

Assumptions for development of the new centering – leveling device

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Abstract. Precision angle measurements are widely used in manufacturing circular scales which are the main component of angle encoders. Accuracy of such encoders have a great impact on production quality, costs and pace in various fields of activity. Therefore accuracy control leads to improvement of production. To evaluate the accuracy of a scale it has to be test and compared to a standard reference. It is achieved through calibration process, requiring complex methodology and equipment. Therefore design of a new centering – leveling device is presented. Moreover, methods and means for encoder scale calibration are discussed as well as the problem of centering and leveling of the scales is presented in the paper. The preliminary results of tilting and centering of the adjusting plates of the device are analyzed.

I. Introduction

Precision angle measurement is a critical part of technical diagnostics used in physical metrology. New precision angle measurement methods are to be implemented in to precision measurement devices as self-diagnostic tools enabling real-time on-site quality control of the performed measurements. Such methods give assumptions for new generation of self-calibrating systems able to perform measurements with minimal deviations from the real situation. Therefore, the implementation of these new methods is the essential part for development of new diagnostic systems for next generation precision measurement devices. The variety of methods and means of circular scale measurements shows the need of precision angle measurements. Constant improvement of measurement accuracy is state of art topicality in the fields of machinery production, rotary angle measurement systems, total stations and circular scale quality diagnostics. The drives of circular scale measuring devices must meet high requirements. Wide range drive for the scale rotation is usually used for the best results. Moreover, very high requirements are applied to the circular scale centering - leveling and linear scale justifying devices which are used to measure nanometric displacement changes of the measuring object. The errors of centering and leveling of circular scale have significant effect on the measurement results. The new centering – leveling device which improves the quality of the measurement results is presented in this paper. The use of angle standards, linear scales and encoder gratings is becoming more common. Improvement and application of microscopy, modern lithography, laser interferometry increase the required accuracy and the efficiency of both line and angle standard calibration [4].

II. Methods of circular scale measurements

Circular scale is an efficient and reliable mean of getting and passing the information about the angular position the object or an axis of measuring instrument. Scales are made of various materials depending on the operational conditions, accuracy and price. The most common way of manufacturing circular scales is by processing glass with the method of photolithography for the pattern application. Circular scales can be implemented in many devices and measuring systems such as rotary encoders, indexing tables, angle comparators and calibrators for the determination of the rotational movement. Rotary encoders are suited for capture of a rotational motion or an axis angle, and can be used for indirect path measurement of linear axes. Mechanical transmission element, converts the rotational motion of the drive (motor) into a linear motion of an axis. Nonuniformity of the scale pattern and the eccentricity of the pattern or irregular shape of the scale can cause big measurement errors as well as other factors such as scale installation on the measured rotary axis, the scanning head alignment and signal processing circuits [7]. Scale pattern errors appear during the manufacturing process of the scales. During the calibration process the circular scale division errors are determined. Most common way to determine the errors of the scale pattern is comparing it with the reference scale [8].

A. Classical circular scale measurements methods

The reference angle of 180° can be created by the means of circular scale, two opposite positioned microscopes and the axis for the scale rotation. By the adjusting microscope's position in the tangential direction, such

position can be achieved. The first microscope is set on the geometrical axis of the stroke at the zero position. The second microscope then shows the reading which is equal to the error of the opposite stroke. The third microscope is set on the stroke of the scale at the measurement pitch. The measurement is performed by rotating the scale by the pitch and taking readings of first and second microscopes until the scale strokes reach opposite microscopes. This half circle measurement method can be simplified by using stroke symmetry method. In this case, the readings are taken only of the third microscope while the opposite strokes of the scale are under first two microscopes and their values are equal but opposite signs. The method of constant angle repetition can be performed by creating the reference angle using the microscopes and repeating it constantly while rotating the scale. The readings should be taken after every angular displacement. Moire method is based on overlaying two circular scales. One of the scales is set as a reference scale and the other scale with different number of strokes or their angular position is rotated above it. Both scales must be concentric. Due to the mismatch between both scales strokes the regular pattern can be seen while rotating the scales. While scanning the rotating scales the output signal describes the nonuniformity of the pattern. Moire fringe patterns can be effectively used in angular measurements for the determination of the angular stroke position determination. To perform such measurement methods there is a need to use high precision rotary tables, autocollimators and multi-angular prisms and microscopes. Therefore, there are precision angle measuring systems combining all these accuracy improving components. However, to ensure the best results, the calibrated scales must be precisely leveled and centered along with adjustment devices used while performing the measurements [1].

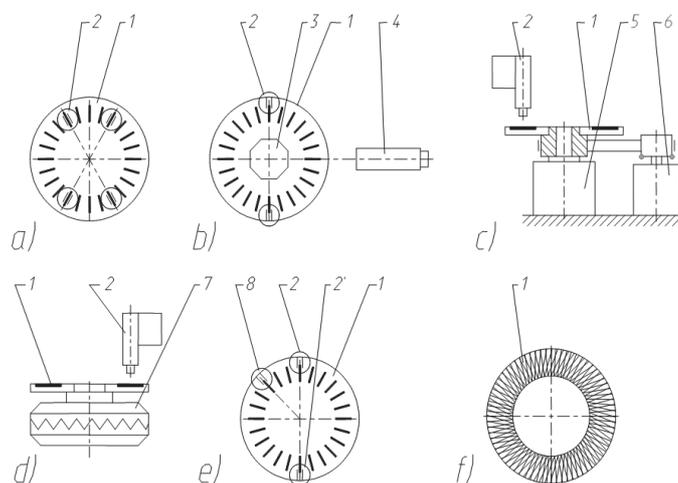


Figure 1. Methods for circular scale measurement:

- a) - constant angle repetition and using 4 microscopes in circular scale; b) –calibration using prism, autocollimator and 2 microscopes; c) – rotating and comparing transmitted signals during the standard time intervals; d) – calibration while comparing strokes with precise Moore Indexing table standard; e) – calibration while using three microscopes; f) – the method of Moiré pattern

The parts of the circular scale measuring systems shown in Figure 1 are: 1 – circular scale to be calibrated, 2, 8 – stroke’s position reading device, 3 – multi-angular prism, 4 – autocollimator, 5 – rotation axis, 6 – gear, 7 – Moore Index table. Reference angle used in the diagram is: constant angle placed in the circle (a), multi-angle prism – polygon (b), standard time intervals at which the pulses from the microscope are compared (c), standard angle values fixed by the Index Table (d), constant angle formed by three microscopes (e) and geometry of Moiré fringe pattern created by reference raster scale and the scale to be measured [2, 3].

B. Modern circular scale measurements methods

The newest circular scale measurement methods are based on circular scale pattern scanning technologies. As it is described in [6], the rotating circular scale covered with photosensitive layer is being read by the laser beam directed to a micro-lens which helps to point the beam to the pattern of circular scale. The measuring system is controlled by PC. The technology of angular measuring structures by laser pattern generators with circular scanning provides the formation of scales and limbs with a number of marks of more than 36 000 reaching the scale error of 1,5 arc seconds. Moreover, this error can be reduced by improving balancing, centering and leveling of the scale during the measurement process. There is also a laser measurement system developed

comprised of laser head, interferometer, receiver and measurement electronics. While performing measurements with this high precision measuring systems (the measurement accuracy varied from $0,02\mu\text{m}$ to $0,14\mu\text{m}$ depending on the measuring speed) controlled by computer arising of error – related problems caused by angular deviation of the microscope and the scale was noticed [4].

Therefore, to avoid such problems a special centering leveling device was developed at Vilnius Gediminas Technical University.

III. The centering – leveling device

There are many positioning devices developed to increase measurement accuracy. The centering – leveling device developed at Vilnius Gediminas Technical University is used for justifying, leveling and centering measured object to perform more accurate measurements. This device can be implemented into other precision measurement systems, for example, it can be attached to a rotary indexing table with the circular scale on the top of it. While performing measurements with microscope or laser reading system, the position of the scale can be slightly changed by leveling and centering it. This device consists of the frame, justifying plate, micro-displacement bushing, leveling and centering screws, springs and spherical parts.

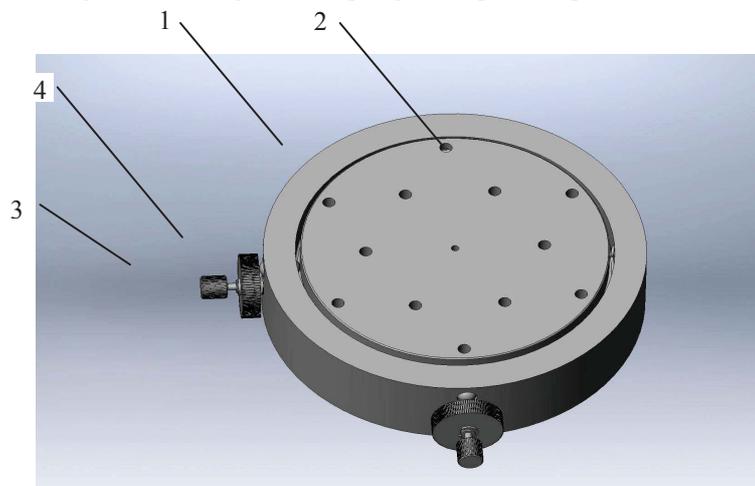


Figure 2. Main components of centering - leveling device.

As it is shown in Figure 2, the main components of centering – leveling device are: 1 – the frame of the device, 2 – adjustment plate, 3 – leveling screw, 4 – centering screw. Autocollimators are widely used in precision angle measurements. They perform exact optical–visual or photoelectric measurements of small angles of tilt of a reflecting plane mirror. They are used in many fields of industrial and dimensional metrology, for example to calibrate angle measuring tables with the aid of precision polygons or to measure the straightness, parallelism and rectangularity of machine tools and coordinate measuring machines.[5]

To determine leveling resolution of the device the mirror was placed on the top of the device. The autocollimator was directed to the mirror as it is shown in Figure 3.

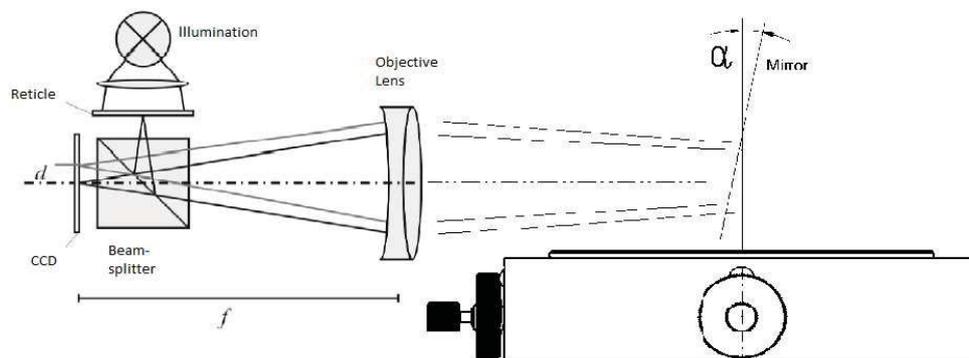


Figure 3. The principle of levelling using autocollimator.

By adjusting left and right leveling screws separately the minimum step of vertical movement of the adjusting plate was defined. According to the readings of the autocollimator the angle by which the mirror was shifted is

known and can be expressed as it is shown in Equation 1:

$$\alpha = \frac{d}{2f} \quad (1)$$

Where: α – angle, d – difference between two positions of reflected beam, f – focal length of the autocollimator. The experiment has shown that the minimum tilting angle can reach up to 2,75 seconds of arc by adjusting left leveling screw and 3,2 seconds of arc by adjusting right leveling screw (Fig. 4).

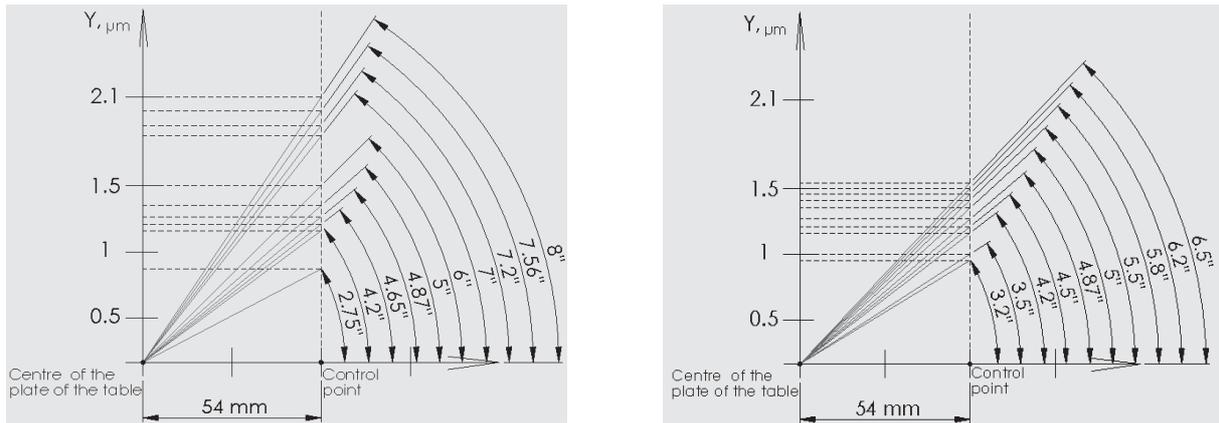


Figure 4. The results of leveling of centering – leveling device by adjusting left leveling screw (on the left) and right leveling screw (on the right)

During the experiment the minimum horizontal movement of the adjusting plate was determined. The results are shown in Figure 5.

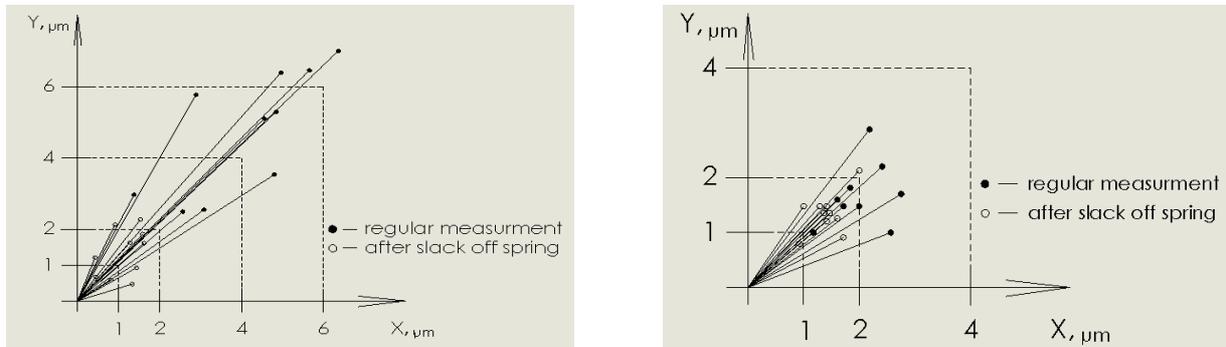


Figure 5. The results of centering of centering – leveling device by adjusting left centering screw (on the left) and right centering screw (on the right)

As we can see from Figure 5, the pitch of adjustment plate horizontal movement varied from $1,5 \mu\text{m}$ to $6,5 \mu\text{m}$, however after the slacking the spring off the pitch decreased and varied from $0,8 \mu\text{m}$ to $2,5 \mu\text{m}$ while adjusting the left centering screw. Measurement results while adjusting right centering screw showed that the peak value of the pitch can reach up to $1,5 \mu\text{m} - 3,0 \mu\text{m}$. To minimize both centering and leveling pitches further mechanical improvements are planned and will be presented in future publications.

IV Conclusions

Analysis of classical and new circular scale calibration methods led to an assumption of the need of better tilting and centering of the scales while performing the measurements. Therefore, the new adjustment device was

suggested to solve such problems.

Experimental results showed that minimum tilting angle reaching up to 2,75 arc seconds and minimum centering pitch of less than $1\mu\text{m}$ is possible to achieve.

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