-Projekt 6758.3 IWS-IW „Neue WZM-Konzepte – Die Werkzeugmaschinen 2011: Messmittel – Steuerung - Modellbildung“.

Concept of the system, measuring uncertainty

On the work-piece side the R-Test consists of three analogous incremental probes which are arranged orthogonally to each other. The probes are equipped with plane probing tips (Ø 10mm, see Fig. 1).

At the TCP (tool centre point) a precision sphere is mounted. The spatial displacements of the TCP are captured by the three incremental probes. The translatory measuring range in X-, Y- and Z-direction is ±3mm. Swivelling motions about the TCP can be carried-out partly up to ±90°.

For the uncertainty estimation the following factors have to be considered: flatness and orientation of the probing planes, form deviation of the sphere, centring of the sphere, measuring uncertainty of the probes, orientation of the device on the machine-table and thermal influences. Factors depending and not depending on the displacement to be measured have to be distinguished.

For a displacement of 2mm the expanded measurement uncertainty $U_{x=2}$ is 2.8µm, for a displacement of 0.5mm the expanded measurement uncertainty $U_{x=2}$ is 1 µm.

Measurement Examples

For the measurements interpolating movements of linear and rotary axes are carried-out. The position of the TCP is nominally kept the same in the table’s coordinate system. Ideally no displacements of the TCP occur during the motions. Die to geometric and dynamic influences systematic displacements can be measured which permit to obtain the geometric and dynamic parameters.

During the interpolating motions, three displacement components are measured simultaneously (X-, Y- and Z-direction, corresponding to the radial, tangential and vertical direction for circular interpolation) in the measurement coordinate system.

Figure 2 shows the radial displacement component during an interpolating motion of the X-, Y- and C-axis. For this measurement motions clockwise (red) and counterclockwise (blue) have been combined. The results are similar to double-ball-bar measurements in the X-Y-plane. Additionally the position and the orientation of the rotational axis are obtained.

Simultaneously the Z-component of the motion and the relative motion between the rotary table and the circular motion tangential to the motion are available for interpretation.

Figure 3 shows the tangential components of the displacements. Errors in the synchronisation between rotational movement and the interpolating motion are shown for clockwise (red) and counterclockwise (blue).

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Figure 2: X-Y-plot of the radial displacements during interpolation of X-, Y- and C-axis.

Figure 3 shows distinct periodic effects on the circumference. These effects can be traced back to the teeth of the worm gear transmission. The reason for the difference between the two senses of motion cannot be told.

The vertical displacement components of the measurements shown in figure 2 and 3 are influenced by the straightness and roll of the participating linear axes, and the component errors of the rotary axis. The vertical displacement components therefore only allow a global assessment of the machine’s accuracy. The least square plane shows the orientation of the C-axis to the X- and Y-axis.

The use of continuous measurements during interpolating movements shows less influence of local effects on the determination of geometric parameters.

**Calibration of IWF-Hexaglide**

The ability to measure spatial relative displacements was used for the Calibration of the IWF-Hexaglide test-bed. During programmed swivelling movements of the tool around the TCP systematic displacements occur which can be used for the calculation of the geometric parameters. This procedure principally can be applied on all machines with rotary/swivelling axes.

**Status**

In the KTI-Projekts 6758.3 „Neue WZM-Konzepte – Die Werkzeugmaschinen 2011: Messmittel – Steuerung – Modellbildung“, the R-Test is developed and applied at the industrial partners. Interim measurements at the IWF and in the industry fulfilled the high expectations in the measurement system.

**Project Partners**

- Bystronic Laser, Niederönz, Laser-/Water-Jet-Cutting
- Heidenhain (Schweiz), Schwerzenbach, Measuring Systems and Controls
- LSRO, EPFL-Lausanne, University
- Mikron AG, Nidau, Universal- and HSM-Milling
- Siemens Schweiz, Zürich, Controls and Drives
- StarragHeckert, Rorschacherberg, 5-Axes-Machining
- Willemin Machines, Bassecourt, watch/medical industry

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