Calibration of high-resolution autocollimators against an angle comparator

A. Just , M. Krause, R. Probst, R. Wittekopf

Section 5.23 Angle Metrology

Abstract

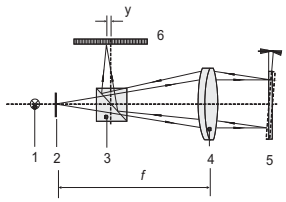
- Calibration of autocollimators (AC) with the aid of the angle comparator (WMT 220)
- Direct traceability to the SI unit of plane angle, the radian (rad)
- Uncertainty of calibration U= 0.007" (k=2) for high-resolution electronic autocollimators
- Main component of WMT 220: divided circle disc with radial phase grating (2^{17} lines in 360°), scanned by eight photoelectric reading heads
- WMT 220: resolution 0.0012"; uncertainty U = 0.005" (k=2)
- Measurement steps down to 0.005" (close to the autocollimator resolution) allow informations about short-period deviations of AC

AC applications

Measurement of small angles by tilt of a plane mirror
- Calibration of angle measuring tables with a precision polygon
- Measurement of straightness, parallelism and rectangularity of machine tools and coordinate measuring machines

Scientific applications
- Experiment for determination of the constant of gravitation G (torsion balance)
- sub-nm-topography measurement by deflectometry

Principle of an electronic autocollimator



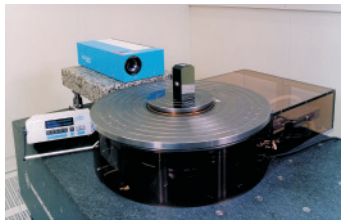
(1) illumination unit; (2) slit; (3) beam splitter; (4) collimator objectiv, focal length f ; (5) plane mirror, tilt angle ; (6) CCD line;

Lateral displacement of slit image: $y = f \tan(2\ )$

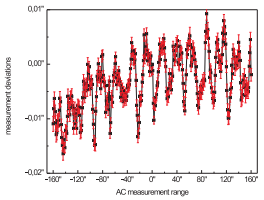
Measurement arrangement for the calibration of a high-resolution electronic autocollimator (AC) on the angle comparator WMT 220 in the Clean Room Laboratory

Measurement setup:
- AC centred to WMT 220 rotation axis on an adjustable granite plate
- horizontal measuring axis and optical axis of AC adjusted in the WMT 220 measuring plane
- plane mirror block (/20) adjusted in the rotation axis
- constant ambient temperature (±0,05K) and laminar air flow

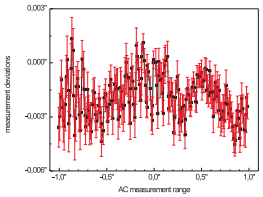
Calibration performance:
- direct comparison with WMT 220
- static measurement by positioning to defined AC or WMT values
- choice of measurement range and specified measurement steps
- readout of 100 single values of both measurement systems (mean standard deviation of single value: sd = 0.001" (WMT) sd = 0.003" (AC))
- two measurement series in both rotational directions (drift 0.003" / 16 hours)
- repeat measurements in different relative positions to WMT 220



Calibration results for a high resolution electronic autocollimator



AC measurement deviations in a range of ±160" in steps of 1"
- Black: mean values of 18 measurements (forward and backward in nine relative positions)
- Red: standard deviations over all 321 measurement points, averaged approx. 0.001"



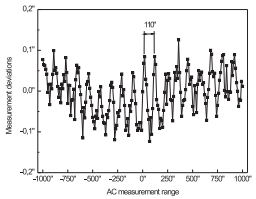
AC measurement deviations in a range of ±1" in steps of 0.01"
- Black: mean value of 12 measurements (forward and backward in six relative positions).
- Red: standard deviations over all 201 measurement points, averages approx. 0.0009"

Measurement uncertainty budget

Type	Uncertainty component	Estimate function	Distribution contribution	Uncertainty
A	Standard deviation of the mean values		Normal	0.0020"
B1	Measurement deviation of the comparator	0.0008"	Rectangular	0.0008"
B2	Uncertainty of the Comparator calibration	0.0025"	Normal	0.0025"
B3	Interpolation deviation of the comparator	0.0006"	Normal	0.0006"
B4	Resolution of the Comparator	0.0012"	Rectangular	0.0004"
B5	Resolution of the Autocollimator	0.0010"	Rectangular	0.0003"

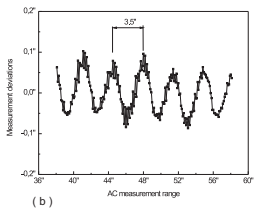
Standard uncertainty u_c = 0.0033"
Expanded measurement uncertainty U (k=2) = 0.007"

Aliasing Effect - Importance of calibration in small measurement steps



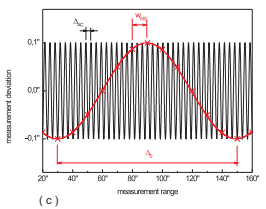
(a)

AC deviations
Measurement range ±1000" in steps of 10",
Deviations approx. 0.1" appearing with a period of 110"



(b)

AC deviations
in a partial measurement range of 20" in steps of 0.1",
deviations approx. 0.1" with a period of approx. 3.5"



(c)

Illustration (c) for the aliasing effect appearing in graphs (a) and (b) : The non-typical long-periodic deviation with $_S$ = 110" (a) results from a real short-periodic deviation $_{AC}$ with the period of 3.5" (b) when using the sampling measurement step W_{ms} of 10"

Physikalisch-Technische Bundesanstalt Braunschweig und Berlin

Bundesallee 100
D-38116 Braunschweig, Germany

Tel. / Fax: +49 531 592 5220 / 5205

E-mail: andreas.just@ptb.de
reinhard.probst@ptb.de