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DEVELOPMENT OF 2D OPTICAL MEASUREMENTS

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Abstract. The analysis of 2D measurement methods and means is presented. The actual optical-electronic devices using bar codes are discussed. The correlation functions of measuring and reference codes in the electronic level instrument are calculated showing possible errors in height determination. The new electronic level design is proposed simplifying the main design and as well as the meter of the level. The principal correlation and error determination equations are given, and the diagrams of the new design are included.

Key words: optics, level, instrument.

1. INTRODUCTION

Optical digital levels are based on the data received from the code meter and processed in an optical – electronic measuring instrument. A view from the code meter is sent into the photocell matrix (sensor) where, at first, the distance to the meter is assessed by focusing the optical image; then, a correlation of the bar code in the length of the sensor is calculated. The optical image is projected into the photocells matrix or CCD camera where bar images are processed into the voltage and consequently, digital output. Visual aiming at the bar-meter is performed at first, and then the instrument operates automatically by focusing the lens to the target, transferring a bar image into the matrix assessing the results (distance and height) by correlation analysis. Most digital levels NA 2002 and NA 3003, etc., operate in such mode {1,2,3]. Three main methods of image processing are used in the instruments: a correlation method (levels by Leica: NA 2000/ 2002/ 3003), a geometrical method (levels by Zeiss: D; N; 10/ 20) and a phase method employed by Topcon in the systems DL-101/ 102. The bar strokes of three types of the width are put on the whole length of the meter (Fig. 1). The phase shift between the strokes is used to receive the information on the height. The sum of all three codes used on the meter permits to assess the height and the distance to the meter. The same types of the information processing is used in many optical devices [2], for bar-code image processing, etc.

Two stages of the correlation analysis is used in the level technique. The first stage is a coarse correlation measuring the distance of the displacement of the lens during its focusing on the target – the surface of level meter. The next step is fine correlation for accurate determination of the meter‘s distance to the instrument and the position in the height. The calculation of correlation coefficients takes some time and volume of memory of the instrument. There are to $5x10^4$ calculations performed in modern levelling instruments.

Various codes of information modulation are used in such instruments. Very good geometrical characteristics of meters must be ensured, good contrast of the strokes (bars) on the surface is required to avoid ambiguity of the readings. Modern optical sensors and other techniques are used in the instruments [4]. The manufacturers develop their different codes of information modulation for the purpose of making it easier to produce and simplify their calibration and verification procedures.

The information processing is quite complex in those optical devices. For example, the strokes on the meters must be put on the whole length of the level meters. Its length reaches 4050 mm. The bar code has about 2 000 elements, every of them being of 2,025 mm of width. The manufacture of such devices is complicated.

The matrix of photocells consists of at least 256 elements, placed at the distance of 25 μm from each other. The accuracy of placement of the photocells also influences on the accuracy of the performance of the whole instrument. The assessment of the information performing a correlation analysis is also complicated. For example, in some level instruments the calculation of 50 000 coefficients of correlation is performed.

2. THE ACCURACY ASSESSMENT OF THE OPTICAL LEVELS

The accuracy assessment of data processing by the instrument and some assumptions for the modernisation of the measuring instrument are presented with further proposals for simplifying of the code meter and the reading instrument as well.

The covariance of the coordinate H (the height of the code meter in the optical axis of the instrument) and reference code value R is calculated using expression [5]:

$$K_{hr} = \rho(h,r)\sigma_h\sigma_r , \tag{1}$$

where $\rho(h,r)$ – correlation coefficient; σ_h, σ_r – standard deviation of values H and R .

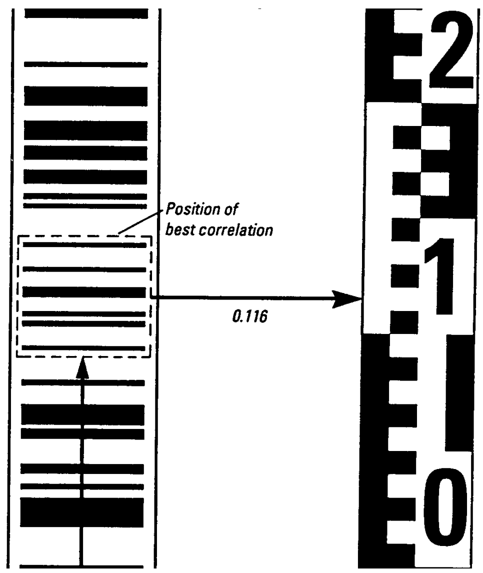

Fig. 1. A view of the digital and bar-code meters

Estimate $\rho'(h,r)$ of correlation coefficient of values H and R is calculated according to the common formula of mathematical statistics [5, 6]

$$\rho'(h,r) = \frac{\frac{1}{n}\sum_{i}^{n} h_i r_i - \bar{h}\cdot\bar{r}}{m_h \cdot m_r}. \quad (2)$$

The estimates m_h and m_r of the standard deviations σ_h and σ_r are expressed by statistical formula

$$m_h = \sqrt{\frac{1}{n}\sum_{1}^{n} h_i^2 - \bar{h}^2}, \quad (3)$$

$$m_r = \sqrt{\frac{1}{n}\sum_{1}^{n} r_i^2 - \bar{r}^2}. \quad (4)$$

The mean value of the information received in the photoelectric matrix can be calculated using the formula of information entropy

$$H(x) = -\sum_{1}^{n} p_i \log_2 p_i \quad (5)$$

and consequently

$$H(x) = -\sum_{1}^{256} p_i \log_2 p_i = \log_2 256 = 8\, bits,$$

where $p_i = 1/256$ – the probability of coincidence i coordinates of the code image of the meter with the reference code.

Assessing the dispersion of the readings from the code meter by comparing it with reference code stored in the memory of the instrument gives

$$\sigma_a^r = \sigma_{ah}^2 + \sigma_{ar}^2 + 2k(\Delta_{ah}, \Delta_{ar}) \quad (6)$$

and putting it into the relevant formulas, the real dimensions of the instrument and the accuracy of the readings can be assessed. The actual example of calculations performed gives the standard deviation value of $m_{\rho hr} \le 0.05$. The accuracy of the correlation ρ_{hr} is approximately equal to 5-11%.

3. A NEW APPROACH TO THE OPTICAL LEVEL INSTRUMENT

The new structure of the measuring instrument is proposed using a very simplified bar-code meter and the reading device operating without correlation value assessment (Fig. 2). The main parts of the instrument: 1- optical levelling instrument, 2 - base, 3 - bar meter, 4 - rotary encoder (angular transducer).

The bar meter consists of only two (or three) strokes; the position (the height from the basis) is determined according to the optical axis of the device. Then the distance S to the meter can be calculated using the readings from the device as

$$S = d / tg(\alpha + \alpha_1)_{rad} - tg\alpha_{rad}, \quad (6)$$

where d is the known (calibrated) distance between the strokes (bars) on the meter, and angles α and α_1 are the values of angles between the instrument's optical axis and upper and lower strokes on the meter surface. The angles are determined by the readings of the device.

The new approach to the construction of the level instrument and bar meter gives a possibility to simplify the instrument and the bar meter especially. The short distance between the strokes on the meter gives an opportunity to calibrate it with high accuracy and use it as a reference measure for further calculations during the measurements.

The optical leveling instrument is simplified as having only the photoelectric cells for the detecting the strokes (bars) on the level meter (3). The optical image of the bars show the distance to the meter *S* measured as usually in the digital levels, by linear transducer. Photocells activated by two bars serve for measurement of the position of two strokes relative to the optical axis of instrument [7]. It can be reset to "0" and used as a reference point for further measurements.

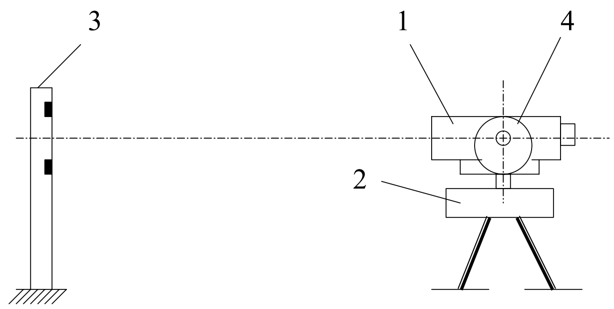

Fig. 2. A general view of the levelling instrument and bar meter

Metrological calibration of the distance *d* between the bars gives an opportunity for precise measurement of the height after replacement of the meter in the area or for levelling of equipment in the plant, etc. Rotary encoder (4) helps for enlarging the range of measurement when placing the meter in short distance and afterwards placing it on the long distances and variuos heights.

4. CONCLUSIONS

The accuracy analysis of optical level instruments is presented showing some probability assessment of the measurand evaluation.

Calculations of the correlation function presented can be used for assessment of the accuracy of measurement and instrument applied. It also can be used for determination of accuracy of similar optical instruments.

A new approach to the construction of the optical levelling instrument is proposed that permits to simplify the design of the instrument and its production. Metrological calibration of the meter proposed can be performed more precisely and the procedure of accuracy verification is simpler.

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