Calibration Method for the Bubble Angle of Inclination for the Spirit Levels Based on the Calibration Device

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Abstract. A calibration method for the bubble angle of inclination for the spirit levels based on the calibration device was proposed. A special calibration device is used to calibrate the angle value of the bubble for the spirit levels. According to the proposed calibration method, the uncertainty evaluation model is established and the source of uncertainty is analyzed. Taking a spirit level with a nominal precision of 0.5mm/m as an example, the calibration of the bubble angle of inclination is realized by using the method proposed.

1. Introduction
The spirit level is a measuring tool which uses the principle of liquid level to directly display the angular displacement with the level bubble and measure the deviation of the measured surface from the horizontal position, vertical position and inclined position [1]. According to the national standard GB/T 1146-2009 level bubble [2], the angle value of tubular level bubble is defined as the dip angle of level bubble when the bubble moves 2mm along the axial direction. The angle value of the level bubble reflects the sensitivity of the spirit level. The smaller the angle value is, the higher the sensitivity is. However, the bubble angle of inclination is not found in the calibration specifications JJF 1085-2002 [3], industry standard JB/T 11272-2012 [4], and QB/T 4621-2013 [5]. In this paper, a method of measuring the angle of inclination for the spirit levels based on the calibration device is proposed, and the measurement uncertainty is evaluated.

2. Calibration method for the bubble angle of inclination
A special calibration device as shown in Figure 1 is constructed, which is mainly composed of platform, reading microscope, wide range dauge, dauge bracket, fixed support, lifting support, etc. The platform is horizontally placed on the fixed support and lifting support, and the support axis spacing is L (for convenience of calculation, L is 500mm or 1000mm). Install the wide range dauge on the rigid bracket, adjust the dauge so that its measuring rod is coaxial with the lifting support and perpendicular to the platform. The calibrated spirit level is placed on the worktable, and the longitudinal direction of the rule is consistent with that of the platform.
Figure 1. Diagram of calibration device for the bubble angle of inclination
1 - platform; 2 - spirit level; 3 – reading microscope; 4 – wide range dauge;
5 – dauge barcket; 6 - fixed support; 7 – lifting support; 8 – lifting screw; 9 – base level

When measuring, first rotate the lifting nut to make the level bubble in the horizontal position of
the spirit level's center, and adjust the pointer of the wide range dauge to the zero marking line. Use a
reading microscope to measure the distance \( l_1 \) between the bubble and the right marking line. Rotate
the lifting screw, when the bubble moves to the right mark line and read the reading \( h_1 \) of the wide
range dauge. Then the angle value of the level bubble of the level bar \( \tau_1 \) according to the following
formula

\[
\tau_1 = \frac{2 \text{mm} \times 10800' \times h_1}{\pi L l_1}
\]  

(1)

Where \( \tau_1 \) is the angle of inclination when the bubble moves to the right, \( h_1 \) is the lifting support
rising height, \( L \) is the spacing of two supports, \( l_1 \) is the axial movement of the bubble when it
moves to the right.

The angle of inclination \( \tau_2 \) for the bubble moving to the left is measured by the same method. The
bubble angle of inclination \( \tau \) of the spirit levels is calculated by the following formula

\[
\tau = \frac{\tau_1 + \tau_2}{2}
\]  

(2)

3. Evaluation of measurement uncertainty

3.1. Measurement result

According to the above method, the bubble angle of the spirit level with nominal accuracy of
0.5mm/m is measured, and the measurement results are shown in Table 1.

Table 1. Measurement results of the bubble angle of inclination for the spirit levels

| measured parameters | measured result   |
|---------------------|------------------|
| \( L \)             | 1000.0 mm        |
| \( h_1 \)           | 6.811 mm         |
| \( l_1 \)           | 1.242 mm         |
| \( h_1 \)           | 6.251 mm         |
| \( l_1 \)           | 1.250 mm         |
| \( \tau_1 \)        | 37.71'           |
| \( \tau_1 \)        | 34.38'           |
| \( \tau \)          | 36.05'           |
3.2. Measurement model
According to the calibration method, the measurement model is

\[ \tau = \frac{(\tau_1 + \tau_2)}{2} = \frac{1\text{mm} \times 10800'}{\pi L} \left( \frac{h_1 + h_2}{l_1 + l_2} \right) \]  

(3)

Where \( \tau \) is the angle of inclination, \( \tau_1 \) is the angle of inclination when the bubble moves to the right, \( h_1 \) is the lifting support rising height, \( l_1 \) is the axial movement of the bubble when it moves to the right, \( \tau_2 \) is the angle of inclination when the bubble moves to the left, \( h_2 \) is the lifting support rising height, \( l_1 \) is the axial movement of the bubble when it moves to the right, \( L \) is the spacing of the two support.

Because each factor is independent of each other, the combined standard uncertainty is calculated by [6]

\[ u_c^2(\tau) = c_1^2u^2(L) + c_2^2u^2(h_1) + c_3^2u^2(l_1) + c_4^2u^2(h_2) + c_5^2u^2(l_2) \]  

(4)

Where coefficients of sensitivity are calculated by the following formulas

\[ c_i = \frac{\partial \tau}{\partial x_i} = \frac{\tau}{L} \]  

(5)

\[ c_2 = \frac{\partial \tau}{\partial h_1} = \frac{1\text{mm} \times 10800'}{\pi L l_1} \]  

(6)

\[ c_3 = \frac{\partial \tau}{\partial l_1} = \frac{1\text{mm} \times 10800'}{\pi L l_1^2} \]  

(7)

\[ c_4 = \frac{\partial \tau}{\partial h_2} = \frac{1\text{mm} \times 10800'}{\pi L l_2} \]  

(8)

\[ c_5 = \frac{\partial \tau}{\partial l_2} = \frac{1\text{mm} \times 10800'}{\pi L l_2^2} \]  

(9)

3.3. The source of standard uncertainty
The source of standard uncertainty factors of measured results is shown in Table 2.

| \( u(x_i) \)          | the source of standard uncertainty                              | coefficient of sensitivity \( c_i \) | \( |c_i| \times u(x_i) \) |
|-----------------------|-----------------------------------------------------------------|-------------------------------------|--------------------------|
| \( u(L) \)            | the standard uncertainty introduced by the measurement of \( L \) | -0.0361'/mm                        | 0.0624'                  |
| \( u(h_1) \)          | the standard uncertainty introduced by the measurement of \( h_1 \) | 2.7686'/mm                        | 0.0259'                  |
| \( u(l_1) \)          | the standard uncertainty introduced by the measurement of \( l_1 \) | -15.1865'/mm                      | 0.0864'                  |
| \( u(h_2) \)          | the standard uncertainty introduced by the measurement of \( h_2 \) | 2.7502'/mm                        | 0.0257'                  |
| \( u(l_2) \)          | the standard uncertainty introduced by the measurement of \( l_2 \) | -13.753'/mm                       | 0.0782'                  |
3.4. Calculation of standard uncertainty

3.4.1. Calculation of \( u(L) \)
The deviation of spacing of two support is \( \Delta L \leq 3 \text{mm} \), assuming that the normal distribution is obeyed in the measurement range, then the standard uncertainty caused by the deviation of spacing of two support is

\[
u(L) = \frac{3 \text{mm}}{\sqrt{3}} = 1.7321 \text{mm}
\]  

(10)

3.4.2. Calculation of \( u(h_1) \)
Under the same conditions, the rising height of lifting support corresponding to the same axial movement distance was measured for 10 times, and the standard deviation of single measurement experiment was 0.0035mm, then

\[
u(h_1) = 0.0035 \text{mm}
\]  

(11)

The MPE of the wide range dauge is 0.03mm, assuming that the normal distribution is obeyed in the measurement range, then the standard uncertainty caused by wide range dauge error is

\[
u(h_2) = \frac{0.03 \text{mm}}{(2\sqrt{3})} = 0.0087 \text{mm}
\]  

(12)

Since \( u(h_{1.1}) \) and \( u(h_{1.2}) \) are not related, then

\[
u(h) = \sqrt{u^2(h_{1.1}) + u^2(h_{1.2})} = 0.0094 \text{mm}
\]  

(13)

3.4.3. Calculation of \( u(l_1) \)
Under the same conditions, the axial movement of the bubble when it moves to the right was measured for 10 times, and the standard deviation of single measurement experiment was 0.0049mm, then

\[
u(l_{1.1}) = 0.0049 \text{mm}
\]  

(14)

The MPE of the reading microscope is 0.01mm, assuming that the normal distribution is obeyed in the measurement range, then the standard uncertainty caused by reading microscope indication error is

\[
u(l_{1.2}) = \frac{0.01 \text{mm}}{(2\sqrt{3})} = 0.0029 \text{mm}
\]  

(15)

Since \( u(l_{1.1}) \) and \( u(l_{1.2}) \) are not related, then

\[
u(l) = \sqrt{u^2(l_{1.1}) + u^2(l_{1.2})} = 0.0057 \text{mm}
\]  

(16)

3.4.4. Calculation of \( u(h_2) \)
Since \( h_2 \) and \( h_1 \) are measured in the same way, there are

\[
u(h_2) = u(h_1) = 0.0094 \text{mm}
\]  

(17)

3.4.5. Calculation of \( u(l_2) \)
Since \( l_2 \) and \( l_1 \) are measured in the same way, there are

\[
u(l_2) = u(l_1) = 0.0057 \text{mm}
\]  

(18)

3.5. Combined standard uncertainty

According to the above analysis, according to formula (4), the combined standard uncertainty \( u_c(\tau) \) of the measurement results of the angle of inclination for spirit levelr can be calculated as follows
\[ u_c(\tau) = \sqrt{c_1^2u^2(L) + c_2^2u^2(h_1) + c_3^2u^2(l_1) + c_4^2u^2(h_2) + c_5^2u^2(l_2)} = 0.137' \quad (19) \]

### 3.6. Expanded uncertainty

Taking the inclusion factor \( k = 2 \), the expanded uncertainty of the angle of inclination for spirit level is

\[ U = ku_c(\tau) = 2 \times 0.137' \approx 0.28' \quad (20) \]

### 4. Conclusion

By using the proposed calibration method, the bubble angle of inclination for the spirit levels can be realized. The bubble angle of inclination is one of the important metrological characteristics of spirit levels which reflects the sensitivity of the spirit levels. It is suggested that this measurement characteristic should be added in the revision of relevant technical specifications.

**References**

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