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CALIBRATION ANGLES AT THE LEVEL OF TENTH OF SECONDS

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Abstract: The main purpose of this paper is to show how to reach a high precision in calibration of angle measuring devices for industry. Actually, the demand for use of optical polygons is growing, manly for calibration of CNC machines, and so their own calibration. The article will deal with basic concept and the actual technology, giving information and testing results as well as the evaluation of the uncertainty using "CIRCLE CLOSURE".

Keywords: calibration, angles, uncertainty.

1. BASIC INFORMATION

Measuring angles at the level of tenth of seconds is coming more and more demanding in the industry. The highest level are in the NML's like PTB – Germany; NIST – USA; NPL – England; INMETRO – Brasil, which gives uncertainty, in Calibration Reports, around 0,1".
For angle measurements, it is very fortunate that no standard is required for traceability. All the accuracy relies on the repeatability of the measuring process.
At the Mechanical Metrology Laboratory (LMM) of IPT Metrological Center (CME) the realization of the angle standard has been performed by using an autocollimator DA20 – Taylor Hobson Limited [1], a Moore 1440 indexing table – Moore Special Tool. Inc.[2] and a Precision optical polygon (12 faces) – Starrett - Webber Gage Division [1] , applying the "CIRCLE CLOSURE"[3]. The accuracy is around the tenth of seconds.

2. PURPOSE

The main purpose of the laboratory (LMM) was to improve the ability in calibrating angle measuring devices without using a reference standard but using one update equipment. The goal should be to create the capacity for calibrating reference standards for industry, at the level of seconds to fulfill the needs for the verification of CNC machines which have a forth axel or a rotary table. Precision of 10" are no longer enough. The other point is that the use of the "CIRCLE CLOSURE" is time demanding [3]. The figure 1 shows one arrangement used for calibration either of an indexing table or an optical polygon [1]. The results of similar calibration will be discussed further in this paper, as well as the results of an informal inter-comparison with PTB, showing a very good agreement.

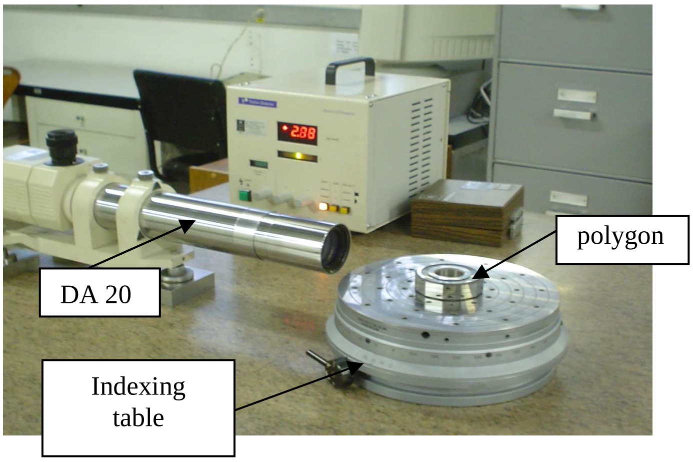

Fig. 1 Calibration assembly

3. METHOD

The measuring method used is the classic "CIRCLE CLOSURE" in which is required that the "measurand" (for instance,. the polygon) and the "standard" (indexing table) are concentrically assembled each other, using the faces as mirrors. Then rotating angles of 30° (=360°/12), each angle of the optical polygon is compared to similar angle of the indexing table.

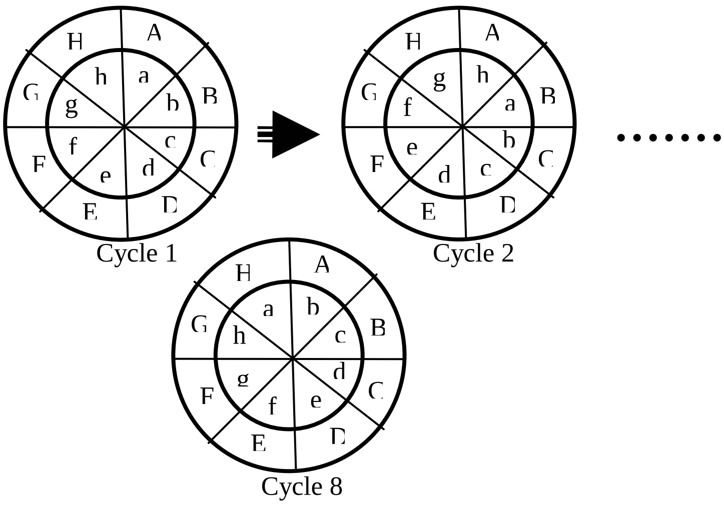

Fig. 2 Sketch of the circle closure

Once one cycle is completed (12 first comparison), the polygon is shifted of an angle of 30° in relation to the indexing table [2]. Figure 2 shows an example for an eight sided polygon. After the last cycle it is possible to calculate the deviation of each angle using the statement that the sum of the angles is exactly 360° or that, the sum of all angle deviations is zero. The algorithm for calculation comes from table 1 and figure 3.

$$n \times A_j + \sum_n \varepsilon_i = \sum_n I_j \quad with \ \sum_n \varepsilon_i = 0 \qquad (1)$$

$$and\ so : A_j = \frac{\sum_n I_j}{n}$$

Table 1 Measuring scheme

Polygon	Angular position of the indexing table							
	I	II	III	IV	V	VI	VII	VIII
a	A	H	G	F	E	D	C	B
b	B	A	H	G	F	E	D	C
c	C	B	A	H	G	F	E	D
d	D	C	B	A	H	G	F	E
e	E	D	C	B	A	H	G	F
f	F	E	D	C	B	A	H	G
g	G	F	E	D	C	B	A	H
h	H	G	F	E	D	C	B	A

All figures a to h and A to H are angles deviations

$$\left.\begin{array}{l}
nxa + A + B + C + D + E + F + G + H = \sum L_{1j} \\
nxb + A + B + C + D + E + F + G + H = \sum L_{2j} \\
nxc + A + B + C + D + E + F + G + H = \sum L_{3j} \\
nxd + A + B + C + D + E + F + G + H = \sum L_{4j} \\
nxe + A + B + C + D + E + F + G + H = \sum L_{5j} \\
nxf + A + B + C + D + E + F + G + H = \sum L_{6j} \\
nxg + A + B + C + D + E + F + G + H = \sum L_{7j} \\
nxh + A + B + C + D + E + F + G + H = \sum L_{8j}
\end{array}\right\}$$

Fig. 3 Basic equation

Using the equation (1)one gets the values of the angles of the polygon.

Each line gives the deviations of the angles of the polygon. If the values were taken from the diagonal one gets, for example :

$nxA = a + b + c + d + e + f + g + h = \sum L_{i1}$ gives the deviation of the angle A of the indexing table, and in this way the "standard" can be checked.

4. RESULTS

To performed this calibration were used one clinometer – Hilger&Watts, model 142/44, type TB-80, resolution 0,2" [1] and one optical polygon – Starrett-Webber Gage Division, 12 faces, grade 0. As reference an indexing table MOORE Special Tool Co.,Inc. model 1440, spacing of 15' and an autocollimator – Taylor Hobson, resolution of 0,02", and range ± 20" were used [4]. The nominated polygon was calibrated by PTB – Germany and the results were compared in order to check the reliability of the LMM´s measurements.

A)Extract of the CALIBRATION REPORT - IPT 45 470

Costumer: Laboratório de Metrologia – DME – IPT
Object: Clinometer – Hilger & Watts
Range: 360°
Resolution: 0,2"

Table 2 Calibration data

Indication (° ' ")	Error (")
0 00 00,0	0,0
30 00 00,0	0,2
60 00 00,0	-0,2
90 00 00,0	-0,4
120 00 00,0	0,4
150 00 00,0	-0,2
180 00 00,0	-0,8
210 00 00,0	-0,3
240 00 00,0	-0,4
270 00 00,0	0,3
300 00 00,0	0,6
330 00 00,0	0,4
360 00 00,0	0,0

Uncertainty: 0,8" at confidence level of 95% and k=2,0

B)Extract of the CALIBRATION REPORT-IPT 45 599

Costumer: Laboratório de Metrologia – DME – IPT
Object: Polygon – Starrett-Weber Gage Division
12 faces
Grade 0

Table 3 Calibration data

Face (N°)	Error (")
1	0,0
2	0,2
3	-0,2
4	-0,4
5	0,4
6	-0,2
7	-0,8
8	-0,3
9	-0,4
10	0,3
11	0,6
12	0,4

Uncertainty: 0,6” at confidence level of 95% and k=2,0

The figure 4 shows the reproductibility of the measuring process, giving the compatibility of the method giving the errors, of the indexing table Moore, calculated from the calibration results of clinometer and polygon.

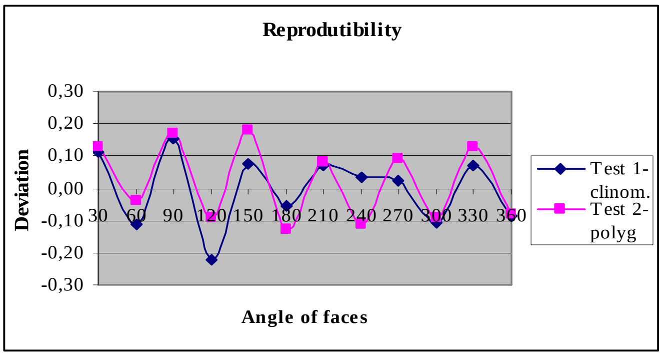

Fig. 4 -Reprodutibility of the indexing table MOORE 1440

The figure 5 shows the compatibility of the method comparing the calibration results from PTB – Physikalisch-Techniche Bundesanstalt.

5. CONCLUSION

To achive the goal, which is measure with a smaller uncertainty, it would be necessary reduce the uncertainty of the autocollimator [3];[5-8] as shown in table 4.

The summary of determination of the uncertainty is showed in table 4.

Table 4 Summary of the uncertainty budget - polygon

Uncertainty budget			
Resolution (mean value)	0,10 (*)	0,06 (**)	infinit
Auto collimator (Namas Certificate)	0,50 (*)	0,25 (**)	infinit
Repeatability	0,06 (*)	0,03 (**)	2
Reprodutibility	-0,07 (*)	0,04 (**)	infinit
Closing error	0,14 (*)	0,08 (**)	infinit
Combined uncertainty		0,275	ν_{ef}
Expanded uncertainty		**0,55**	**822**

(*) Estimators

(**) Standardized uncertainty

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