Calibration Method and Uncertainty Analysis of Hydrostatic Level Based on Step Blocks

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Abstract. A calibration method for hydrostatic level based on step blocks was proposed. According to the calibration method, the evaluation model of measurement uncertainty was established, and the sources of uncertainty were analyzed. Combined with the measurement example, the evaluation process of the measurement uncertainty for hydrostatic level based on step blocks was described.

Keywords: metrology; hydrostatic level; step blocks; uncertainty in measurement.

1. Introduction

Hydrostatic level is a kind of measuring instrument to monitor the elevation difference and its change. It uses the communicating vessels principle to connect the reference point and the monitoring point liquid tank, and measures the relative liquid level change or pressure change between the monitoring point and the reference point in real time, so as to obtain the vertical deformation displacement of the monitoring point relative to the reference point. The hydrostatic level is mainly used for monitoring vertical deformation and inclination in projects such as dams, nuclear power plants, high-rise buildings, foundation pits, tunnels, bridges, etc [1]. Many scholars have conducted research on hydrostatic level instruments, mainly focusing on the invention of new hydrostatic level instruments and their calibration devices [2-4], the calibration methods of static level instruments [5-6], and the analysis of the impact of external factors on the accuracy of hydrostatic level systems [7-8]. At the same time, there is a lack of current effective regulations and specifications for the calibration of hydrostatic level indication errors. This article proposes a calibration method for the vertical displacement indication error of a hydrostatic level based on step blocks, and evaluates its measurement uncertainty.

2. Calibration method

To achieve the calibration of the indication error of the static level, a calibration device is constructed. The step blocks of different heights are placed on a flat plate. The height range of the upper and lower end faces of the step block is (50~500) mm, and the uncertainty of height measurement U=0.004mm (k=2). The flatness of the upper and lower end faces of the step block is not more than 0.01mm, and the parallelism is not more than 0.02mm. The schematic diagram of the measurement process is shown in Figure 1.

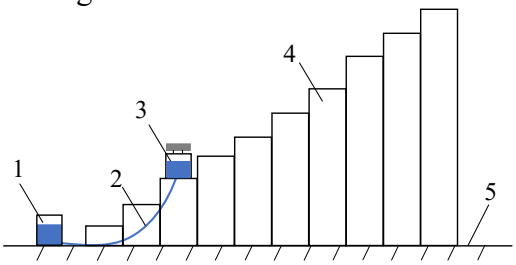


Figure 1. Schematic diagram of calibration method for hydrostatic level based on step blocks
1- hydrostatic level (liquid tank); 2- hydrostatic level (liquid hose);
3- hydrostatic level (sensor); 4- step blocks; 5- flat panel

Before calibration, inject liquid into the hydrostatic level liquid tank as required and empty the air from the liquid hose. In a laboratory environment, the hydrostatic level is turned on and preheated for 30 minutes before calibration begins. Firstly, place the hydrostatic level sensor and the liquid tank on a flat plate. After the liquid stabilizes, read the sensor reading and record it as a_0. Place the hydrostatic level sensor on the first step block and read the sensor reading again as a_1. Keeping the position of the liquid tank unchanged, place the hydrostatic level sensors on different step blocks in sequence to obtain the readings of the sensors at different step heights. The forward displacement of the hydrostatic level at the height of the i-th step block. The indication error of δ_i is calculated by the following equation

$$\delta_i = a_i - a_0 - h_i \tag{1}$$

Where a_0 is the indicating value of the zero point of the hydrostatic level, a_1 is the indicated value of the static level on the i-th step block, h_i is the actual height of the i-th step block.

Using the same method, keep the hydrostatic level sensor stationary on the flat plate, place the liquid tanks on different step blocks in sequence, and calculate the indication error of the negative displacement of the hydrostatic level according to equation (1). Take the peak to peak values of the positive and negative displacement indication errors as the calibration results of the hydrostatic level indication errors.

3. Evaluation of measurement uncertainty

3.1 Measurement result

Under laboratory environmental conditions, calibrate the displacement indication error of the hydrostatic level using the above calibration method. The resolution of the calibrated hydrostatic level is 0.1mm, the measurement range is ± (0-500) mm, and the maximum allowable error is 0.5%FS (i.e. MPE is 5.0mm). The calibration process is shown in Figure 2.

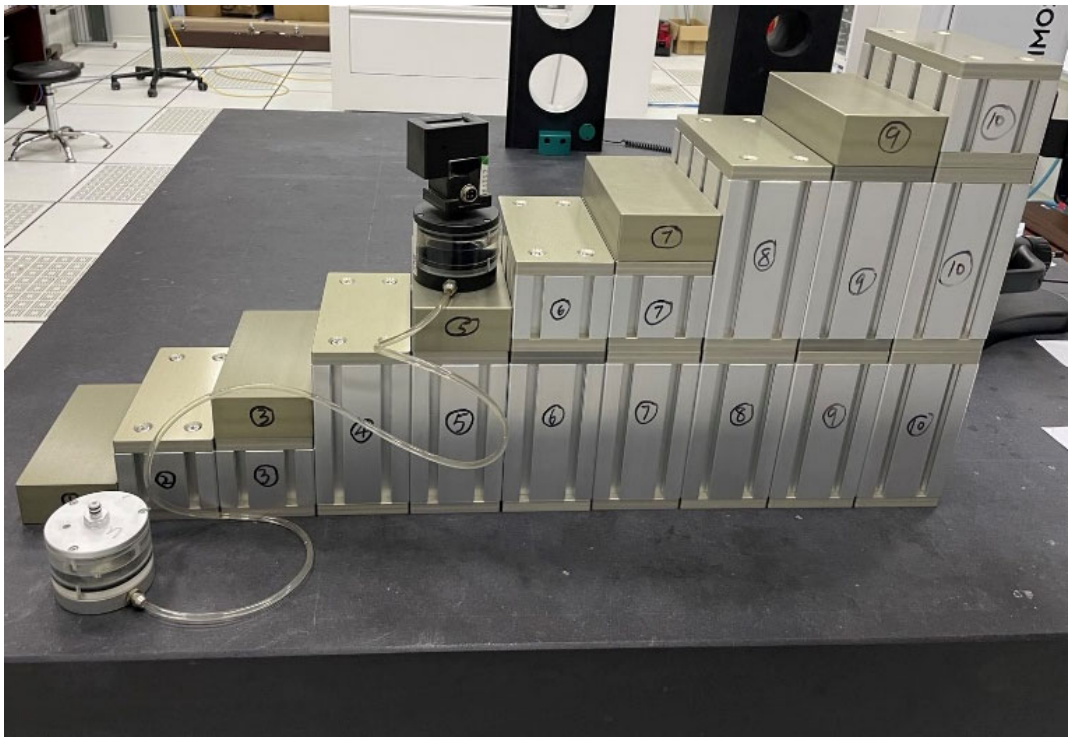


Figure 2. Schematic diagram of calibration process for hydrostatic level based on step blocks

The measurement results are shown in Table 1.

Table 1. The measurement results of hydrostatic level indication error (unit: mm)

No.	Standard height	indication	indication error
1	0.00	-8.0	0.00
2	49.95	42.0	0.05
3	100.03	92.2	0.17
4	150.00	142.3	0.30
5	200.04	192.3	0.26
6	249.99	242.4	0.41
7	300.08	292.5	0.42
8	350.05	342.5	0.45
9	400.08	392.6	0.52
10	450.03	442.7	0.67
11	500.12	492.8	0.68
12	0.00	-7.4	0.00
13	-49.95	-57.3	0.05
14	-100.03	-107.3	0.13
15	-150.00	-157.3	0.10
16	-200.04	-207.3	0.14
17	-249.99	-257.2	0.19
18	-300.08	-307.2	0.28
19	-350.05	-357.2	0.25
20	-400.08	-407.1	0.38
21	-450.03	-456.9	0.53
22	-500.12	-506.9	0.62

3.2 Measurement model

The measurement model for the indication error of the hydrostatic level is shown in equation (1). Due to the strong correlation between the static level values a_0 and a_i, the uncertainty introduced by the two is equal. If a_0 and a_i are not related to the actual height h_i of the step block, then the combined standard uncertainty $u_c(\delta_i)$ is as follows [9]

$$u_c^2(\delta_i) = 2c_1^2u_1^2 + c_2^2u_2^2 \tag{2}$$

Where u_1 is the standard uncertainty introduced by the measurement of the hydrostatic level indication, and u_2 is the standard uncertainty introduced by the height of the step block, coefficient of sensitivity c_1 is equal to 1, c_2 is equal to 1.

3.3 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 2. Source and explanation of standard uncertainty components in measurement results

$u_i(x)$	Source of $u_i(x)$	Evaluation method
u_{11}	Standard uncertainty components introduced by measurement repeatability	Type A
u_{12}	The standard uncertainty component introduced by the quantization error of instrument resolution	Type B
u_{21}	Standard uncertainty components introduced by the uncertainty of step block height measurement	Type B
u_{22}	The standard uncertainty components introduced by the flatness and parallelism of the upper and lower end faces of the stepped block	Type B

3.4 Calculation of standard uncertainty

3.4.1. Calculation of u_{11}

Under the same conditions, select step blocks of the same height for hydrostatic level measurement, conduct 10 repeated measurements, and calculate that the standard deviation of a single measurement experiment is 0.070mm. The standard uncertainty component introduced by measurement repeatability is

$$u_{11} = 0.070\text{mm} \tag{3}$$

3.4.2. Calculation of u_{12}

The resolution of the static level is 0.1mm, the standard uncertainty component introduced by the quantization error of resolution is

$$u_{12} = 0.29 \times 0.1\text{mm} = 0.029\text{mm} \tag{4}$$

Due to u_{12} is smaller than u_{11}, the later is taken as the uncertainty influencing component of the hydrostatic level measurement, then

$$u_1 = u_{11} = 0.070\text{mm} \tag{5}$$

3.4.3. Calculation of u_{21}

The uncertainty in measuring the center height of the step block end face is U=0.01mm (k=2), then the standard uncertainty component u_{21} introduced in measuring the center height of the step block is

$$u_{21} = 0.01\text{mm} / 2 = 0.005\text{mm} \tag{6}$$

3.4.4. Calculation of u_{22}

The flatness of the upper and lower end faces of the step block is not exceed 0.01mm, and the parallelism is not exceed 0.02mm. Considering the extreme case, the error of 0.015mm introduced by the superposition of flatness and parallelism on the center height of the step block shall be evaluated according to a uniform distribution. The standard uncertainty component u_{22} introduced by the flatness and parallelism of the upper and lower end faces of the step block is

$$u_{22} = 0.015\text{mm} / \sqrt{3} \approx 0.009\text{mm} \tag{7}$$

Then the standard uncertainty component u_2 introduced by the height of the step block is

$$u_2 = \sqrt{u_{21}^2 + u_{22}^2} \approx 0.010\text{mm} \tag{8}$$

3.5 Combined standard uncertainty

Based on the above analysis, according to equation (2), the combined standard uncertainty $u_c(\delta_i)$ for the calibration of hydrostatic level indication error can be calculated as follows

$$u_c(\delta_i) = \sqrt{2c_1^2u_1^2 + c_2^2u_2^2} \approx 0.099\text{mm} \tag{9}$$

3.6 Expanded uncertainty

The calibration result of the indication error of the hydrostatic level is to take the peak to peak values of the positive and negative displacement indication errors, and take the inclusion factor k=2. Therefore, the expanded uncertainty of the calibration of the static level indication error is

$$U = 2ku_c(\delta_i) = 2 \times 2 \times 0.099\text{mm} \approx 0.40\text{mm} \tag{10}$$

According to the evaluation results, the expanded uncertainty of this method is less than one third of the MPE of the instrument, which is 5.0mm.

4. Conclusion

A calibration method for hydrostatic level based on step blocks was proposed. By using the proposed calibration method, the calibration of displacement indication error of static level can be

achieved. The expanded uncertainty of the calibration results for the indication error of the hydrostatic level is less than one-third of the maximum allowable error of the instrument, indicating that the method proposed in this paper is effective and feasible.

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