KGM-plus - Device for Simultaneous Measurement in Six Degrees of Freedom on Machine Tool Trajectories

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Abstract:

The performance of linear axes is often tested on the basis of one set-up per one or two types of deviations from a NC path. With the application of multi-axes machining the contouring performance in more than two degrees of freedom is of interest.
The paper describes a measuring instrument to check the contouring performance of a machine tool in the six degrees of freedom. The three translations and the three rotations of the relative movement between tool side and workpiece side are measured simultaneously. Results of first measurements are presented and discussed.

Keywords:

Machine tool, Contouring performance, Measuring instrument

1 Introduction

The performance of a linear axis, i.e. positioning accuracy, straightness, roll, pitch, yaw, is generally measured on the basis of one set-up per one or two geometric deviations. For performance testing of rotary axes (or spindles) the simultaneous measurement of five degrees of freedom is common practice and this can be found already in existing standards [1] [2]. The simultaneous measurement of the five degrees of freedom of a spindle is helpful for the interpretation of the dynamic behaviour of the spindle.
For the contouring performance of linear axes of a machine tool the measurement of two translations in a plane are common, which is already described and summarised in standards [1] [3]. This is helpful for the interpretation of the deviations from a programmed path.
The simultaneous measurement of five to six degrees of freedom of a linear axis with a straightness standard is described in [4], a later development with laser-interferometers is described in [5]. These systems are mainly used for point-to-point measurements (static mode) parallel to a linear axis.

2 The system KGM+

The system KGM+ allows the simultaneous measurement of six degrees of freedom as a relative movement between the tool side and the workpiece side of a machine tool. The path to be checked has to be nominally in a plane. The plane is preferably situated parallel to a coordinate plane of the machine tool, i.e. in a XY-, YZ- or XZ-plane. Within the plane the path can be freely chosen, it might be linear, circular, a step, etc.

2.1 System-description

The system KGM+ [6] is based on a Heidenhain grid encoder [7] which is a two-dimensional linear scale. With one optical head the two translations in the plane of the grid plate, e.g. X and Y, are measured (Figure 1).
The combination with a second optical head gives the measurement of the rotation in the plane of the grid plate, e.g. C.
In the version used here, the grid plate itself is touched with three linear displacement transducers, i.e. the grid plate is taken as a plane master. The probes are incremental Heidenhain probes equipped with linear scales. By this, the signal processing is identical to the signal processing for the grid encoder.

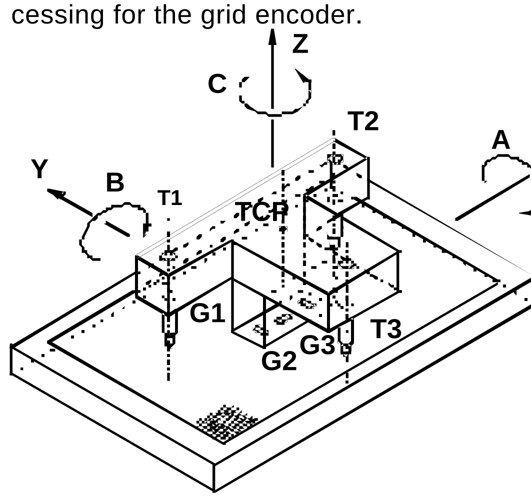

Figure 1: The KGM+ (enhanced cross grid measuring system; Gi..optical head (grid), Ti...linear displacement transducer, TCP.. Tool Centre Point.

Three linear displacement transducers measure the translation square to the grid plane, e.g. the Z-direction, and the two rotations around the axes in the grid plane, e.g. the rotations A and B.
The grid plate is mounted on the workpiece side, i.e. on the machine table. The two optical heads and the three probes are mounted in a fixture which is held in the blocked tool spindle.
The resolution of the grid encoder is 4 nm in its two directions, the resolution of the three linear displacement transducers is 20 nm. The resolution for the rotations depends on the distances between the optical heads and between the linear displacement transducers. In order to simplify the handling of the system, in this version the distances have been chosen as 90 mm and 60 mm, therefore the resolution for the rotation in the grid plate (rotation C) is 0,1µm/m (0,02 arcsec) and 0,5µm/m (0,1 arcsec) for rotations square to the grid plate (rotations A and B).
The area for contouring has a diameter of approximately 120 mm, the allowed travel square to the grid plate is ±0,5 mm. The system accuracy is about ±2 micrometer without applying any compensation. The accuracy for the rotations of this first system is in the order of ±25µm/m (±5 arcsec) for the rotations with no compensation. The maximum feed rate is above 24 m/min. The data, i.e. a set of 6 coordinates, can be read with a frequency of up to 5000 Hz.

3 Application

3.1 General

One application of the system is for testing the accuracy of the programmed paths in all six degrees of freedom at low feed rates. Here the accuracy of the system is of importance and this first version of the system would need some compensation.
Another application is testing the dynamic behaviour of NC drives, e.g. reversal test, test of uniformity of feed, and step-response-test for one axis, testing steps and circular test for two NC axes, as described in [8].
Another application we want to show in this paper, is the influence of the feed rate on the accuracy of a path. Here the deviations at a low feed rate are taken as a basis, and the changes that occur at higher feed rates are looked at. The simultaneous measurement of the six degrees of freedom gives the possibility to detect any cross-talk, i.e. that the movement of one machine axis introduces deviations in other axes or directions.

3.2 Measurements on a machining centre

The principal sequence of the machine axes of the horizontal machining centre under test is shown in Figure 2. The nominal path in the XY plane is a step where each of the single straight lines is 20 mm long. The programmed contouring feed rate is 5 m/min.

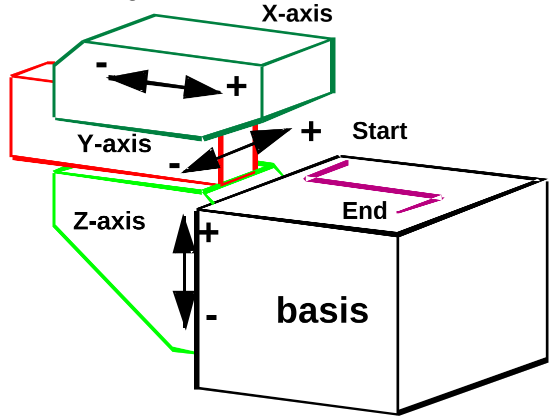

Figure 2: Axis configuration of machine tool

XY-deviations

Figure 3 shows the deviations in the XY-plane. The deviations from the straight lines are up to 52 micrometers due to axis cross-talk.

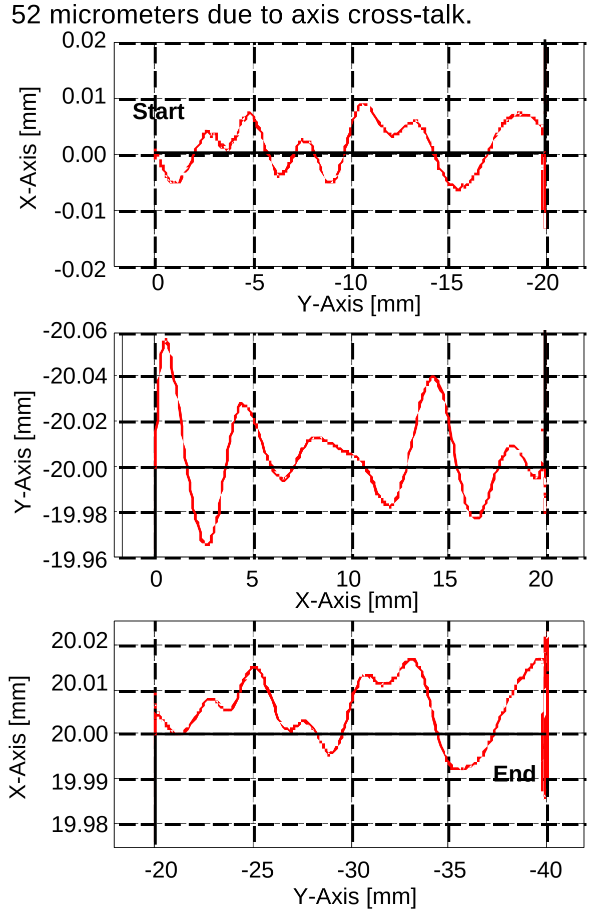

Figure 3: Deviations in X and Y along test path

Already at this velocity (5m/min), dynamic deviations exceed the static deviations by an order of magnitude.

Based on the X- and Y-coordinates which are shown in Figure 3, the velocity and the acceleration along the step can be evaluated (Figure 4 and 5). The velocity shows temporal variations which remain hidden, when being limited to X-Y-representation. A vibration can be observed during the X-axis movement, which can not be detected in Figure 3. The programmed feed rate of 5 m/min is reached with an overshoot of 15%.

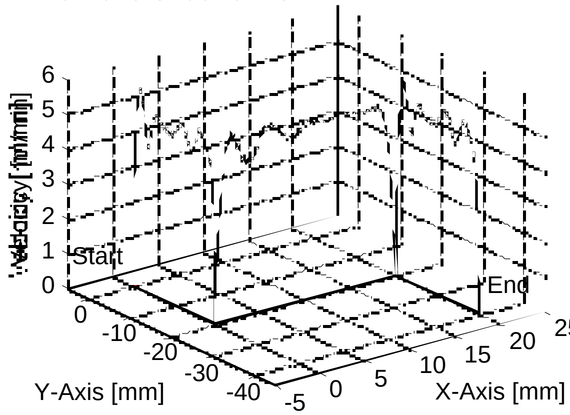

Figure 4: Measured velocity along the path

The acceleration time series (Figure 5) shows the drive-forces acting on the system during these movements. As will be shown later, deviations in Z, A and B have strong similarity with this acceleration curve. By this, acceleration-forces as primary cause for dynamic deviations is verified again.

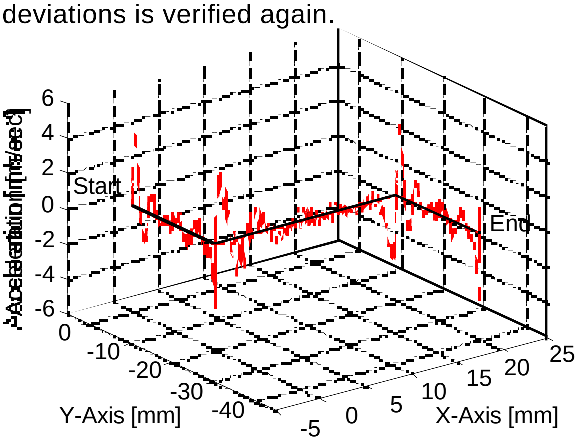

Figure 5: measured acceleration along the path

Vertical displacements

Looking at the vertical displacement, we recognize the effect of acceleration and deceleration of the X movement on vertical displacements. Y-movements show only minor effect on the Z coordinate. Deviations in Z-direction reach 41 µm (see Figure 6) which is the range that could be observed in the X-Y-plane. Whereas the deviations in X-Y-plane are also influenced by axis positioning, overshoot etc., these deviations in Z-direction are exclusively caused by axis cross-talk.

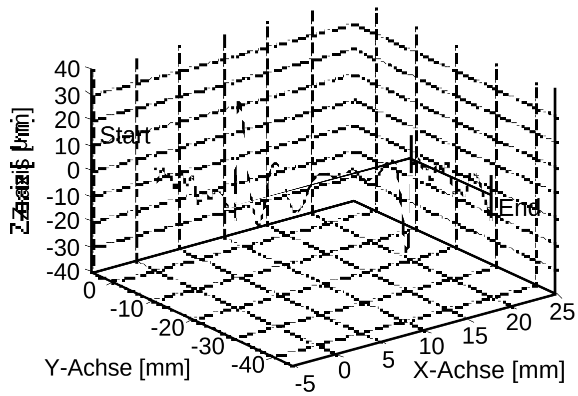

Figure 6: Measured Deviations in Z-direction

Roll, Pitch and Yaw

Looking at the rotation A – a rotation around axis X - we recognize the effect of deceleration of the X movement. The deviation (Figure 7) is up to 290 µm/m (58 arcsec). During Y-displacements, deviations show similarity to the acceleration values at these sections (see Figure 5).

When taking into account the axis configuration shown in Figure 2 and the movements that are to be carried-out here, the A-rotations are obviously resulting from acceleration- and deceleration forces in combination with the actual mass- and stiffness-configuration.

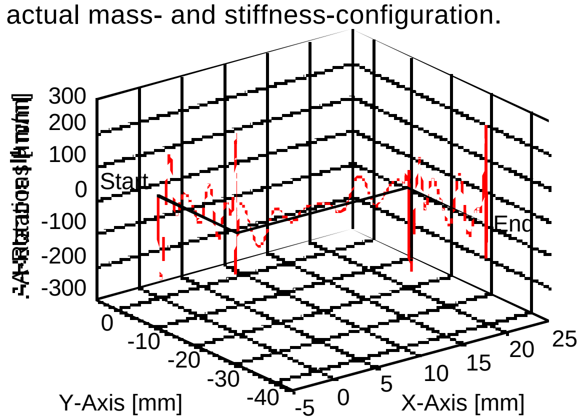

Figure 7: Deviations in A-direction

The B-Rotation – rotation around axis Y – (Figure 8) reaches -125µm/m (25 arcsec). In this case, the acceleration during the X-positioning shows similarity to the measured angular devia-

tions. The vibration, that could be observed on the acceleration values can also be noticed.
The deviations are mainly caused by inertial forces due to accelerations as in the case of Z-, A- and B-deviations

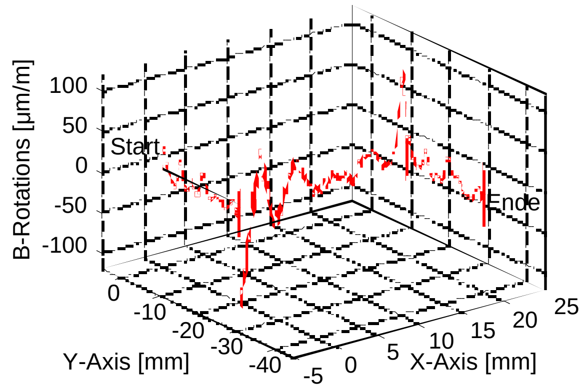

Figure 8: Deviations in B-direction

In contrast to the other rotatory components of motion the rotation in C – a rotation around axis Z - of up to 35µm/m (7 arcsec) has slight similarities to the acceleration values only during sections in parallel to the Y-axis. In this case, the offset between drive-force and the centre of inertia appears to be small in comparison with the other axes.

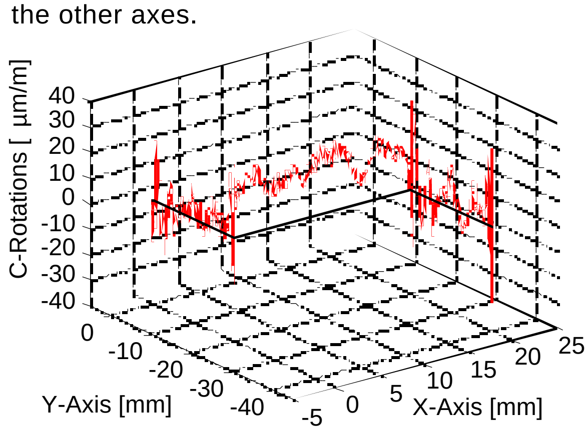

Figure 9: Deviations in C-direction

4 Outlook

Another application of the system will be a long version of KGM+ to be applied for testing linear axes. Here we want to verify the advantage of measuring all six degrees of freedom in one shot, especially at higher feed rates.
Another areas of further work are the improvement of the presentation of the results and the experimental verification of computer simulations to the path accuracy at higher feed rates on machine tools [9].

5 Summary

The system KGM+ for testing the six-dimensional contouring performance on NC paths in one plane is described in its design, resolution, accuracy and limitations.
The principal application for evaluation of the path accuracy of NC machine tools is presented. A practical application of testing the influence of acceleration forces on measurements carried-out on a vertical machining centre is shown.
The system and its application are still under development.

6 Acknowledgements

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