Calibration Method and Measurement Uncertainty Evaluation of Indication Error of Digital Pattern Area Measuring Instrument Based on Square

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Abstract

Propose a method for calibrating the indication error of a digital pattern area measuring instrument based on the square in length measuring instrument with optical principle. Establish a measurement uncertainty evaluation model based on calibration methods and analyze the sources of uncertainty. Combining with measurement examples, this paper elaborates on the measurement uncertainty evaluation process of the indication error of the digital pattern area measuring instrument based on the square.

Keywords

Metrology; pattern area measuring instrument; indication error; uncertainty in measurement

1. Introduction

A pattern area measuring instrument is a measuring device mainly used for measuring the graphic area on drawings. This instrument is widely used in land and resources survey, cadastral surveying and management, urban and rural planning and other departments for land area and property area calculation, as well as civil engineering and mechanical engineering design work [1]. Common measuring instruments include graph to number conversion measuring instruments, digital measuring instruments, and mechanical measuring instruments. Its working principle is to use tracing to track the outer contour of the graphic and measure parameters related to the area. According to the principle of integration, the area value can be directly read out using a cursor after being calculated by a mechanical computing device, or the area related parameters of the measured shape can be converted into electrical signals using a photoelectric conversion circuit, and the area value can be calculated by the computing circuit [2]. Regarding the traceability of digital measuring instruments, technical specifications [2] specify their metrological characteristics, mainly including measurement repeatability and indication error of measuring instruments. This specification requires the use of standard graphic templates for calibrating the indication errors of measuring instruments, which are relatively complex to produce. To reduce the calibration error of the measuring instrument, this paper proposes a digital graphic area measuring instrument calibration method based on the square body in the optical instrument measuring tool [3], and analyzes its measurement uncertainty, providing reference for the calibration of digital measuring instrument indication error.

2. Measuring principle

The digital pattern area measuring instrument is mainly composed of moving polar axis, calculation processing component, tracking arm, tracing mirror, measuring roller and other components. Its structural schematic is shown in Figure 1. One end of the polar axis is fixed at the pole, and one end of the tracking arm is equipped with a tracking mirror. When the tracing mirror moves along the boundary of the figure, the entire mechanism will rotate around the pole, while the tracking arm itself will also expand and rotate. When the tracing mirror moves, the rolling distance of the measuring roller is related to the change in its distance to the pole.

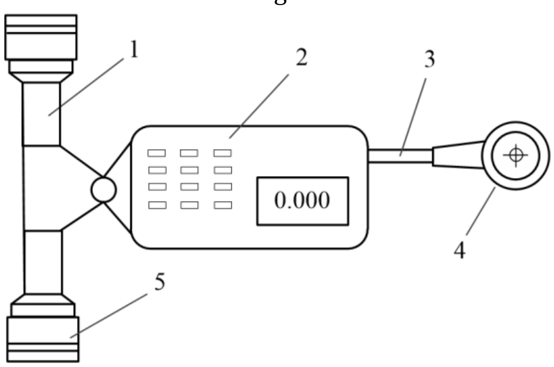

Figure 1. Schematic diagram of the structure of a digital pattern area measuring instrument

1- dynamic polar axis; 2- computational processing components; 3- tracking arm; 4- trace mirror; 5- measuring roller

The core of the measurement principle of such instruments is to indirectly calculate the area by measuring the length of the trajectory, and its mathematical basis is Green's formula or Shoemaker's formula. The formula is described as: the area enclosed by a closed figure can be obtained by scanning the area on the coordinate axis when a moving point moves around its boundary once. Assuming the pole arm length of the digital measuring instrument is L, the radius of the measuring roller is r, and the rotation angle of the measuring roller is $\Delta\alpha$, the expression for the measured area is

$$S = -Lr\,|\Delta\alpha| \tag{1}$$

3. Calibration method

In a laboratory environment, place a calibrated square on a workbench, which is a component of an optical instrument fixture with a (70×70) mm square. Place a transparent glass firmly on the square, select the edge point of a corner on the square as the starting point, align the measuring mark of the measuring instrument with the starting point, press the measuring key of the measuring instrument, and trace the measuring mark along the contour line of the square for 5 times to calculate the relative error of its average reading. The calibration process is illustrated in Figure 2.

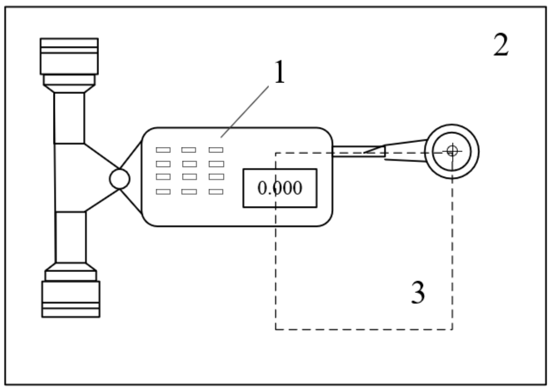

Figure 2. Schematic diagram of calibration method for indication error of digital pattern area measuring instrument based on square

1- pattern area measuring instrument; 2- working glass; 3- square

When calibrating, tracking the contour line in a clockwise direction for one cycle is called the upper half measurement loop, and tracking the contour line in a counterclockwise direction for one cycle is called the lower half measurement loop. The upper and lower half measurement loops are called one measurement loop. A total of 5 measurements were taken and 10 data were collected. The average of the 5 measurements was taken to calculate the relative error $\Delta\bar{S}$. The calculation is published as follows

$$\Delta\bar{S} = \left(\frac{\sum \bar{S}_i}{5} - S\right) / S \tag{2}$$

Where $\bar{S}_i$ is the average value of the measured values, S is the square end face area value.

4. Evaluation of measurement uncertainty

4.1. Measurement model

The measurement model for the indication error of the digital pattern area measuring instrument is shown in equation (2). Due to the non correlation between the measured value $\bar{S}_i$ and the standard value S, the composite standard uncertainty $u_c(\Delta S)$ is [4]

$$u_c^2(\Delta S) = c_1^2 u^2(\bar{S}) + c_2^2 u^2(S) \quad (3)$$

Where $u(\bar{S})$ is the standard uncertainty introduced by the measurement value, $u(S)$ is the standard uncertainty introduced by the standard value, and the sensitivity coefficients $c_1=1$ and $c_2=1$.

4.2. Sources of standard uncertainty

The sources of standard uncertainty components for the calibration results of the hydrostatic level indication errors are shown in Table 2.

Table 1. Source and explanation of standard uncertainty components in measurement results

ui(x)	Source of ui(x)	Evaluation method
$u(\bar{S})$	The standard uncertainty component introduced by the digital quantization error of the measuring instrument	Type B
$u(S)$	The standard uncertainty component introduced by standard area measurement	Type B

4.3. Calculation of standard uncertainty

4.3.1. Calculation of $u(\bar{S})$

The minimum resolution displayed by the calibrated measuring instrument is one reading, and one resolution reading equals 0.1cm2. Assuming that the quantization error follows a uniform distribution, then

$$u(\bar{S}) = 0.5/\sqrt{3} = 0.289 \quad (4)$$

4.3.2. Calculation of $u(S)$

According to the calibration certificate of the square, the measured values of its end face edge length are 70.02mm and 70.03mm, respectively. The expanded uncertainty of its edge length measurement is U=0.04mm (k=2). Then

$$u(S) = \sqrt{(70.02\text{mm})^2 \times (\frac{0.04\text{mm}}{2})^2 + (70.03\text{mm})^2 \times (\frac{0.04\text{mm}}{2})^2} \approx 1.98\text{mm}^2 = 0.198 \quad (5)$$

4.4. Combined standard uncertainty

The standard uncertainty summary of the calibration of the digital measuring instrument based on the square body is shown in Table 2.

Table 2. Summary of standard uncertainty

ui(x)	Source of ui(x)	ci	$\lvert c_i \rvert \times u(x_i)$

$u(\bar{S})$	The standard uncertainty component introduced by the digital quantization error of the measuring instrument	1	0.289
$u(S)$	The standard uncertainty component introduced by standard area measurement	1	0.198

Based on the above analysis, according to equation (3), the combined standard uncertainty $u_c(\Delta S)$ can be calculated as follows

$$u_c(\Delta S)=\sqrt{u^2(\bar{S})+u^2(S)}\approx 0.350 \tag{6}$$

4.5. Expanded uncertainty

Take the inclusion factor k=2, the relative expanded uncertainty of the indication error of the pattern area measuring instrument with a division value of 0.1cm2 is

$$U_{\text{rel}}=\frac{ku_c(\Delta S)}{S}=\frac{2\times 0.35}{490}\approx 0.15\% \tag{7}$$

5. Conclusion

Establish an evaluation model for measurement uncertainty and analyze the sources of uncertainty based on the calibration method of digital pattern area measuring instrument indication error based on square. Based on measurement examples, this paper elaborates on the process of evaluating the measurement uncertainty of the indication error of a digital measuring instrument based on a square body, calculates its extended uncertainty, and provides reference for the evaluation of the measurement uncertainty of the indication error of a digital pattern area measuring instrument.

References

[1] Zhan Changgen Cadastre Surveying [M]. Beijing: Surveying and Mapping Press, 2012.

[2] JJG 660-2006 Pattern Area Measuring Instruments [S]. China Metrology Press, 2006.

[3] JJF 1941-2021 Calibration Specification for Material Measures of Length Measuring Instrument with Optical Principle [S]. China Metrology Press, 2021.

[4] JJF 1059.1-2012 Evaluation and Expression of Uncertainty in Measurement [S]. China Metrology Press, 2012.