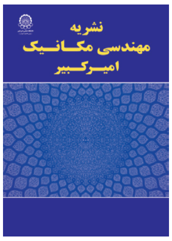

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Design and Construction of an Electronic Tiltmeter Calibrator and Estimation of Calibration Uncertainty

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ABSTRACT: Electronic tiltmeter is used as a tool of setting the accurate angles in advanced equipment. The accuracy and precision of tiltmeter should be evaluated by means of precise calibration equipment. This study aimed to calibrate and evaluate the accuracy of a precise dual axis electronic tiltmeter. To this end, a calibration setup with accurate positioning capability was designed and constructed. Then the calibration setup was employed to investigate linear and nonlinear behavior of electronic tiltmeter and extract the corresponding equations. In order to assess the reliability of the tiltmeter sensor, nonlinearity error and repeatability of the tiltmeter at different angles were obtained. Afterwards in an analytic way, arithmetic and geometric means were compared and the factors which affect the calibrator output error were identified to obtain that how much the accuracy and measurement error of each of those factors affect the uncertainty of angle measurement in the calibration process. The results indicate that both introduced methods of averaging can be used to derive relationship of uncertainty propagation accurately. Uncertainty analysis of the constructed base and calibration process demonstrate that the employed equipment correspond with the evaluation of a precise electronic tiltmeter.

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1- Introduction

Today, a variety of sensors and measuring tools are widely used to measure and control the movement of machinery and equipment. Encoders, Tachometer, and digital levels are the most accurate measurement tools. The accuracy and reliability of these tools has a direct impact on the proper functioning of the device [1, 2].

Calibration of electrolytic sensor with analog output, are the main step in construction of an angle measurement system consist of power supply, sensor and its reader. The aim of calibration a tiltmeter is to determine the exact relation between output voltage of the sensor and true angle of inclination [3, 4].

Because of the inevitable errors in measurement instruments, there are some uncertainties in measurement associated with the calibration process. Typically, two methods are used for determining the uncertainty in measurement: ISO- Guide to the expression of uncertainty in measurement (GUM) and Monte Carlo.

Based on GUM method in ISO standard, identical uncertainty in every step of calibration process was defined and determined, then combination of the values was obtained and total uncertainty was calculated. Estimation of measurement uncertainty, includes the creation of a mathematical model that takes account all variables.

In this paper firstly, a calibration tool was designed and constructed. Then a calibration procedure and uncertainty measurement analysis of the calibration process of a precise dual axis tiltmeter is proposed based on GUM method.

In order to calibrate tiltmeter a precision table was designed and constructed in how we are capable of adjusting both axes simultaneously.

In calibration section the effects of compensating error equations and analog to digital conversion are inquired into. It is also obtained that how much the accuracy and measurement error of each of parameters, including device installation and electronic equipment error, affect the uncertainty of angle measurement and calibration.

The existing equations to analyze uncertainty is derived and investigated using both geometric and arithmetic means methods. Repeating experiments helps to analyze linearity and nonlinearity of obtained equations and repeatability of tests.

2- Operating Principle of Tiltmeter and Reader Circuit

In electrolytic tiltmeter, when the sensor is level, the conductive liquid covers an equal area on each excitation electrode. The AC resistances, R1 and R2, between the excitation electrodes and the pickup electrode are equal. When the sensor is tilted, the liquid covers more of one excitation electrode than the other. R1 and R2 are not equal. The amplitude of output signal, measured at the pickup electrode, indicate the magnitude of tilt movement (Fig. 1) [5].

3- Determination of the Angle of Calibrator and Tiltmeter

Fig. 2 shows schematic and picture of calibration setup consist of granite base and adjustable precision plate. In the proposed arrangement, a digital micrometer was used to measure the height of calibrating base and adjust the angle of electrical tiltmeter. Angle of rotation in calibration plate is equal to: $\tan\theta = H / L$.

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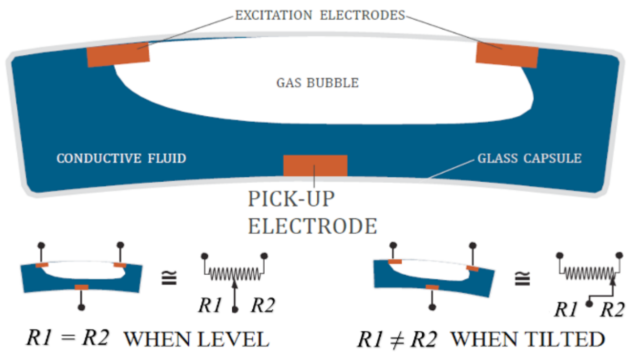

Fig. 1. Mechanism of electrolytic tiltmeter sensor [5]

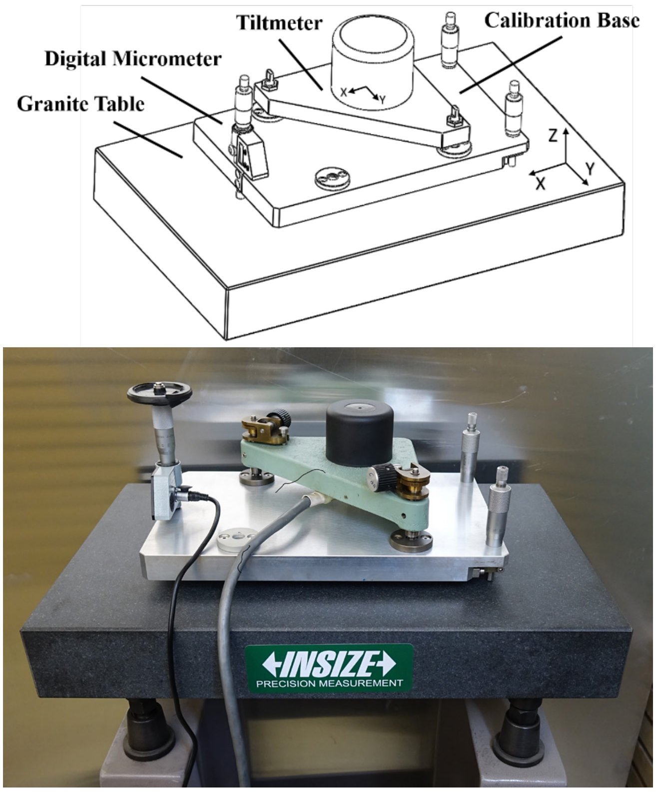

Fig. 2. Schematic of granite base and adjustable precision plate

4- Output Signal Model

As a first approximation, the tangent of the angles should be linear functions of the output signals V_x and V_y . If we assume

$$\tan(\gamma_x) = f(V_x, V_y) \tag{1}$$

For tiltmeter angle approximation, three equations as a function of output voltage were introduced (Eqs. (2) to (4). For generated tilts $\gamma_x(\phi,\theta)$ and $\gamma_x(\phi,\theta)$, and measured output signals $V_x(\gamma_x,\gamma_y)$ and $V_x(\gamma_x,\gamma_y)$, the a_i and b_i coefficients can be solved.

$$\tan(\gamma_x) = a_0 + a_1 V_x \tag{2}$$

$$\tan(\gamma_x) = a_0 + a_1 V_x + a_2 V_y \tag{3}$$

$$\begin{aligned}\tan(\gamma_x) &= a_0 + a_1 V_x + a_2 V_y + a_3 V_x^2 \\ &+ a_4 V_x V_y + a_5 V_y^2 + a_6 V_x^3 + a_7 V_x^2 V_y + a_8 V_x V_y^2 \\ &+ a_9 V_y^3\end{aligned} \tag{4}$$

5- Estimation of Uncertainty

Table 1. Uncertainty parameters and its effects on combined standard uncertainty

Error Source	u_V	Measure µrad	ratio	SD µrad
Calibrator Accuracy	u_θ	$4.36/\sqrt{3}$	0.5	1.258
Alignment	u_α	$0.017/\sqrt{3}$	≈ 0	≈ 0
Multimeter	u_V	$0.035/\sqrt{3}$	2.542	0.051
Total (68%)	$u_{c\,68\%}$	-	-	1.260
Total (95%)	$u_{c\,95\%}$	-	-	2.518

According to ISO Guide [6], determination of measurement uncertainty begins setting out a mathematical model that holds all variables influencing the measuring. Table 1 represents coefficients of main parameters and its effects on combined standard uncertainty. The combined standard uncertainty of measured angle is a function of standard uncertainties associated to (1) Resolution of digital micrometer, (2) accuracy of digital micrometer, (3) tilt error of base plate on granite table, (4) distance from two axial base of precision base, (5) misalignment of tiltmeter and precision table and (6) and the multimeter error.

6- Results and Discussion

The Results using ISO GUM simulation method showed values of expanded uncertainty for the same coverage probability of 68% and 95% are 1.260 and 2.518 µrad, respectively.

7- Conclusions

In this paper, to calibrate a precise two directional tiltmeter, the design and construction of a system with adjustable height with one-micron resolution has been done. The relationship between error of output angle and effective parameters on test errors was defined and analytically extracted. Nonlinear behavior and repeatability of tiltmeter output were evaluated. Finally, tiltmeter error was extracted from comparison of tiltmeter reader and adjusted angle with precise calibrator. It can be concluded that:

- Uncertainty of tiltmeter is as a function of (1) uncertainty of right angle in precise calibrator, (2) uncertainty in output voltage and (3) fitness of final angle in reader circuit of calibrator.
- Uncertainty in setting the right position of digital micrometer and uncertainty in the measured output voltage, were the main error factors in calibration process of electronic tiltmeter.
- In view of the linear behavior of the tiltmeter sensor in the measurement range to get smaller error, Eq. (3), which includes voltages of both axes X and Y (V_X and V_Y), is recommended to fit the curve of the voltage in the process of calibration and digitizing the tiltmeter output.

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