ADJUSTMENT AND EVALUATION OF INCREMENTAL OPTICAL ROTARY ENCODERS

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ABSTRACT

The subjects of this paper are incremental optical rotary encoders and methods for a minimizing of measured errors of the controlled process of rotary encoders. This paper presents centering methods for incremental optical rotary encoders. In general, there are two methods to adjust optical rotary encoders. The first method deals with a centering mark and the second method bases on analogue signals from oscilloscope. In addition, the paper describes measuring methods and equipment for the automated accuracy control of optical rotary encoders and a method for compensation of measured errors. The paper presents a novel special coupling device for control encoders. The design of the novel coupling device provides an unrestrained connection between controlled and reference encoders. The elaborated experimental setup increases the calibration accuracy of rotary encoders considerably.

Index Terms - rotary encoder, incremental encoder, angular displacement, code wheels, eccentricity, coupling.

1. INTRODUCTION

The field of application rotary encoders is the wide range of technological equipment. The technological accuracy of rotary encoders determines a geometric accuracy for technological movements in the workspace. The applications of rotary encoders in industry improve a degree of automation of the production process, productivity and a quality of the product. That is why the rotary encoders have high requirements on accuracy and operating speed. In this regard (In this context), the first problem is the problem of adjustment and subsequent control of rotary encoders.

2. ADJUSTMENT

Fundamental errors of incremental optical rotary encoders based on circular pattern and coding wheel, are eccentricity, geometric errors of the circular pattern and radial runout of the bearing.

Eccentricity (Δe) is a mismatch of the centre of rotation to the center of the circular pattern or coding wheel (Fig. 1). This can be described by an equation such as

$$\varphi_{\ e} = [\sin \theta_H - \sin(\varphi + \theta_H)] \cdot \ e/R$$

where θ_H is an initial direction of eccentricity, φ is the angle of rotation of the circular pattern from initial to current position, R is the working radius of circular pattern.

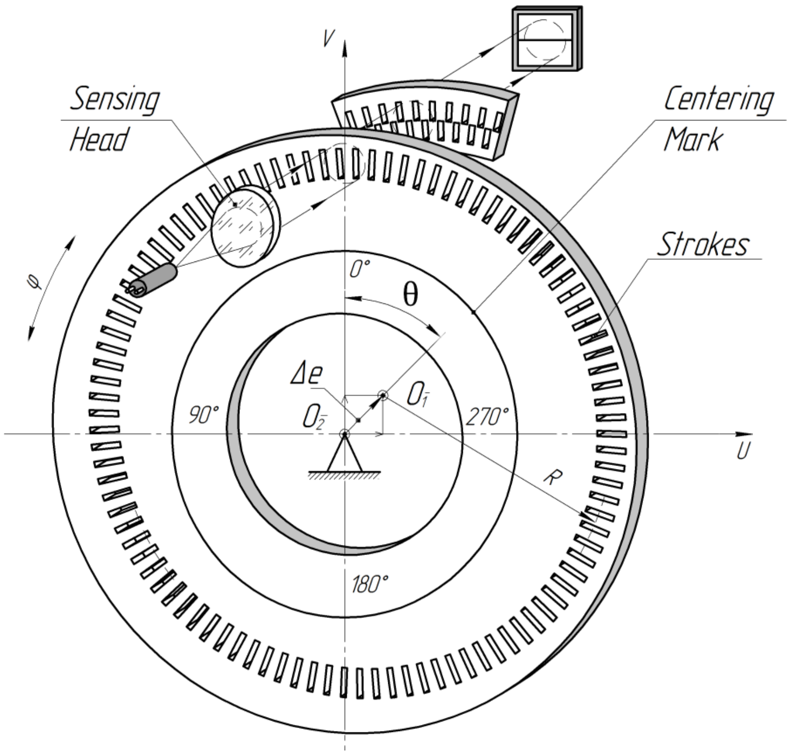

Fig.1. Eccentricity (O_1 is the center of scale, O_2 is the center of rotation, Δe is eccentricity, θ is a phase angle)

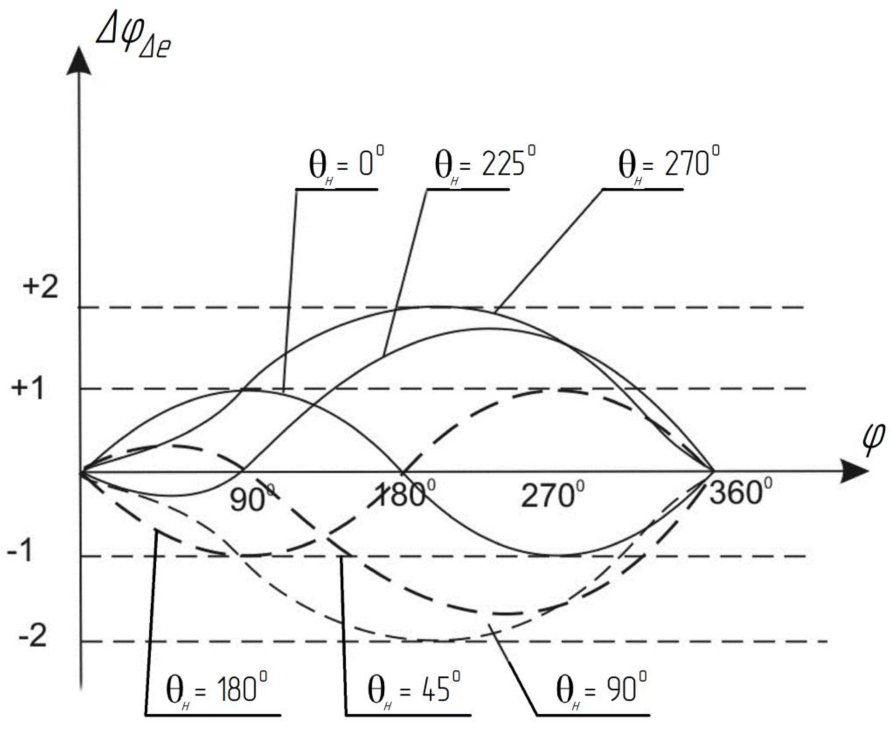

Fig.2. Eccentricity - dependency of the initial phase of the eccentricity vector.

The eccentricity depends on the initial phase of eccentricity vector and has a periodic time equal to 2π (Fig. 2). In order to decrease the eccentricity by assembly the circular pattern is centered relatively to the axis of rotation using a centering mark in form of a ring that has been generated concentric to the circular pattern in one process. Centering can be effected by automatic adjustment machines with high performance and accuracy [1]. The principal functional scheme is shown in Fig. 3.

As a result of an eccentricity of the circular pattern also the centering mark will show the same radial displacement, while the mechanical axis *1* is rotating. A microscope objective *2* generates an image of this centering mark on the CCD *3*. Based on this information the piezoactor *4* is actuated to shift the circular pattern in the centered position. Subsequently, the centered circular pattern is fixed with photopolymerizable adhesive (UV adhesive) under the exposure of ultraviolet light *5*. Form deviations of the ring mark, differences of the position of the ring mark relative to the working tracks, bearing radial runout and further errors of the microscope and piezoactor system are causes for a residual centering error.

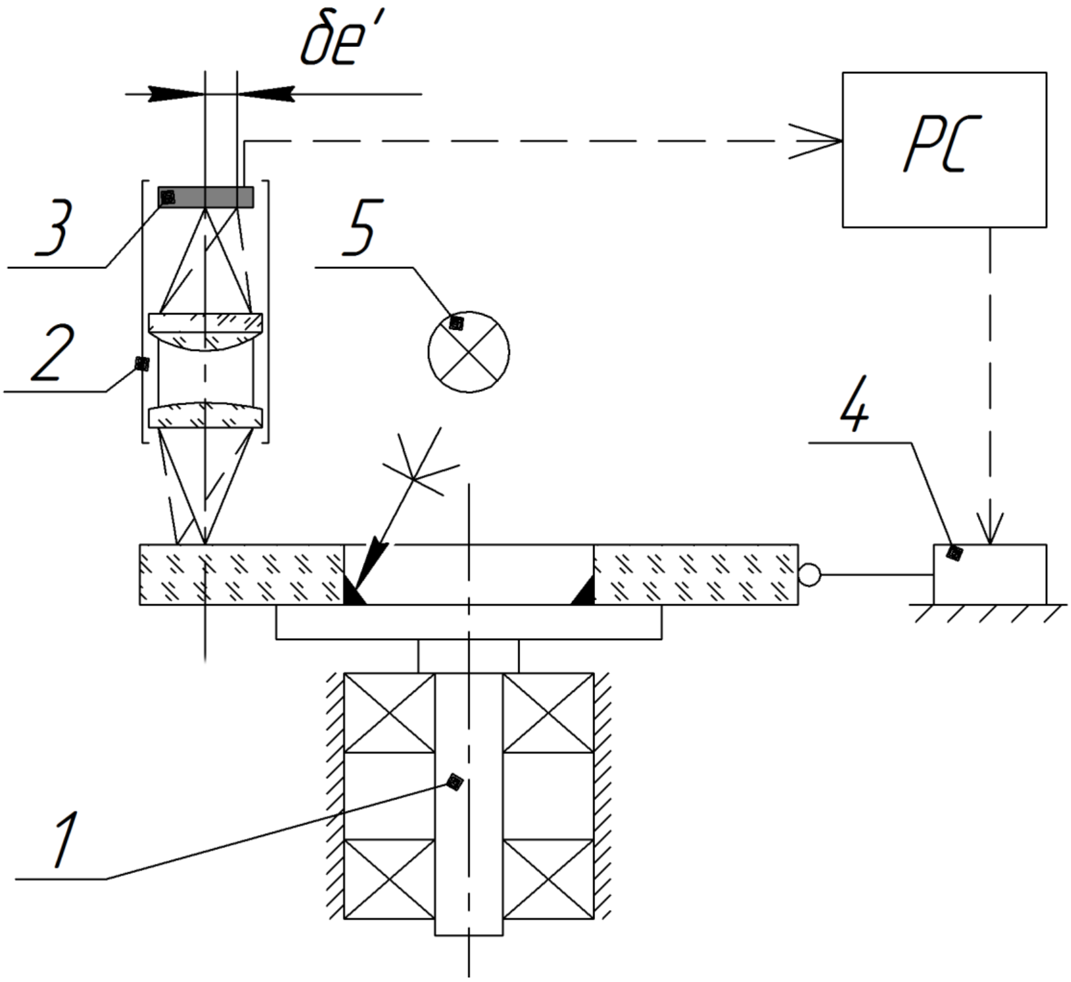

Fig.3. Schematic of an automatic adjustment machines

A centering of circular pattern does not compensate the first harmonic influence of the periodical error. Periodical error can be presented as a Fourier series with even and odd expansion terms [2]:

$$\Delta\varphi_{\Sigma} = \sum_{n=0}^{k} a_{2n+1} \, sin(2n+1)\varphi + \sum_{n=0}^{l} a_{2n} \, sin \, 2n\varphi$$

where a is a harmonic amplitude; k and l are numbers of odd and even terms of expansion, respectively. The first harmonic has a periodic time equal to 2π and the largest amplitude. It has the same effect on the measurement error as well as the eccentricity of the circular pattern.

This error appears from kinematic eccentricity Δe_k and has the direction θ_{Hk}. Angular measurement errors are conditioned by the first eccentricity that is named “geometric eccentricity” and the second “kinematic” eccentricity. The resulting error can be described as summarized eccentricity by an equation such as:

$$\Delta e_{\Sigma} = \Delta e \cdot \sin\theta_{Hk} + \Delta e_k \sin\theta_{Hk}$$

The centering of circular pattern with a centering mark eliminates a geometric eccentricity. The kinematic eccentricity cannot be fully eliminate and generates a measurement error if the reading is only done by a single reading system. The elimination of the summarized eccentricity is possible with the following equation:

$$\Delta e \cdot \sin\theta_{Hk} = -\Delta e_k \sin\theta_{Hk}$$

when the circular pattern is centered using the electric signals generated by the reading system and not the method using the centering mark.

Fig. 4 shows the experimental measurement setup for the centering of circular pattern *1* with electric signals. A digital oscilloscope receives the electric signals from two reading systems *2* and *5* mounted in diametrical positions of the centered circular pattern.

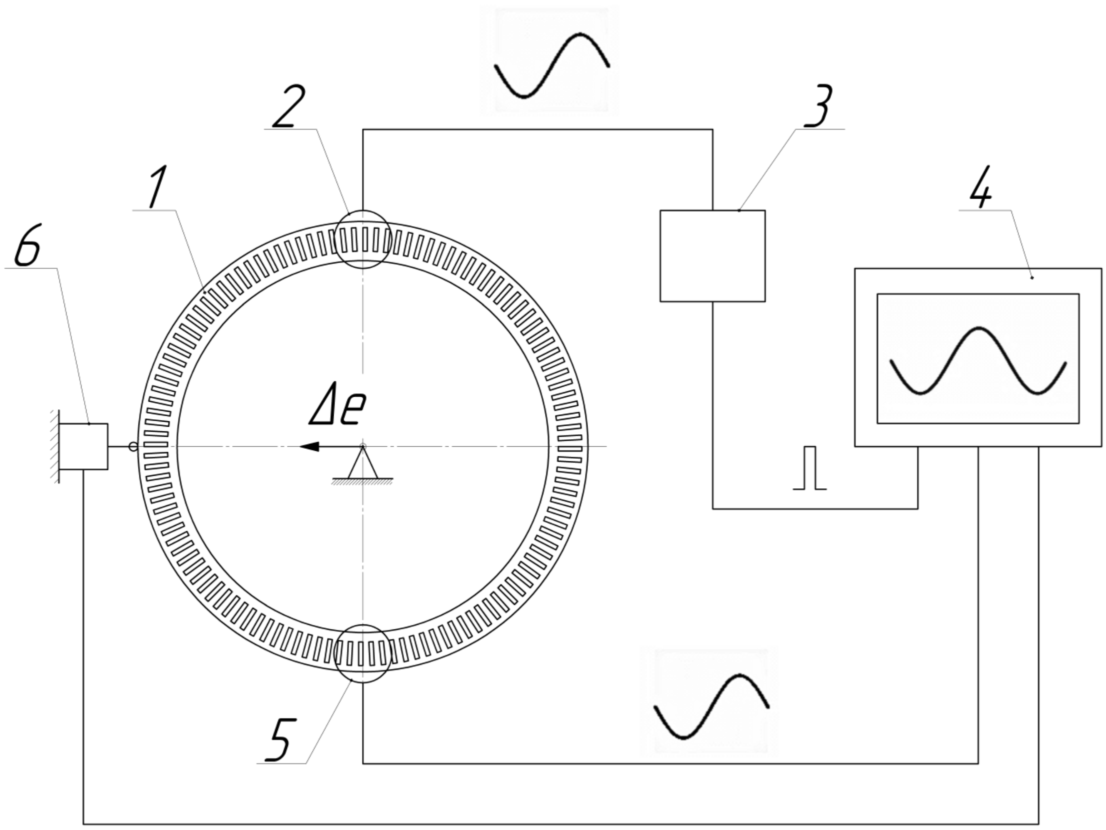

Fig.4. Setup for centering of circular pattern with electrical signal. Setup elements: 1 – circular pattern, 2 and 5 – reading systems, 3 – signal conditioner, 4 – digital oscilloscope, 6 – piezoactor;

Sensitivity of the method for measurement eccentricity of circular pattern is relatively high because there is the amplification of electric signals in the oscilloscope, the high visual sensitivity of operator in cases of the determining of a mutual displacement of the square wave impulse and the inclined form of the quasi-sinusoidal signal. *For example*, for $L = 20\mu m$, $h_{max} - h_{min} = 1mm$; $H = 50mm$ obtain the following total value of the eccentricity $e_{\Sigma} = 0{,}05\mu m$.

The piezoceramic actuator moves the circular pattern in a centered position according to signals generated by a computer (PC). The adjusted position of the circular pattern is fixed with rapid curing photopolymerizable adhesive using ultraviolet light.

Further on, there are adjustments to set signal amplitudes and phase shift signals for the centering of the circular pattern in incremental optical rotary encoders on equal levels [3]. The setting of the signal amplitudes are usually achieved with adjustment light beams, registered by the photo detectors, or with an adjustment resistor in their power supply. The required phase shift of the signal is obtained through the mechanical adjustment of photo detectors or reading systems.

A compensation of the radial runout (i.e. lateral motion) of the mechanical axis of rotation of the bearing and odd harmonics of errors of the circular pattern is achieved with two reading systems. For compensation of even harmonics of the circular pattern four reading systems are necessary, mounted on the centered circular pattern perpendicular to each other. Their nominal relative angular position needs to be adjusted.

3. ACCURACY CONTROL

Accuracy control of the incremental optical rotary encoder typically depends on the experimental setup and the method of comparison with a reference encoder. The optical rotary encoder and reference encoder are connected using a precise coupling. The precise coupling influences the control accuracy of the encoder, because it could cause intrinsic inaccuracy. In order to eliminate this effect, a special coupling device was designed. The design provides an unrestrained connection between controlled and reference encoder.

Fig. 5 shows the functional layout of the experimental measurement set up. The mechanical axis of the test sample *3* is connected through a rigid coupling *2* with the axis of the reference encoder *1*.

The restriction of the test samples rotation around its own mechanical axis is realized by device *4*. This fixed device compensates all other five degree of the possible movements of the test sample.

This device represents a four-bar linkage parallelogram mechanism with ball joint. This joints connect the test sample and a bar linkage. The rotational axis of the bar linkage is orthogonal to the parallelogram mechanism plane. Motor *9* realises a conjoint rotation of the test sample and the reference encoder.

A digital autocollimator *6* [4] in combination with a mirror *5*, fixed to the base of the test sample, is used to control the location errors of the coupling device in real time. Signals are used for algorithmic correction of the measurement results of incremental optical rotary encoder and possible errors of fixed device *4*. The output of the autocollimator is connected through electronic block *7* with PC *8*. A synchronous rotation of test sample *1* and reference encoder *3* is realised by motor *9*, which is connected through programmed-controlled device *10* and electronic block of control *7* with PC *8*. The outputs of the encoder under test and the reference encoders are connected too with PC *8* through electronic block of control *7*.

A counter balance device *11*, for example as mass with a sheave or a spring mechanism, is used to reduce the load on the bearing of the reference encoder.

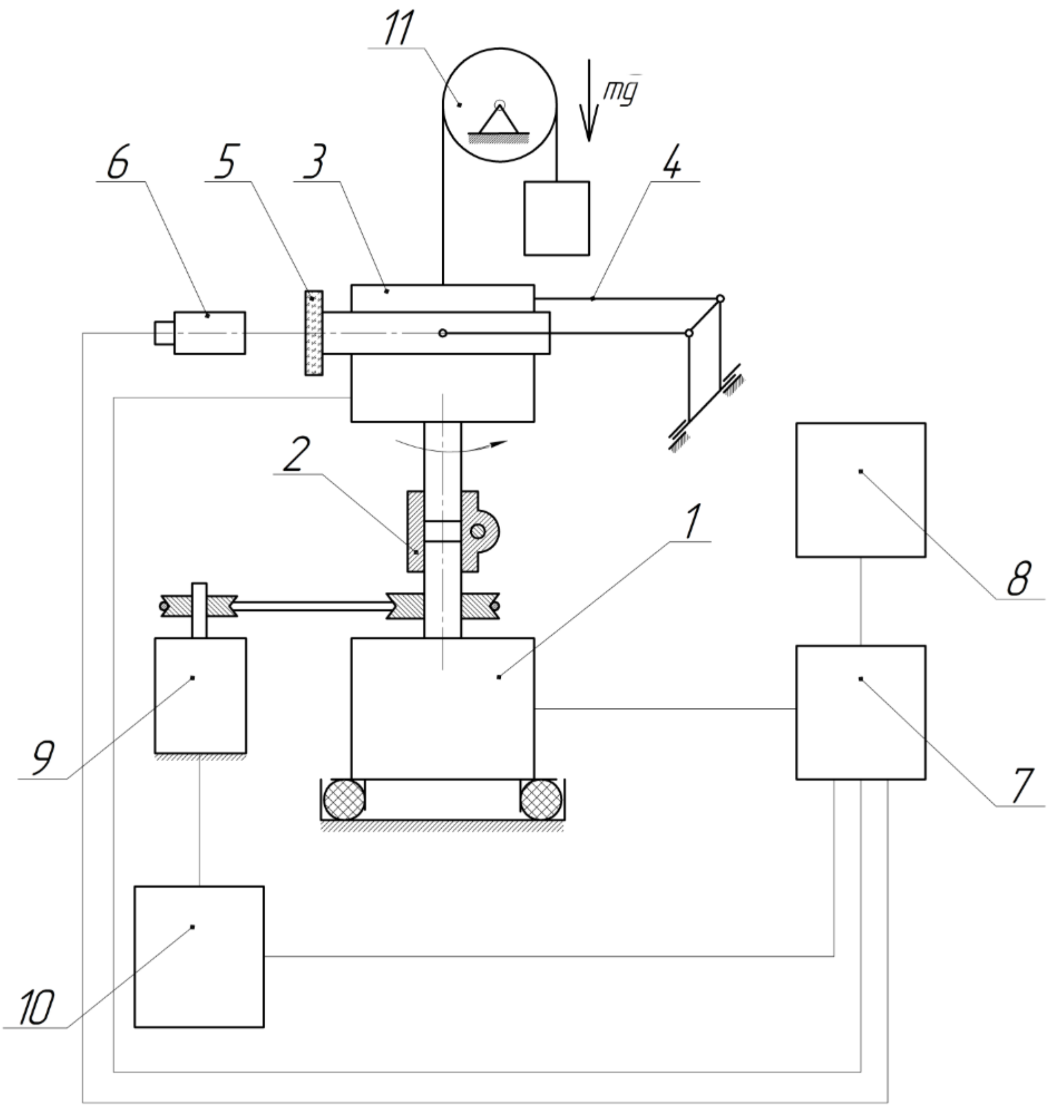

Fig.5. Experimental measuring set up and its kinematic chain; Setup elements: 1 – reference encoder, 2 – rigid coupling, 3 – encoder of interest, 4 – special device coupling, 5 – mirror, 6 – autocollimator, 7 – electronic block, 8 – PC, 9 – motor, 10 – control device.

The resulting error ($\Delta\varphi_k$) is calculated by the PC und can be describe as a difference between angle values from controlled (φ_k) and reference (φ_o) encoders and corrections of the autocollimator for each control position (i):

$$\Delta\varphi_{ki} = (\varphi_{ki} - \varphi_{oi}) + \Delta\varphi_{ai}$$

The described experimental setup allows the calibration of incremental optical rotary encoders in an unlimited number of control points. It compensates error influences of the rigid coupling of the encoder under test and the reference encoder. This increases significantly the accuracy of the calibration.

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