INVESTIGATIONS IN THE LENGTH AND ANGLE MEASUREMENTS

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Abstract: The paper deals with a short review of length and angle measurements from the stage of linear and circular scales production and calibration to the process of mounting them into the rotary encoders and linear translational transducers with subsequent calibration and, finally, a calibration of the informational measuring systems assembled into the automatic technological and measurement equipment, as co-ordinate measuring machines. Systematic pitch errors and uncertainty of the scales calibration are determined before using them for measurement systems of the machines. A systematic error compensation is chosen by mechanical, numerical or mechatronic means. Some examples and the results of compensation are presented.
Keywords: length, angle, measurements, transducer, calibration, accuracy

1   INTRODUCTION

Linear and circular raster scales are used in most measurement and technological equipment as the reference measure. Accuracy calibration of these scales is the first step of information for the accuracy improvement of the final measurement systems of the machines. Data of machine's accuracy parameters are received by selecting them from moving parts of the machine in working conditions or measuring the part produced by this machine. Standard and reference measures used for the most precise measurements are described in the article [1]. Problems of sampling strategy for the estimation of some accuracy parameters of the parts and the machines are presented in the investigations described in [2,3]. The effect of the sampling strategy on the results of measurement is dependent on the pitch of measurement or the beginning of measurement. It in general fits to the part to be measured, transducer or the machine at all. The results developed give some value of information entropy restricted by the finite number of measurands registered in one-, two- or three-directional measurement [4]. It is important for coordinate measurements and for numerically controlled machines as well. Measurement of known reference surface is used [5] with subsequent mathematic interpolation to construct mathematic equations for measurement of three-dimensional complex surfaces.

Laser interferometer systems are used successfully for calibration of step gauges [1], linear raster scales and transducers [2,3]. Some special approach to measurements must be taken in the cases when thorough calibration of the scales or transducers is performed. Low frequency error or bias must be determined together with high frequency error, it is, the error that occur at the pitch of rotary movement of some minutes of arc and at the pitch of linear translational displacement of some tens of micrometers. Determination of such errors and their compensation systems has some differences [2,5,6]. Example of low frequency error calibration and correction for circular scales production machine is shown in the Fig. 1a and that of the high frequency error in the Fig. 1b.
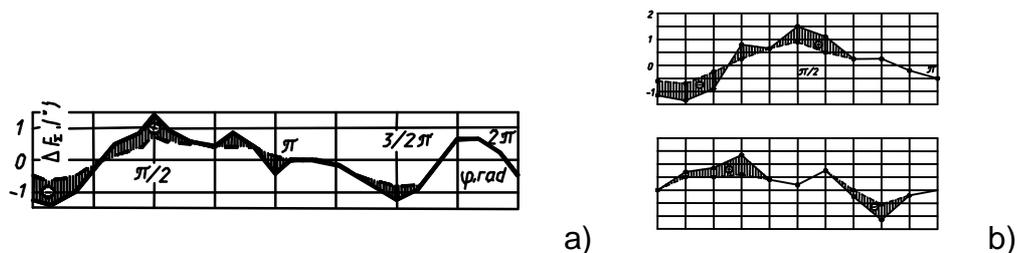
Figure 1. Low frequency (a) and high frequency (b) error correction

Process of accuracy improvement of machines and automatic equipment for scales production is accompanied by continuous and subsequent measurements. For the circular scales formation it is the

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most important task to assure the highest accuracy of angular positioning of the base (machine's table) during producing the strokes of the scale. The arrangement for measurement of angular error of rotation of the table consists from standard (reference) measure, reading devices, such as photoelectric microscopes or autocollimator, means of rotating or positioning. Some problems and uncertainty of measurements arise from absence of standard measure of small angles calibrated with high accuracy. Sometimes the reference linear scales having the pitch, for example, of 50 µm, can be used for this purpose. Approximation of conversion of linear distances between the strokes of the scale into the angular units must be taken into account depending on radius at which the scale is fixed. Diagrams shown on Fig. 1 indicate the real angular errors in seconds of arc function of angle of the table rotation. Really, the pitch of the table rotation can be controlled at each of $1...3^0$ (Fig. 1"a") as the error of low frequency. The high frequency errors as shown in Fig. 1 "b", are determined at the pitch of 1...5' (minutes of arc). The errors determined must be eliminated or compensated by one or some means for correction: mechanical, compensating the error by additional (plus or minus) displacement of moving part of the machine, numerical correction by impute of additional signals into the drive control device of the machine or by mechatronic means, that comprises some of the features of the methods mentioned above and used in most modern metrological equipment [3,7]. Diagrams in the Fig. 1 show the importance of accuracy determination for correctional purposes. Low frequency error is determined at first. This gives an opportunity to find out the extreme points of error distribution and to perform the measurements at the areas in the vicinity of these points. Then follows the high frequency error correction that permits to improve accuracy for almost two times using quite simple mechanic, numerical or mechatronic means.

2   ACCURACY INVESTIGATION OF THE TRANSDUCERS

Linear positioning errors were investigated for the photoelectric linear translational transducers (LTT), using the special developed automatic computer- controlled comparator for the linear calibration mod. BE-182. The input signal changes were applied on the transducer, causing the phase shift between the two sine-wave signals, deforming the frame of the transducer, etc., and accuracy dependence was investigated. The point of the beginning of measurements was changed at every 2 µm performing the calibration of the full length of the LTT with the pitch of calibration of 10 mm. The diagrams of the accuracy calibration under the various influences on the transducer are presented in Fig. 2 and 3. The curves 1 and 2 in the Fig. 2 show a significant changes of output signal of the LTT
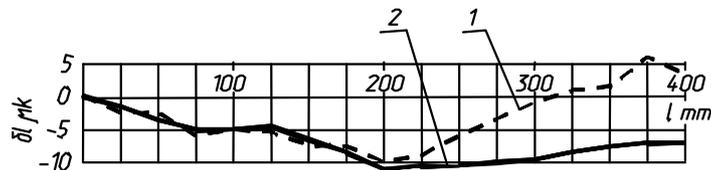

Figure 2. Dependence of the systematic error of the LTT due to the phase shift of input signal

due to the phase shift at the transducer's input. It shows an importance of adequate alignment of transducer's elements (indicator grating, photocells position, relevant spacing between them, etc.) during the assemblage and calibration. Dependence of LTT accuracy due to deformation of the frame is shown in Fig. 3. It shows that the deformation within the range of 5...10 µm has not so significant influence on the accuracy of the transducer as the phase shift in the input signals.
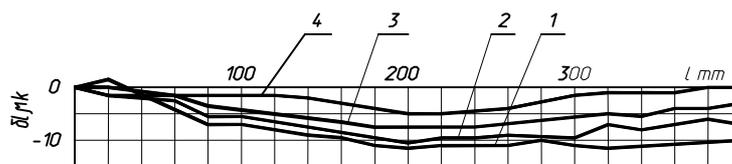

Figure 3. Systematic error dependence due to different of value of frame deformation.
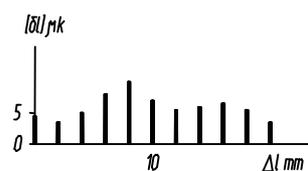
Figure 4. Mean arithmetic values the systematic error

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Great amount of information was selected during the change of the beginning of calibration. The "zero" point was changed at every 2 μm performing the calibration at full length of LTT of 400 mm. Every time the diagrams were drawn and mathematic statistical evaluation was performed. Mean arithmetic values of systematic error at every changed beginning are shown in Fig. 4. The bars of histogram represent a mean value at displacement of the beginning for 2 μm, 4 μm, 6 μm, etc. Empirical dispersions at these positions were designated as $S_2{}^2$,$S_4{}^2$, ... The confidential intervals were evaluated by the means of mathematic statistics changing the position of interval of calibration and histograms of comparing of the results were developed. It shows that the evaluations of empirical dispersions at spatial intervals S_6^2, S_8^2 belong to the same random value entity. The values calculated were obtained by using expressions:

$$G_m = \frac{S_m^2}{S_0^2 + S_2^2 + ... + S_{18}^2} = \frac{S_m^2}{\sum\limits_{i=0}^{2k} S_i^2}, \qquad (1)$$

$m = 6,8;\ k = 1, 2,...,9,$

and

$$t_m = \frac{\overline{d}l_m - \overline{d}l_k}{\sqrt{\dfrac{S_m}{n_m} + \dfrac{S_k}{n_k}}}, \qquad (2)$$

where: $\overline{d}l_m$ - mean arithmetic value calculated (m = 6; 8); S_m - evaluation of the dispersion in the range of measurement; n_m - quantity of measurements; S_k - evaluation of the dispersion in the range of measurement consisting of n_k measurements.

Calculation of G_b gives the results of 0,098 and 0,115. At the value of P = 0,99, critical value is 0,212. The checking of t_m at P = 0,99 and degree of freedom (n-1) shows that the values do not exceed 2,807. It shows the validity of calculations performed.

Experimental investigations show the significance of errors with high frequency in the digital output of the transducer and for informational measurement system of the machine where it is implemented. Some new correctional circuits and design were presented in [8] using numerical and mechatronic means of error compensation in metal cutting machine's system.

3   COMPARATORS FOR LINEAR AND ANGULAR MEASUREMENTS

Comparators of model BE-182 for calibration of linear raster scales and translation transducers, for circular raster scales and rotary encoders of models BE-186 and BE-187 were developed and put into the practical usage (Fig. 5). The main parts are: 1 - base, 2 - table, 3,4 - reference measure and scale or LTT to be measured, 5,6 - photoelectric microscopes, 7-13, 17, 18 - drive and electronic units, 14-16 - computer, 19-21 - laser interferometer; (A-K) - analogue - code converter. Measurements can be performed in such variety:

a) comparing of accuracy of translation transducer with laser interferometer as standard measure;

b) translation transducer comparing with translation transducer as reference measure,

c) comparing of accuracy of linear raster scale (measurement by help of photoelectric microscopes, standard or special ones) with laser interferometer as standard measure;

d) two linear raster scales with photoelectric microscopes using one of them as reference scale;

e) translation transducer comparing with raster scale and vice versa.

Important feature of the comparator is dynamic mode of operation. Measurement is performed during the movement of the scale or the transducer to be measured. Such measurement shows the errors in working conditions of the scale or transducer including influence of dynamics of machine. The distance between the measurement points the table travels at the enhanced and slow (measuring) velocity. Enhanced velocity of movement is about 0.2m/min, and during the measurement of the stroke position the table moves at 100μm/s. The working cycle of the comparator consists from preparatory operations, number of measuring reciprocal strokes, pitch of measurement and other parameters pre-setting in the computer. Wide range of commands enables to perform of measurement with many varieties of pitch, changing the beginning of the scale's position, including of correctional or compensation parameters for temperature, pressure, humidity and material differences, etc. Environment of measurement is kept in very stringent conditions including air conditioning system, temperature regulation, and damping of the base of the comparator against the shock and vibrations.
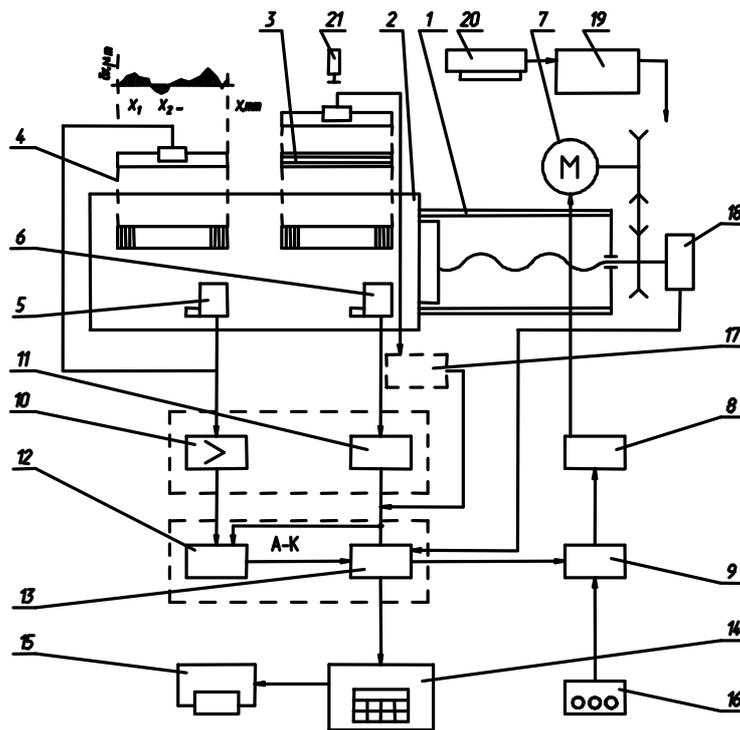
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Figure 5. Principal diagram of the comparator

The results of measurement could be presented in the form of printout protocol, error graphic diagram or only by maximal error results There also are calculated mean arithmetic value of the results of measurement, mean square value, the dispersion and maximal positive and negative values of errors determined. The diagram of systematic error also can be presented under requirement. In the case of serial measurements, the accuracy of measurement is lower and the efficiency or productivity of measurement is at most importance. Many of individual adjustment and preparation operations are neglected and the cycle of measurement is simplified.

Comparators for measurement of circular raster scales and rotary encoders. Automatic comparators for measurement of circular raster scales and rotary encoders were developed the similar to the linear comparators in large. Rotary encoder of high accuracy was chosen as standard measure for the comparator. Pneumatic aerostatic axis of high precision was used for the table rotation with fixed circular scale or transducer to be measured. Runout of the axis of rotation was not exceeding 0.1 µm. The measurement process is also performed at continuous rotation of the spindle with the standard measure and the object to be measured. Piezoelectric drive was used for the rotation of the spindle with which the highest accuracy of axis rotation was achieved. Velocity of the rotation of the spindle, 0...10 rev/min; spindle rotation trajectory run-out: in radial direction 0.08 µm, in axial direction, 0.07 µm. Diameter of raster scales to be measured: 160...400mm. Some devices for achievement of the highest accuracy of measurement were designed, among them, the co-ordinate adjustment table for quick and very precise adjustment of the object to be measured on the comparator, it features with low height and smooth co-ordinate displacement.

4   CONCLUSIONS

Investigations performed have enabled to develop modern equipment for calibration of linear and circular raster scales and transducers. Calibration methods used for coordinate measurement equipment, as they are described in [9,10], show the complexity and special methodical preparation needs for the task solution. Our investigations in the field of methods and means for calibration of linear and circular scales and transducers have a purpose to transfer it to the methods and means for complex calibration of the machines and multicoordinate measuring and production machines. As result of investigations some methods of selecting the reference measure for multicoordinate measurements were proposed [11,12]. Complete measurement of automatic machine's accuracy

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parameters is proposed to perform by using of the same kind of machine, as a master machine. The final position of machine's element or cutting tool, or the measuring probe is compared with those of the master machine's. All accuracy parameters of the machine are involved in the determination of this position. Characteristic feature of the control is the path of the laser beam used for calibration purpose going through the all coordinate movements of the machines. For easier alignment of the measurement system, the fibre optics system also is used. Environment conditions of the control also have minor influence, as it is performed at the same conditions of both machines. It enhances the accuracy and productivity of the calibration process.

   The determination of the accuracy parameters of coordinate position of the parts of multicoordinate machines, robots and coordinate measuring machines is quite complicated from the beginning of the sampling process. Great quantity of information in the measuring volume and lack of spatial reference measure are the main obstacles for the metrological tasks to be solved. Some different approach to this problem is presented in the investigation given in [12] where accuracy elements of measurement are discussed and some new methods and means for complex accuracy assessment are proposed. Determination of points, equally distributed in the working volume of measurement is used. This permits to minimise of number of points to be measured for volumetric error assessment of the machines. The error correction system using piezoelectric nanometric displacement of the final point of instrument or touching probe is proposed.

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