ANALYSIS OF NEWLY DEVELOPED METHODS OF ANGLE MEASUREMENT

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Abstract: Testing and calibration of geodetic instruments is a major issue in metrological procedure, having strong impact in precise geodetic and industrial instrumentation.

This paper describes and analyses newly developed angle measurement methods as well as compares both newly developed and classic angle measuring methods.

Several recently developed and enhanced methods of angle measuring systems are presented in the paper.

Keywords: accuracy, angle measurement, calibration methods, precision.

1. INTRODUCTION

Angle measurement is a very important field of science. Many fields of industry rely on precise angle measurements. Angle measurement is one of the leading factors ensuring quality in most fields of industry such as civil engineering and survey, machinery and laboratory equipment. In the field of geodesy total stations are used to measure horizontal and vertical angles as well as lengths.

Accuracy of measurement is the main parameter to be considered while developing or enhancing angle measuring methods. Measurement accuracy depends on instruments, devices and methods used to perform a task.

There are many methods developed for angle calibration. Classical angle measuring methods originating of geodesy and astronomy, such as Wild, H. Bruns, Heuvelink, S. Yelisejev are frequently used to control angle measuring accuracy of geodetic instruments [1]. Most of the methods are used to calibrate flat angles, however experiments show that the accuracy of vertical and horizontal angle measuring systems differ.

There are two circular scales embedded into each total station to perform vertical and horizontal angle measurements. When there is no possibility to measure separate raster scale there are some ways to determine the accuracy of whole angle measuring system which is embedded in the instrument.

2. ANGLE ENCODERS

Since there are two circular scales embedded into each total station, there are two different systems providing information about both vertical and horizontal angular position. Circular scales can be used as the reference measure. They are implemented into the rotary encoders as the main standards for light beam modulation and angle displacement indication. The calibration of these scales is the first step of the accuracy improvement in angle measurement systems.

Rotary encoder is an electromechanical device used to encode angular movement of the shaft or axis of the measuring system to a certain analogue or digital signal. The most common types of angle encoders are: absolute and incremental. Absolute angle encoder has fixed zero position and shows the absolute mean of angular position of rotated shaft (Fig. 1).
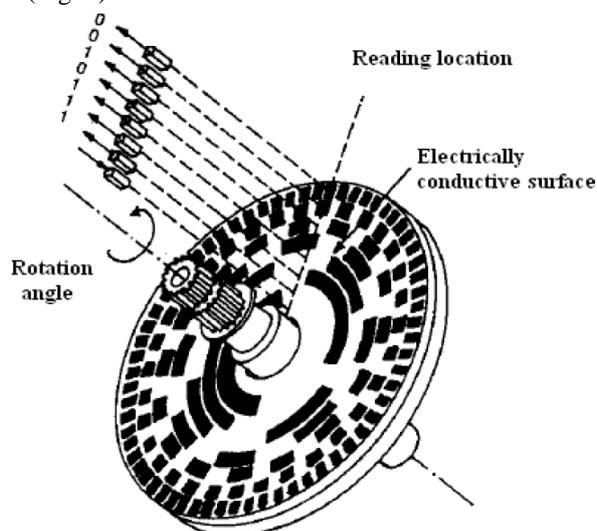

Fig. 1. Absolute encoder

Incremental encoder shows the difference between previous and present encoder position [1, 2].

Digital encoder generates a unique digital binary code for each position of the axle. Rotary encoder has a circular raster scale, mounted on the shaft and divided by many strokes which define angular position with the discretion level of up to seconds of arc. The coded scale consists of concentric circles covered with different sized marks. The pattern generated by the rotation of encoder represents different values. The modulation of the light beam crossing raster scale is the main principle of operation of the rotary encoder (Fig. 2).

Geodetic angle measuring instruments have two angle measuring systems – horizontal and vertical. The main difference between them is the position of the main standard of angle measurement – the raster or coded scale which is placed horizontally or vertically. The instrument operates by pointing its optical system to the object to be measured and taking the readings form the angle measuring systems about the angular position of the object in two perpendicular planes [3]. The vertical and horizontal array boards have the same circuitry but different mounting and packaging.
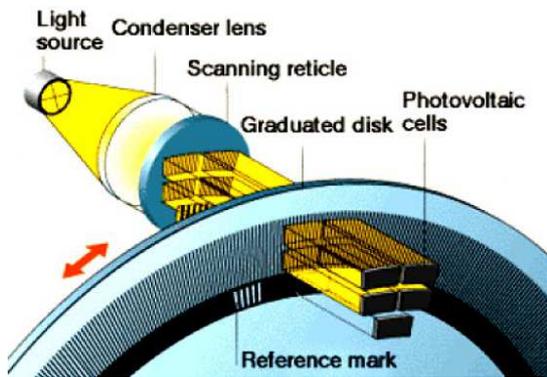

Fig. 2. Principle of operation of incremental angle encoder

3. ANGLE MEASUREMENT METHODS

There are several aspects in performing efficient precision angle calibration:

1. Application of classic angle calibration methods such as method of π angle and method of the Moiré fringes helps to evaluate angle measurement errors;
2. Special high precision equipment for angle calibration is needed to ensure the reduction of measurement errors;
3. The progress of measuring equipment development motivates to improve classical methods or create new methods for angle calibration.

There are many methods used for standard or reference angle measurements. Most commonly used methods, such as method of approximation, method of Heuvelink, method of Wild and method of π angle are related by comparison of angular scale stroke values with values of the reference scale or other standard. This is the most reliable technique in case of reducing the errors [1].

Comparison of the angular position of scale strokes with the reference angle, created by the strokes of the same scale is also called the calibration with setting the constant angle in the full circumference [1,4]. The disadvantage of these methods is that the accuracy of error determination differs depending on the position of the strokes on circular scale.

According to classical method of constant angle placement in the circular scale, the error of circular scale stroke position can be defined as shown in the equation (1):

$$x = \frac{1}{3}\sum\left(x^I + x^{II} + x^{III}\right) \qquad (1)$$

where: $x^I = -\overline{x_m}$, $x^I_{+60°} = \overline{x_{+60°}} - \overline{x_m}$, $x^I_{+120°} = \overline{x_{+120°}} - \overline{x_m}$ are readings of the stroke's position in the scale at different angles.

The standard deviation of stroke position determination error can be defined as shown in equation (2):

$$m_x = \sqrt{\frac{\sum \Delta x^2}{6n}} \qquad (2)$$

where: $\Delta x^I = x - x^I$, $\Delta x^{II} = x - x^{II}$, $\Delta x^{III} = x - x^{III}$.

One of the key factors that has an influence on measurement accuracy is the devices used for this purpose. There are several new methods for angle measuring applied in Vilnius Gediminas Technical University. The method where special centering – leveling device is used as well as microscope can be used to determine the angular position between the strokes of circular scales. The reference scale is placed on the centering – leveling device and positioned under the ocular of the microscope [6]. In this case reference scale is used to determine tolerances of centering – leveling device. When this device is calibrated it can be placed on Moore's Precision Index rotary table to determine the errors of the circular scale comparing it to reference scale.

The results of experiments have shown that errors of this centering – leveling device are minor (1-2 µm) as shown in Fig. 3, therefore, the accuracy improvement of further angular measurements using this device is significant.
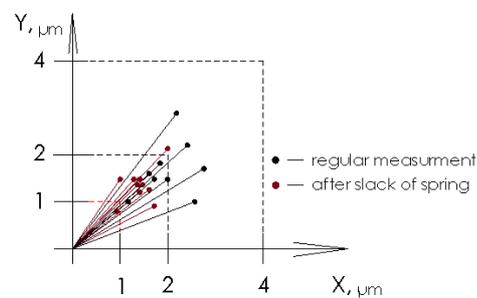

Fig. 3. Errors of centering – leveling device

Other method where rotary table is combined with autocollimators and multi-angular prism is used for flat angle determination. Rotary table was created in collaboration with ETHZ University, Switzerland. This

rotary table is a unique device for its ultra-high precision, developed using mechatronic means for the spindle rotation. The rotary table is controlled by a computer. Piezoelectric drive is fed from the generator of high frequency. The usage of the piezoelectric drive facilitates a very high rotation accuracy of the aerostatic spindle [7, 8]. The object to be measured is placed and leveled on this table.

As an example, this table is used to calibrate horizontal angle measurement system of total stations. The total station is placed on the rotating table. The reflector (mirror) is placed on the top of total station. The autocollimator is positioned that the mirror could reflect its light beam. This is needed to keep total station in the same position while is horizontal scale is being calibrated. The table rotates by desired angle and the total station is turned back to the previous position by the same angle the table was rotated using its own horizontal angle measuring system. Autocollimator helps us to measure the difference between two mirror positions – before rotation and after. The errors are determined by comparing the mismatch of rotation angles of total station and rotary table.

Most of angle measuring methods are suited for measuring flat angles. However, geodetic instruments such as total stations have two angle measuring directions – horizontal and vertical. Therefore, the new method for vertical angle measuring system calibration was developed. This method is based on determining the trigonometric angle by using the reference length scale for vertical readings employing the tacheometer and another reference length scale for the distance from the tacheometer axis to vertical scale determination.

After placing the instrument under control at the initial position, an auxiliary instrument position is achieved by moving the instrument along the slide ways of the test bench for testing geodetic instruments. At distance l from the axis of the instrument, the linear scale is fixed in the vertical position to the horizontal axis of the instrument.

The distance from both positions of the instrument is fixed by using the reference measure of length, for example, end length gauge (length standard) applied for determining the distance from the axis of the instrument to the surface of the scale, which is a quite complicated task to be done initially. At both positions of the instrument, reading h from the scale is taken at the angle φ of the axis of the telescope of the instrument and horizontal line [7]. Readings from the scale are taken and the angle of interest is expressed in equation (3):

$$\varphi_t = arctg\frac{h}{l} \qquad (3)$$

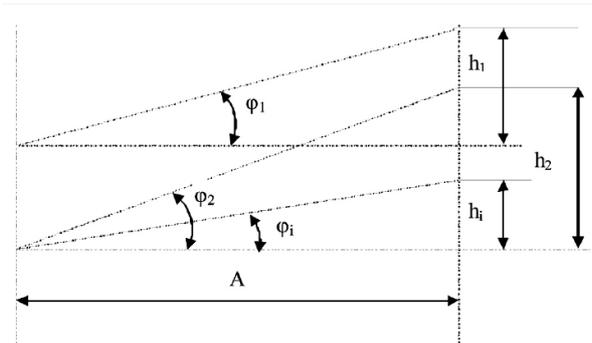The principle of vertical angle measuring system calibration is shown in Fig.4.

Fig. 4. Basic scheme of method of vertical angle measuring system calibration

4. CONCLUSIONS

Analysis of newly developed angle measurement methods has shown that some methods are being improved to measure angles in both vertical and horizontal planes. It is also very important to perform a calibration of circular scale because it is the key component of horizontal and vertical angle measuring systems of geodetic instruments.

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5. REFERENCES

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