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PECULIARITIES OF PRODUCING AND MEASURING CIRCULAR SCALES

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Abstract. The paper deals with investigation into manufacturing circular scales and its accuracy evaluation methods and means considering the new development of production and measurement methods based on advancing laser instruments. The article describes the results of recently conducted analysis and presents initial trials of applying them in practice.

Keywords: angle, circular scales, displacement, determination, laser measurement.

1. Introduction

Laser instruments are widely used as manufacturing and measuring tools. Laser scanners are widely used in geodesy, structural and machine engineering areas. Such application gives new opportunities for measuring the length and angle position of an object in such places and positions where measuring instruments used for a general purpose are not available or have no possibility of application. The paper presents the methods of manufacturing circular scales for determining the angular position of the rotating part of the instrument and looks at some results of employing the laser instrument for producing and measuring scales. The issues of producing and measuring circular scales are discussed in the majority of cases as they are less covered in technical and scientific literature.

The tasks of testing and calibrating angle measuring instruments are quite important since a number of angle measurement devices are employed in many branches of industry. Generally, there are several groups of plane angle measurement methods that could be successfully implemented (Giniotis 2005):

1) solid angle standard method – polygons (multiangular prisms) or angle gauges used for comparing the accuracy of the object under measurement;
2) trigonometric methods are applied when the standard angle is set by means of linear values;
3) circular scale method is put in practice for determining plane angle comparing it with the etalon scale or using a full circle with two, three or four microscopes.

The calibration of the angle measuring instrument is usually performed by means of comparing the instrument under testing against the reference measure or reference instrument. Several technical decisions for angle determination can be implemented. The most significant means used for creating a reference measure consist of:

– polygon/autocollimator;
– Moore Precision Index table;
– circular scale/microscope(s);
– angular encoders;
– ring laser (laser gyro);
– interferometric angle generator.

There is a need for using an expensive and complicated centring – levelling device for the alignment (centring and levelling) of the reference measure and an object to be measured. Additionally, in some cases (as with polygon/autocollimator), only a limited number of angular positions could be tested which is typical using Moore's Precision Index or the circular scale as the entire process of calibration can hardly be automated. Some methods cannot be implemented under industrial conditions.

Various types of circular scales are used in rotary encoders or angle measuring instruments in geodesy (Ingensand 1990; Katowski, Salzmann 1983). Some examples of circular scales are shown in Figures 1, 2 and 3.

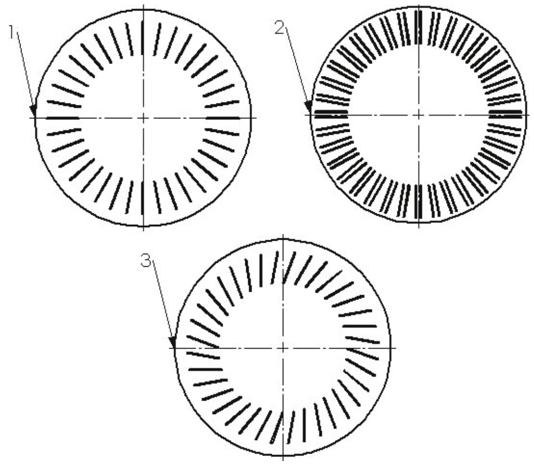


Fig. 1. Some types of circular scales: 1 – raster scale, 2 – scale with double (bifiliar) strokes, 3 – raster scale with decentring strokes

Fig. 2. Real examples of circular scales

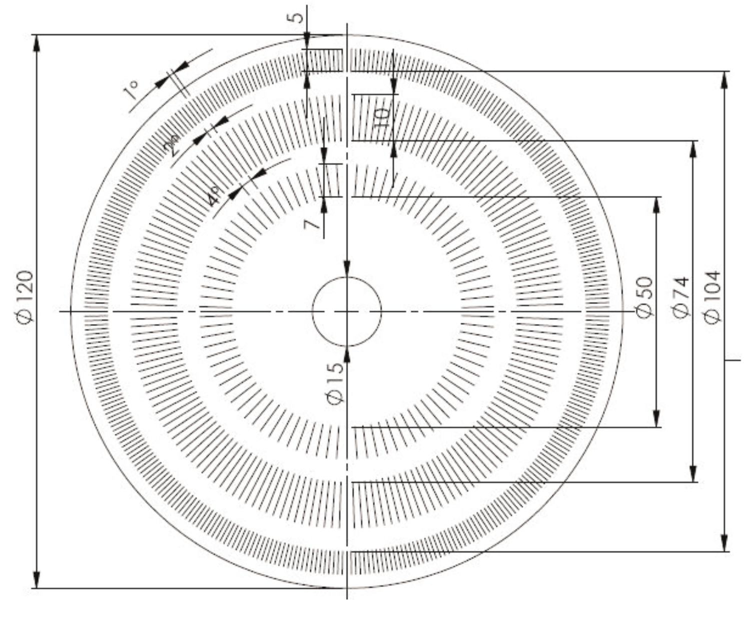


Fig. 3. Drawing a circular scale for experimental laser-cutting

2. Development of producing circular scales

Forming circular scales of high accuracy is based on the classical principles of mechanical cutting and the cutters supplied with artificial diamond tips. Later development was elaborated using photolithographic methods and means using a cutter to cut the layer of photoresist material plating on the surface of the disc. After cutting, the strokes are formed using chemical materials for etching the strokes on the surface of the scale. These methods were further improved using DIADR, AURODUR and other technologies.

Many advantages offer the use of laser cutting technology for developing circular scales (Kiryanov *et al.* 2006). The examples of the scales made by raster scanning technology are developed in the Siberian Branch of Russian Academy. The formation of structure is performed by raster scanning on the surface of the disc rotated on the surface of the rotary table. The authors point to a high accuracy of the raster scale made following this principle.

There were first trials for laser cutting of the circular scales made in the course of this research. Drawing trial scales of laser cutting is shown in Fig. 3. Some trials of laser cutting on various surfaces of the disc were conducted and examples are shown in Figures 4, 5, 6 and 7. Some trials were carried out on the CD surface changing the power of the laser cutter and positioning of the disc.

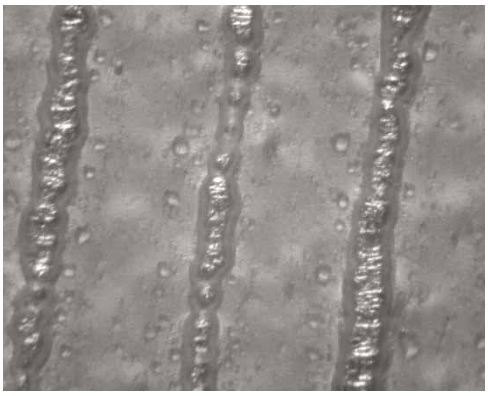
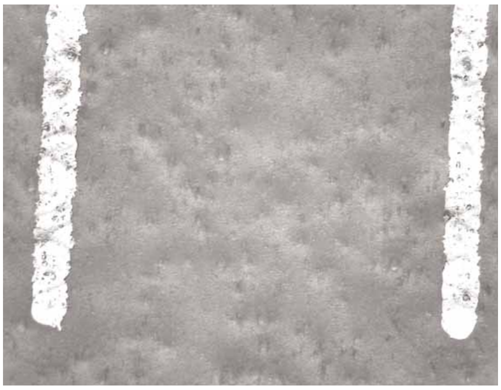
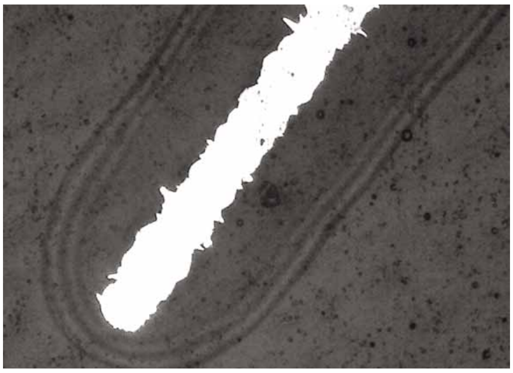


Fig. 4. Strokes of the scale made by the extensive power of the laser cutter

a)

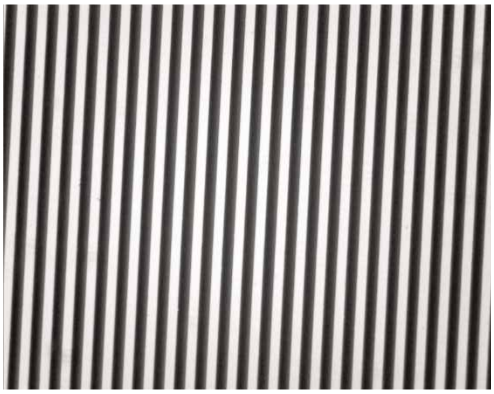


b)

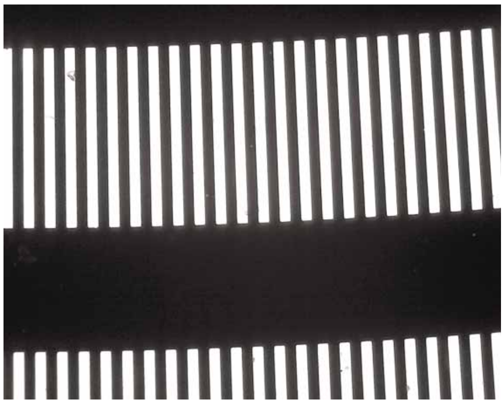


c)

Fig. 5. Further trials (a, b and c) using different laser charge power and positioning means



a)



b)

Fig. 6. Rastre scales made by litographic means: a) linear scale; b) circular scale with a dual track

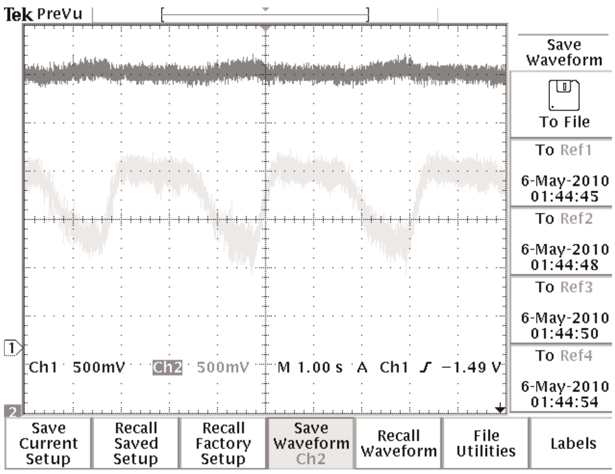


Fig. 7. CD with a periodic record and additional noise waveform. CD surface without the record

3. Circular Scale Calibration

The main methods of circular scale calibration are described in (Bručas *et al.* 2010; Bručas, Giniotis 2008; Giniotis *et al.* 2004a). More interesting methods for calibration are those using laser instruments (Sharp 2009). Also, new developments in circular scale calibration are presented in (Sharp 2009; Giniotis 1997, 2002). The use of optical (including laser) means and methods offers a possibility of achieving high quality and quantity information about the accuracy of the raster scale. This parameter can be assessed applying information entropy for evaluating the accuracy of the raster scale.

Considering the theoretical basis for the information theory and some ways of applying it (Giniotis *et al.* 2004b), full information entropy would be expressed as:

$$H_0 = -\sum_{\Delta} \log_a \frac{1}{m} = \log_a m. \quad (1)$$

It is based on the fact that when a variable has discrete values m, the entropy is maximised and distribution is homogenous since completely homogenous distribution has maximal entropy when all values have the same probability. The simplest demonstration of this fact is provided by binary random variables distributed uniformly when their probabilities are equal to 0.5. Such statistical evaluation is valid for measuring systems when in case of monitoring only predetermined parameters are selected and its values are set within particular limits. Information received after calibration, i.e. the expression of the accuracy of a part of the scale will be:

$$H_1 = \log_a b, \quad (2)$$

where $b = m/k$ is the number of calibrated strokes on the scale. These strokes were measured $\boldsymbol{c}$ times each for statistical evaluation. Then, reduction in information uncertainty (indeterminacy) due to the information received (Giniotis *et al.* 2004b) is:

$$I = H_0 - H_1 = \log_a m - \log_a b; \quad (3)$$

then

$$\log_a b = \log_a m - I \text{; and } b = a^{(\log_a m - I)} = m \times a^{-I}.$$

In case of using the laser measuring head to control accuracy, equation (3) becomes

$$\log_a m - \log_a m = 0.$$

It means that the indeterminacy of the accuracy parameters of the scale is eliminated. The problem is the use a reference measure – etalon for calibration. For this purpose, a high accuracy laser gyro or rotary encoder can be used.

4. Conclusions

The analysis of laser methods and means for circular scale production and accuracy control shows strong possibilities of using them for such purpose.

The equations derived for information entropy assessment show the advantages of assessing the results of calibrated scales. This approach gives more information about the measuring process and the accuracy of the scales.

Further tests should be performed both in the field of scale manufacturing and for the accuracy assessment of the scales. Some improvements could be made taking into account the above mentioned methods allowing an increase in the accuracy of scale production and measurement.

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