CALIBRATION OF LARGE SQUARE STANDARDS

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Abstract: *In this paper the principle and device NME 90^0 for large square standards calibration is described. The self-calibration methods of measurement are used. They allow very low uncertainty of the square calibration with mathematical elimination of measuring column straightness deviations. The process of measurement is full automated and controlled by PC, which collects and evaluates measured data. The uncertainties of the square measurement are also discussed in the paper.*

Keywords: *square standard, cylindrical square, calibration, uncertainty*

1 INTRODUCTION

The measuring device NME 90° [1] for calibration of square standards is at present used in the Slovak Institute of Metrology (SMU). This device is designed on the base of device NME 90^0, developed initially in PTB Berlin and transferred to SMU Bratislava in 1996. There was realised total reconstruction of the device here and created software for data collection and processing, which lead to improvement of its measuring properties.

2 PRINCIPLE OF THE SQUARE STANDARD MEASUREMENT

Because both arms (horizontal and vertical) of the square under test have not ideal surfaces, its angle is defined as the angle between two fitting planes. For simplicity, the profile line is used instead of real surface. The fitting line can be determined as a middle fitting line, according to the least squares criterion, or envelope line determined as touch line to the real profile. The angle of the square under test is then defined as the angle between two fitting lines (see Fig. 1).

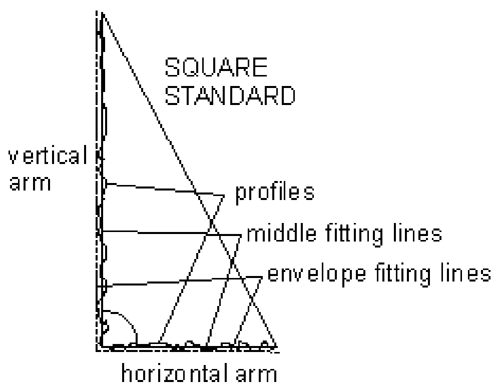

Figure 1.
Square standard – profile and fitting lines

The measuring device NME 90° compares form and angle position of vertical arm of measured rectangular standard with form and position of measuring column. The square standard under test is placed on a granite base plate so its horizontal arm is connected with this plate. The angle of square is defined by fitting line (evaluated from individual measured points on vertical arm) and by horizontal plane, given by granite base plate of device. This determination of square was chosen by constructors of the device, because this way is usually used in industry.

For the measurement of angle standard the well-known method of errors separation technique by means of "self-calibration " (in German region known as "Umschlagmessverfahren") is used. This method allow us to evaluate the profile of square vertical arm without a priori information about the profile of the measuring column. Process of the measurement consist from two steps (see Fig. 2).

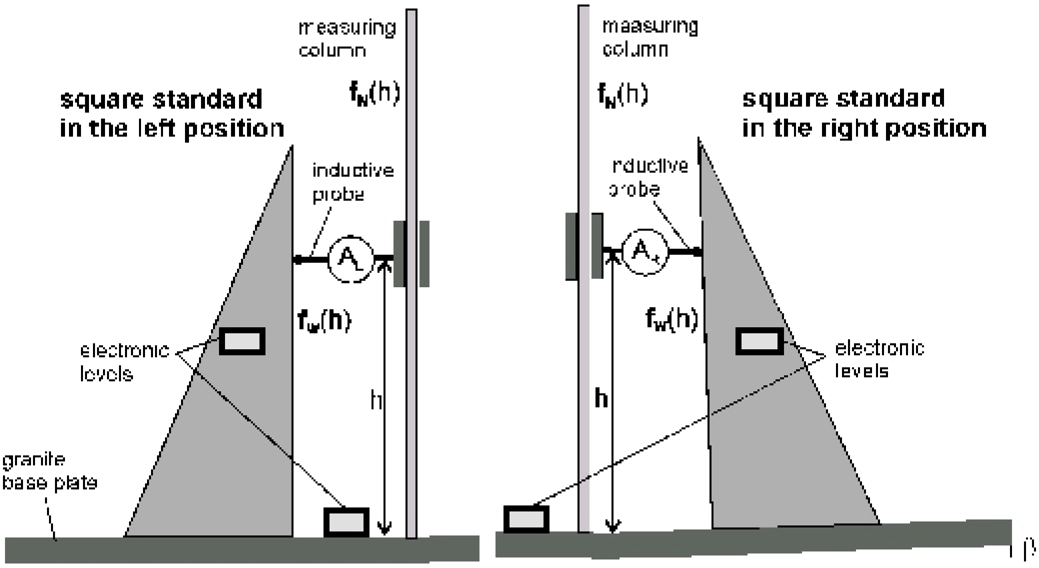

Figure 2. Self-calibration method I. (square standard measurement)

In the first step the square is placed in the left position relatively to the measuring column. When $A_L(h)$ denotes profile of the square vertical arm in the left position measured towards measuring column, than it holds:

$$A_L(h) = f_W(h) + f_N(h) \tag{1}$$

where $f_W(h)$ is profile of the square vertical arm
$f_N(h)$ is profile of the measuring column (a priori unknown device error)
h is vertical coordinate (measured by linear incremental system)
In the second step the same square standard is placed in the right position relatively to the measuring column and profile $A_R(h)$ is measured. For the profile $A_R(h)$ it holds:

$$A_R(h) = f_W(h) - f_N(h) - h \cdot \tan \beta \tag{2}$$

where β is angle of the relative tilt of square under test in the right position relatively to left position.
It is obvious that summing of equations (1) and (2) eliminates a priori unknown profile of the measuring column $f_N(h)$ and for the profile of the square vertical arm we can write:

$$f_W(h) = \frac{A_L(h) + A_R(h) + h \cdot \tan \beta}{2} \tag{3}$$

Now we can evaluate also a priori unknown profile of the measuring column, for which can be written following equation:

$$f_N(h) = \frac{A_L(h) - A_R(h) - h \cdot \tan \beta}{2} \tag{4}$$

3 CYLINDRICAL SQUARE STANDARD MEASUREMENT

Application of previously described self-calibration method in the case of cylindrical square measurement is more complicated. The problem is due to difficulties in placement of electronic level on the cylindrical square (measurement of β).
Therefore the modified self-calibration method II. with auxiliary inductive probe is used (see Fig. 3).

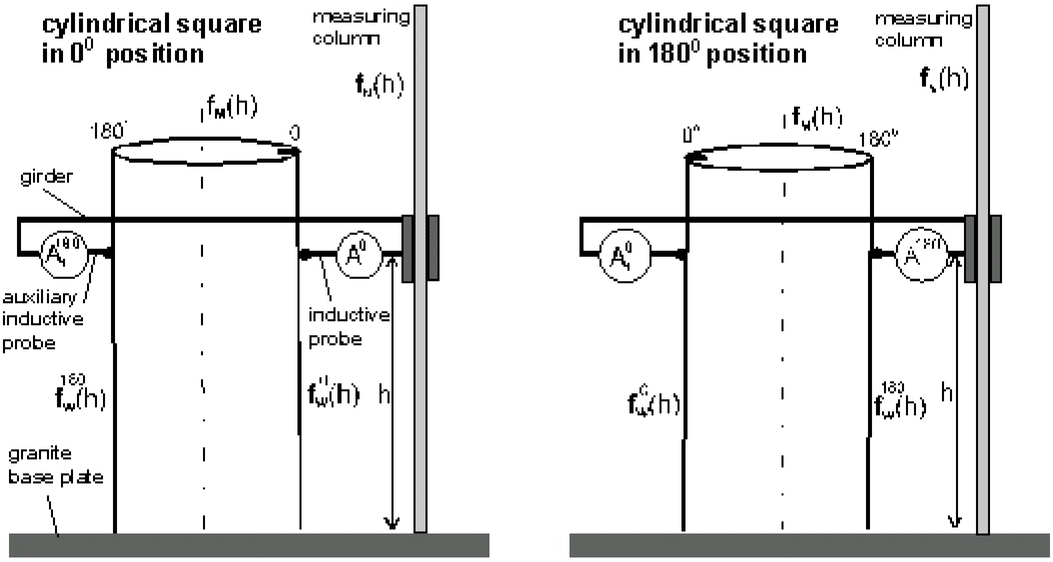

Figure 3. Self-calibration method II. (cylindrical square measurement)

By the application of this method in the first step a cylindrical square is placed in 0^0 position and profiles $A_L^0(h)$ and $A_{LE}^{180}(h)$ are measured by two inductive sensors and linear incremental gauge.
For measured profiles it holds:

$$A_L^0(h)= f_W^0(h)+ f_N(h) \qquad\qquad A_{LE}^{180}(h)= f_W^{180}(h)- f_N(h) \tag{5,6}$$

where $f_W^0(h)$ is vertical profile of cylindrical square at 0^0
$f_W^{180}(h)$ is vertical profile of cylindrical square at 180^0
$f_N(h)$ is profile of the measuring column

In the second step a cylindrical square is placed in 180^0 position and profiles $A_L^{180}(h)$ and $A_{LE}^{180}(h)$ are measured, for which it holds:

$$A_L^{180}(h)= f_W^{180}(h)+ f_N(h) \qquad\qquad A_{LE}^0(h)= f_W^0(h)- f_N(h) \tag{7,8}$$

Summing of equations (5) with (7) and subtraction (6) and (8) gives formula for profile of measuring column:

$$f_N(h)=\frac{A_L^0(h)- A_{LE}^0(h)+ A_L^{180}(h)- A_{LE}^{180}(h)}{4} \tag{9}$$

and for cylindrical square profiles $f_W^0(h)$ and $f_W^{180}(h)$ can be derived formulas:

$$f_W^0(h)=\frac{A_L^0(h)+ A_{LE}^0(h)}{2} \qquad\qquad f_W^{180}(h)=\frac{A_{LE}^{180}(h)+ A_L^{180}(h)}{2} \tag{10,11}$$

A profile of axis of the cylindrical square $f_M(h)$ is often used in the praxis. It is defined as:

$$f_M(h)=\frac{f_W^0(h)- f_W^{180}(h)}{2} \tag{12}$$

and after substitution (10) and (11) to (12) we obtain formula for the searched profile of cylindrical square axis:

$$f_M(h) = \frac{A_L^0(h) + A_{LE}^0(h) - A_L^{180}(h) - A_{LE}^{180}(h)}{4} \tag{13}$$

4 DEVICE DESCRIPTION

Device for the square standards measurement is named NME 90^0. The basis of the device consist from the granite base plate with dimensions (1000 x 2000) mm and with flatness deviation 3 μm. In the middle of the plate a cylindrical guided column is placed. The column is a non moving part of an air bearing. A moving part is built from a ring, which carries a couple of inductive probes and the girder with external inductive probes. Standard measuring range of the inductive probes is ±0.5 mm and resolution 10 nm. To prevent a rotation of the ring it is stabilised by the auxiliary prism and air-vacuum bearing [2]. Here is also linear incremental measuring system (Renishaw) located for the vertical position measurement (measuring range 0-1200 mm and resolution 1μm).

The relative tilt of the angle standard in the left and in the right position is measured by pair of electronic levels. First of them is placed on the granite base plate (reference electronic level) and the second one is placed on the square standard and measures its tilt.

Data from all sensors (inductive gauges, electronic levels and linear incremental gauge) are collected by means of hardware interfaces and specialised software *EZKU* in personal computer, which provides automation of the whole calibration process, preserving of measured data on disks, their numerical and graphical presentation during the measurement, mathematical processing and evaluation of measured data.

Figure 4.
Partial look at the device NME 90^0

5 UNCERTAINTY EVALUATION

There are several main error sources, which determine the uncertainty of squareness deviation measurement results:

- form stability flatness of the granite base plate
- guide stability of moving ring on the guided column
- uncertainty of inductive probes
- slope angle changes on both positions of the granite base plate.

The flatness of the granite base plate depends first on the quality of its manufacturing and also on its installation. In our case there is a granite base plate of 2 m length with flatness deviation of 3 μm. If this value is constant, its compensation enables the differential measurement of slope angle on the both positions (left and right from guided column). More relevant is the flatness change due to temperature differences under and above the plate. These problems are due to the laboratory conditioning and bad temperature conductivity of granite.

The guide stability of moving ring is given by the quality of air bearing. As the quality of the air pressure is guaranteed, the reproducibility of travel moving is sufficient. Position stability of the guide is also under the influence of the base plate flatness and depends on the vertical distance from this plate, as we mentioned above.

Uncertainty of inductive probes measurement depends mainly on the geometrical stability of probes, fixed on the moving ring, because this should define their position to the ring.

The slope of angle β is measured by means of a couple of electronic levels in differential connection. As there is a measurement sensitivity up to 0.01" needed, is the uncertainty of slope angle measurement influenced by micro-vibrations of surroundings and by the zero drift.

On the basis of the described (explained) analysis and a set of calibration measurements a value of extended (k = 2) uncertainty U_C = 0.5" can be obtained for the calibration of large square standards.

With this device, the calibration of the squares (angle standards) with 1200 mm vertical arm length is possible. As the calibration requires the measurement of straightness deviation, enables this device also calibration of straightness standard in vertical position. In this case the value of extended uncertainty (k = 2) of straightness calibration is U_C^L = 0.2 μm.

6 CONCLUSIONS

Described device NME 90^0 allows calibration of large squares (highness of the vertical arm up to 1200 mm) with extended (k=2) uncertainty U_C = 0.5".
Now the work is concentrated on the further improvement of measurement methods and error analysis as well, because in the frame of EUROMET, Slovak Institute of Metrology contemporary co-ordinates comparative measurements of large square standards (EUROMET Project No. 570).

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