CALIBRATION OF THE MEASURING INSTRUMENTS FOR INCLINATION ANGLE

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This article presents a developed method for calibration of the inclination angle measuring devices (inclinometers) via the method of indirect comparing of the value of the measured quantity with the industry standard – optical quadrant. It is considered the mathematical model and the uncertainty of the measured quantity is analyzed.

Keywords: calibration, inclinometer, standard, optical quadrant, uncertainty

1. INTRODUCTION

At the moment the calibration of inclination measuring devices in the range from 0 to 360° is made in laboratory of the “National Center for Metrology”. There is still no batch production of the inclination measuring devices in our country, but a moment is going to come when such measuring devices will be implemented in the transport weight-lifting machines as well as in the agricultural machines as a composite part of the active stability system [1]. The ISO standards, applied in the active stability systems of these machines, will be a compulsory norm. Then with the production of the inclinometers will come up the problem with the accuracy and sensitivity of the newly-produced devices as well as the time for calibration and adjustment, uncertainty of the input measured variable etc.

2. CALIBRATION OF INCLINATION MEASURING DEVICES

Calibration of the inclinometers is one of the pressing operations in the transfer hierarchy of the measurement unit for plane angle from industry standards to the end consumers. This quantity takes part in determination of the probe’s deviation angle from the vector of gravity, as well as in controlling its correct direction. This action can be done not only in static mode but also in dynamic by determining the position of the transport vehicles in space and it can be applied in the construction, production and usage of the inclinometers.

In the web site of the “National Center for Metrology” there is a published table with the calibration possibilities in measuring plane angle from 0° to 360°.

- for angular measures with one working angle with uncertainty 1”
- goniometers with uncertainty 0,5”

3. ESSENCE OF CALIBRATION

By the method of indirect measurement of the value of inclination with an inclinometer it is obtained via a primary transducer (sensor - 1) by transformation of the non-electric quantity in DC voltage (2, 3), functionally connected to the measured angle.

The inclination angle φ (Fig.1) is transformed into a DC voltage U_{CC}, which is measured by a digital voltmeter [2]. The dependency is as follows:

$$\varphi = \frac{\varphi_{\max}}{U_{CC}}.U \tag{1}$$

where:

U is the average arithmetic value of the DC voltage, measured on the output of the voltage amplifier (VA – 4);

U_{CC} – real value of the output voltage of the amplifier, written in its calibration certificate.

The maximal voltage value is calculated by the formula:

$$U_{\max} = I_{\max} U_R .2.\arcsin\left(\frac{t}{R}\right), \tag{2}$$

where:

I_{max} – maximal current value of the range of the current generator 3;

U_R – maximal value of the voltage drop in the used range over the resistance R;

$2\arcsin\left(\frac{t}{R}\right)$ – geometric parameters of the used sensor [3]

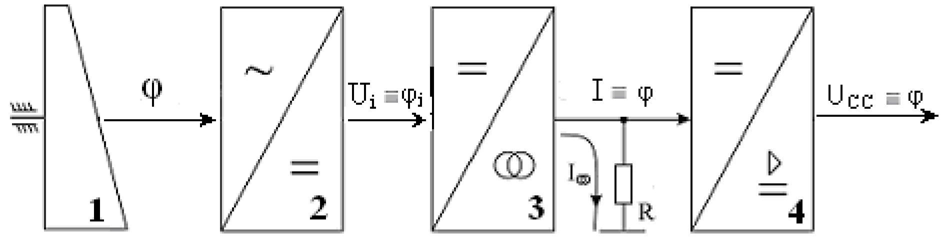

Fig.1. Block diagram of the inclinometer

3.1. Mathematical model

The evaluation of the real value of the angle φ, *deg,* measured by the inclinometer is expressed by the following mathematical model:

$$\varphi = \frac{\varphi_{\max}}{U_{CC} - \delta U_{incl,dr}} \left(\overline{U} - \delta U - \delta U_{Vdr}\right) + \delta\varphi_{res} \tag{3}$$

where:

U – evaluation of the DC voltage, measured at the output of the voltage amplifier during the calibration for the corresponding point of φ;

δU – error estimation of the digital voltmeter, which is measuring the DC voltage on the output of the amplifier:

δU_{Vdr} – error estimation of the voltage drift of the digital voltmeter:

U_{CC} – real value of the voltage at the output of the block 4, pointed out in its calibration certificate;

$\delta U_{incl,dr}$ – error estimation of the voltage drift of the amplifier;

$\delta\varphi_{res}$ – influence estimation of the measured angle due to the end resolution of the reading device of the calibrating inclinometer.

The maximal value of the inclination angle φ_{max} is calculated by the formula (2).

By multiple measurements, the estimation of the DC voltage, obtained at the output of the block 4, is an average arithmetic mean value of the measurements:

$$\overline{U} = \frac{1}{n}\sum_{j=1}^{n} U_j \tag{4}$$

where:

j – measurement index;

n – number of measurements.

The error estimation δU of the digital voltmeter with which the DC voltage is measured at the output of the amplifier is taken from its calibration certificate.

The error estimations of the voltage drift of the digital voltmeter δU_{Vdr} and block 4 $\delta U_{incl,dr}$ are determined:

- as quantities with rectangle distribution and zero estimations and limits corresponding to the nominal stability;
- on the base of the statistical data from the previous years.

The error from the end resolution of the inclinometer is determined as a quantity with rectangular distribution and estimation $\delta\varphi_{res}$, equal to zero.

3.2. Uncertainty analysis

The average quadratic uncertainty of the multiple measurements is calculated by the formula:

$$u\left(\overline{U}\right) = \sqrt{\frac{1}{n(n-1)}\sum_{j=1}^{n}\left(U_j - \overline{U}\right)^2} \tag{5}$$

The average quadratic uncertainty $u(U_{CC})$ due to the voltage amplifier is taken from its calibration certificate. At a given extended uncertainty U and probability of the confidential interval approximately 95% it is calculated by the formula:

$$u(U_{CC}) = \frac{U}{2} \tag{6}$$

The average quadratic uncertainty $u(\delta U)$, connected with the digital voltmeter, is taken from its calibration certificate. At a given extended uncertainty U and probability of the confidential interval approximately 95% it is calculated by the formula (6).

The average quadratic uncertainties due to the errors of the voltage drift of the digital voltmeter δU_{Vdr} and of the amplifier $\delta U_{incl,dr}$ are determined on the base of their probability distributions.

The average quadratic uncertainty $u(\delta\varphi_{res})$ due to the settling error of the pointer of the optical quadrant (industry standard) and the corresponding scale point is determined by the formula:

$$u(\delta\varphi_{res}) = 0{,}2\frac{b}{\sqrt{3}} \tag{7}$$

where b is the value of the smallest scale division of the optical quadrant.

The average quadratic uncertainty $u(\delta\varphi_{res})$ from the resolution of the calibrating digital inclinometer is determined as a quantity with rectangular distribution, zero estimation and limits equal to the half of the smallest step of the readings of the digital inclinometer.

$$u(\delta\varphi_{res}) = \sqrt{\frac{(0{,}5.a)^2}{3}} \tag{8}$$

where a is the smallest step of the readings of the digital inclinometer, expressed in measured quantity units.

The quadrate of the average quadratic uncertainty of the measurements of the real value of the inclination angle is calculated by:

$$u^2(\varphi) = C_1^2 u^2(U_{CC}) + C_2^2 u^2(\delta U_{incl,dr}) + C_3^2 u^2(\overline{U}) + C_4^2 u^2(\delta U) + C_5^2 u^2(\delta U_{Vdr}) + C_6^2 u^2(\delta\varphi_{res}) \tag{9}$$

where the sensitivity coefficients C_i , connected with the input evaluations are equal to:

$$C_1 = -C_2 = \frac{-(\overline{U} - \delta U - \delta U_{Vdr})}{(U_{CC} - \delta U_{incl,dr})^2}\varphi_{\max} \tag{10}$$

$$C_3 = -C_4 = -C_5 = \frac{\varphi_{\max}}{U_{CC} - \delta U_{incl,dr}} \tag{11}$$

$$C_6 = \frac{\partial\varphi}{\partial(\partial\varphi_{res})} = 1 \tag{12}$$

The extended measurements' uncertainty is determined by the formula:

$$U = k.u(\varphi) \tag{13}$$

where k is coefficient of the trusted interval.

In most of the cases the measured quantity can take the value of the normal distribution and average quadratic uncertainty has a satisfactory reliability (the contribution from type A are based on at least 10 following measurements), then the standard trusted interval coefficient $k = 2$ is used and the pointed extended uncertainty corresponds to the trusted interval approximately 95%.

If one of these conditions (normality or satisfactory reliability) is not satisfied, the usage of the standard coefficient for trusted interval $k = 2$ will lead to extended uncertainty, corresponding to trusted interval probability less than 95% [4]. The usage of one and the same probability of the trusted region is necessary in the cases of international comparisons, where two measurement results of one and the same quantity are compared. In these cases the coefficient of the trusted interval k is chosen according to the evaluation of the effective degrees of freedom v_{eff} of the average quadratic uncertainty $u(\varphi)$ connected with the output evaluation φ. They are evaluated using the formula:

$$v_{eff} = \frac{u^4(y)}{\sum_{i=1}^{6} \frac{u_i^4(y)}{v_i}} \qquad (14)$$

where:

$u(y)$ – average quadratic uncertainty, connected with the output evaluation y – in this case $u(\varphi)$;

$u_i(y)$ – the contributions to average quadratic uncertainty – in this case $u(U_{CC})$, $\delta U_{incl,dr}$, $u(\overline{U})$, $u(\delta U)$ и $\delta\varphi_{res}$

v_I – the effective degrees of freedom for the corresponding uncertainty.

For the average quadratic uncertainty, obtained from *n*-times measurement (type A) with uniform distribution of the received values, the degrees of freedom are:

$$v_I = n - 1 \qquad (15)$$

The degrees of freedom of the average quadratic uncertainty, received by the rectangular distribution (type B), are taken to tend to infinity.

On the basis of the obtained evaluation for n_{eff}, from table E1 of EA/02 [4] a value for the trusted region coefficient is chosen for probability 95%. If the value obtained for за n_{eff} is not a whole number it is rounded to the nearest smallest whole number.

4. CONCLUSION

On the basis of the conclusions, made in the theoretical deductions, it is realized a concrete model of a measurement system for determining the angular position of the transport objects.

The average quadratic uncertainty of the inclinometer is proved, according to it, the accuracy of the inclinometer in static mode should correspond to its sensitivity e.g. the cumulative error in static mode should not exceed the value of one step of the electronic block of the inclinometer.

On the basis of indirect method of measuring the inclination angle with an inclinometer can be obtained experimentally and statistically worked out data for results, proving the correctness of the mathematical models for the measurement algorithm as well as for the input-output signals used in the theoretical analysis.

5. REFERENCES

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