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Calibration of a 3D-ball plate

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ABSTRACT

The presented 3D-ball plate is used for testing machine tools with a workspace of 500 mm × 500 mm × 320 mm. The artefact consists of a 2D-ball plate which is either located by a kinematic correct coupling on a base plate or on a spacer. The spacers are placed between the base plate and the ball plate and are also kinematic coupled to the other elements of the artefact. The kinematic couplings provide a high repeatability of the measurement setup. Because of the specific application the known calibration procedures for 2D-ball plates are not applicable.

A calibration method for the pseudo-3D-artefact on a coordinate measuring machine (CMM) is presented, with the aim to minimise the influence of geometric CMM errors. Therefore a computer simulation is used to analyse the effects of these disturbing errors on the calibration of the ball plate and the spacers. Using a reversal method, the plate is measured at four different horizontal positions after rotating the ball plate around its vertical axis. A couple of the CMM errors, e.g., a squareness error C0Y between the *X*- and *Y*-axis of the CMM, can be eliminated by that method—others have to be determined with additional measurements, e.g., the positioning errors EXX or EYY of the *X*- and *Y*-axis, respectively. The paper also contains a measurement uncertainty estimation for the calibration by use of experiments, tolerances and Monte Carlo-simulations. The achieved uncertainty for ball positions in the working volume is less than 2.1 μm (coverage factor $k = 2$).

1. Introduction

The geometric errors of machine tools influence the accuracy of the produced parts. It is therefore recommended to check the geometric accuracy of machine tools regularly. The presented 3D-artefact enables testing of machining centres with a vertical spindle and a workspace of 500 mm × 500 mm × 320 mm (see Bringmann [1,2]).

The 3D-artefact is based on a 2D-ball plate, a standard tool in calibrating CMMs. To create a 3D-artefact the ball plate has to be repositioned in different known locations. Therefore spacers with different heights are inserted between a base plate and the ball plate (see Fig. 1). The resulting translation and rotation of the ball plate with reference to the ball plate on the base plate has to be well known. With this build-up a pseudo-3D-artefact is created defining a grid of points (embodied by spheres), which positions are measured by the machine tool to be checked [2,3]. With a calibrated artefact the relative errors of machine tools at the nominal positions of a grid can be determined by measuring the individual positions of the spheres. A model of the machine tool with its possible geometric errors is necessary to calculate the real deviations of the machine tool based on the measured grid with an optimization algorithm.

Advantages of this measurement procedure are reduced measuring times, reduced measurement uncertainties as well as volumetric measurement and compensation of geometric errors [2].

Typically, the calibration of a ball plate is done by a coordinate measuring machine (CMM). In DKD [4] a method for calibrating 2D-ball plates is presented: the suggested proceeding is a reversal method for rotating the ball plate around its *X*-, *Y*- and *Z*-axis.

Because of the specific application of the ball plate in the presented 3D-artefact – it is only used in a horizontal alignment – the known calibration procedures for 2D-ball plates are not applicable. A method for calibrating the 3D-artefact is developed. Its backgrounds are simulations, which investigate the influence of geometric errors of the CMM on the calibration.

2. Artefact and measurement device

The artefact is made up of a 2D-ball plate which is either located directly on a base plate or on a spacer.

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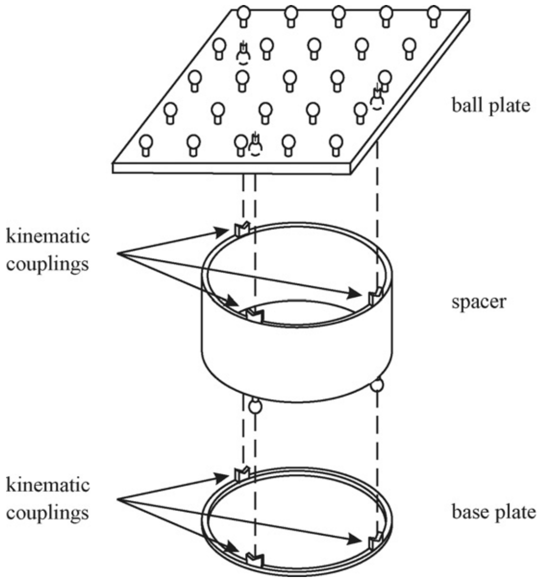

Fig. 1. Schematic measurement setup for calibrating machine tools with a 3D-artefact.

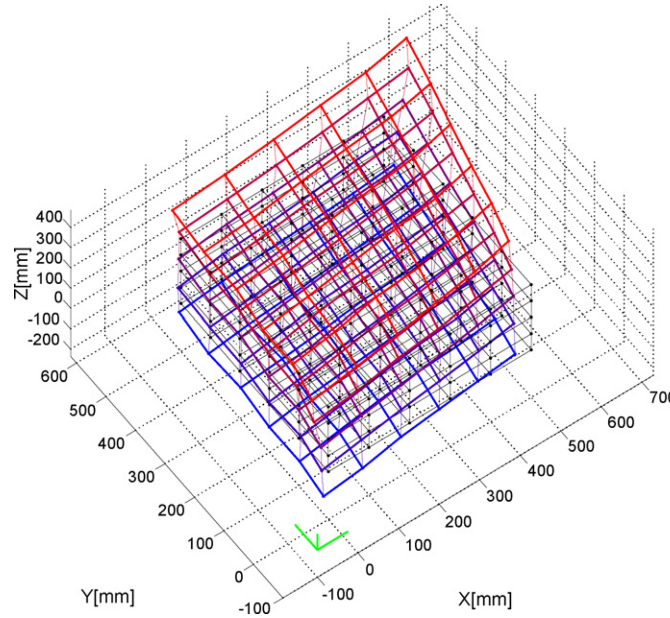

Fig. 2. Exemplary measurements results (magnification 3000×).

The spacers with heights of 80 mm up to 320 mm can be included between the base plate and the ball plate and thus generate a 3D-grid of measuring points (see Fig. 2). With a kinematic coupling between ball plate, spacer and base plate a high repeatability of the measuring setup is obtained [5,6].

The ball plate, a commercially available product and typically used for CMM calibration, consists of 36 spheres creating a quadratic grid with a mesh size of 100 mm. The coordinate system of the ball plate is defined through three spheres in the corners, see CENAM [7]. The coordinate origin is represented by sphere 1, the center points of sphere 1 and sphere 6 define the *X*-axis. The *XY*-plane is defined by spheres 1, 6 and 31 and *Y* is square to the *X*-axis (see Fig. 3).

The measuring device used for calibrating the artefact is a Leitz PMM 864, a CMM in portal design (see ISO [8]). The movement of the table defines the *X*-axis of the machine coordinate system, the horizontal slide moves in *Y*-direction and the centre sleeve in *Z*-direction. Some deviations of the CMM influence the accuracy of the calibration of the artefact. In the following section these deviations are derived.

2.1. Machine errors of the CMM

The geometric errors of CMMs (and also of machine tools) can be classified in location errors and component errors. Location errors describe the position and orientation between two different axis motions, e.g., squareness or parallelism deviations. Component errors describe errors of the moving components themselves, e.g., positioning or straightness deviations. Every component error CE can be described mathematically by a Fourier series:

$$CE(\omega) = \sum_{i=1}^{\infty} A_i \cos(i\omega - \varphi_i)$$

For an exact description of one component error an infinite number of parameters are needed. In the simulation of the geometric behaviour of the CMM (Section 3), the component errors are classified in linear and harmonic errors. A linear error means that the component error increases linearly with a proceeded length. A harmonic error has the form of the corresponding term of the Fourier series. In the following this is marked with (lin), respectively (harm).

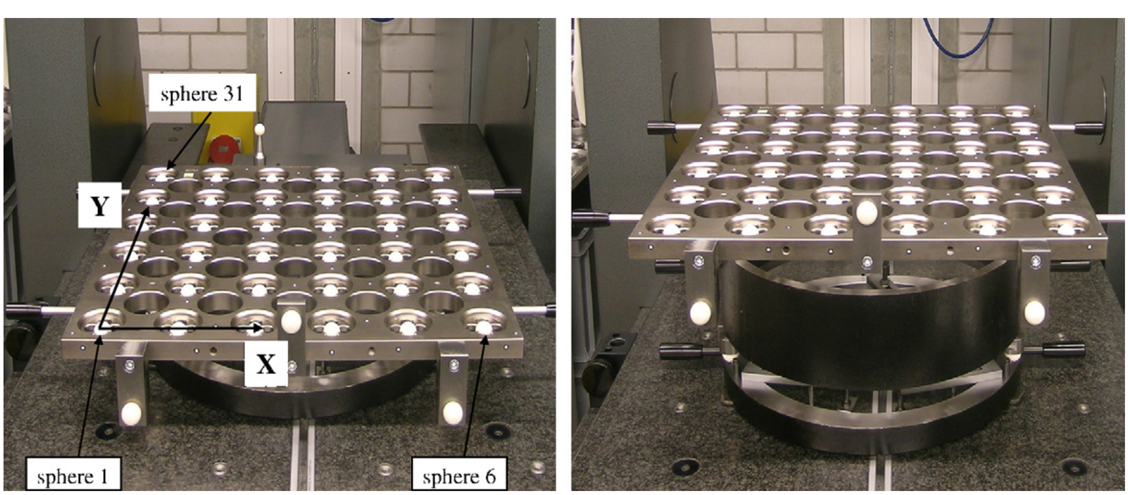

Fig. 3. Ball plate with its coordinate system (left) and measurement setup for calibrating a spacer (right).