Automated Calibration Facility for Accurate Angle Measurements

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Abstract

Accurate angular alignment of production tools and measuring instruments require calibrated angle standards with a low measurement uncertainty. Angle standards are commercially available both as angle gauges and optical polygons. Angle gauges can have an arbitrary angle between its two measurement faces while polygons can have an arbitrary number of faces, say n, but have regular angles between adjacent faces given by the nominal angle of 360°/n. Calibration of these standards is performed using rotary tables or indexing tables and angle measuring devices. Highly accurate measurement facilities are mostly implemented only at national metrology institutes [1]. Until recently polygon and angle gauge calibrations were performed manually at VSL but in 2009 a new facility was finished that enables fully automated calibrations. Automation of these calibrations has the advantage of reducing the effort to execute the laborious calibration procedures while offering the possibility of reducing the measurement uncertainty [2]. The facility is optimized to perform measurements of polygons with up to 72 faces and angle gauges of arbitrary angle.

Polygon calibration

The set up consists of a programmable high precision rotary stage Kugler RT264TB for angular positioning, a set of autocollimators Moller-Wedel Elcomat 2000 for highly accurate angular measurements and a host computer with software that controls the measurement sequence and performs the data acquisition and analysis, see fig. 1. For polygon calibrations the two autocollimators are positioned at a mutual angle close to the nominal polygon angle or at a specific multiple of this angle in order to remain in their most accurate measurement range. The measurement sequence in fig. 1 for polygon calibrations consists of rotating the polygon until adjacent faces are in line with the autocollimators. The errors from exact alignment are then measured by the autocollimators and the procedure is repeated for every adjacent pair of faces until a full rotation has been established. This concept of so-called full circle closure eliminates the need for a calibrated rotary table and provides data to calculate the angular errors for all adjacent polygon faces and the error of the angle between the autocollimators from the nominal polygon angle. The angles of the rotary table itself are not required for the analysis of polygon calibrations. In fact, when the angular positions of the table are recorded the calibration of a polygon also results in calibration data for the rotary table itself at the angles of the polygon. The accuracy for polygon calibrations is therefore fully determined by the stability of the set-up and the accuracy of the autocollimators. The currently established measurement uncertainty for this calibration is 0.3 arcsec (95% coverage) or approximately 1.5 µrad and can potentially be reduced to 0.1 arcsec.

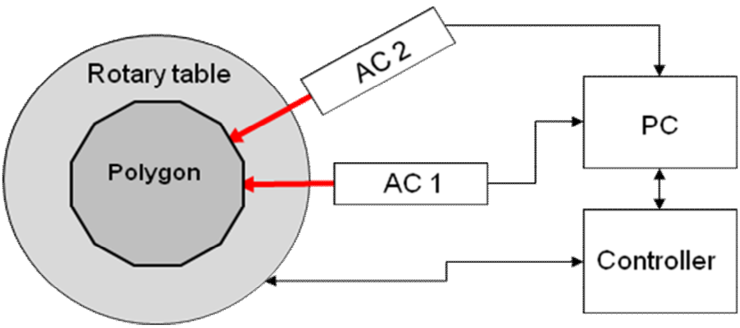

Figure 1: Set up for automated polygon calibrations. The polygon is rotated in steps of the nominal polygon angle over 360 degrees while the two autocollimators (AC) measure the deviations from the nominal polygon angle. Polygons with up to 72 faces can be calibrated.

Angle gauge calibration

In contrast to polygon calibrations the calibration of angle gauges requires the rotation angle of the table as input for the analysis. The set up is shown in fig. 2. The measurement sequence consists of aligning the first measurement face of the gauge to the autocollimator and then rotating the table until the second face is aligned to the autocollimator while recording the alignment errors and the table positions for both alignments. The angle of the gauge is then calculated from the readings of the autocollimator and of the table. The table angle is now part of the calibration uncertainty and therefore the table needs to be calibrated itself. Calibration of the table is performed using a polygon and results in accurate data only at the angles of the polygon. A detailed calibration curve therefore requires a polygon with many faces. The results using a 36 sided polygon are shown in fig. 3 and indicate a typical

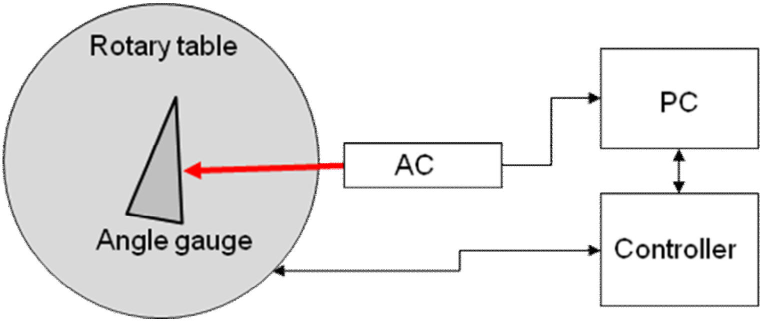

Figure 2: Set up for automated angle gauge calibrations. The gauge is automatically aligned with respect to the autocollimator (AC) at both measurement faces while the alignment error and table positions are recorded.

sinusoidal distortion (with some higher harmonics) of the linearity of the rotary motion as recorded by the optical angle encoder inside the table. The reproducibility of this error is 0.06 arcsec and was measured by evaluating 50 consecutive calibrations. The error curve suggests a rather smooth behaviour for intermediate angles and this was confirmed by repeating the polygon calibration for slightly different positions of the polygon. The good reproducibility provides the opportunity to compensate the measured errors to improve the accuracy of the table while the smooth behaviour allows interpolation between the calibrated points. The result of the compensation is shown in fig. 3 and yields a measurement uncertainty of 0.52 arcsec for a single angle measurement. Using the symmetry of the error as shown in fig. 3, the accuracy of an angle measurement can be further improved by repeating the measurement for different angle positions of the table. Repeating the measurement four times by rotating the table between measurements by 90 degrees reduces the measurement uncertainty to 0.22 arcsec. Using 45 degree increments and measuring eight times results in an uncertainty of 0.18 arcsec. Given this uncertainty for the table, the uncertainty for an angle gauge calibration yields 0.31 arcsec.

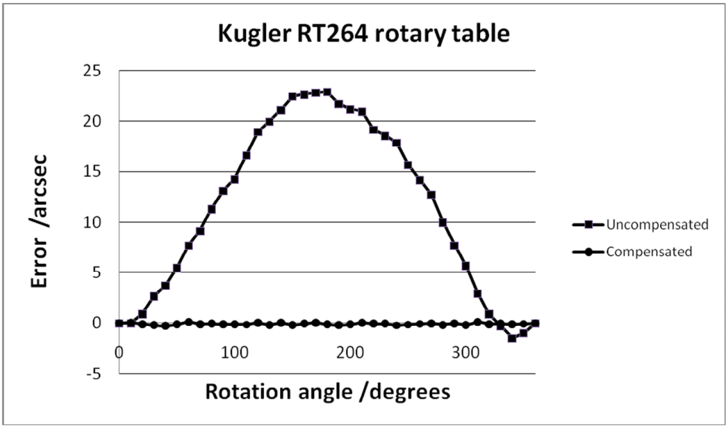

Figure 3: The uncompensated data represent the accuracy of the rotary table without error correction. The good reproducibility enables compensation of the error and improves the accuracy of the table by more than an order of magnitude.

References:

[1] Measurement capabilities of metrology institutes are available via kcdb.bipm.org/AppendixC

[2] Brezina, Grundlagen der Winkelmesstechnik, VEB Verlag Berlin, 1986. ISBN-13: 978-3341000748