In-situ calibration technology of liquid level with precise laser ranging

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Abstract: Here, in order to calibrate the magnetostrictive liquid-level meter in situ, a set of in-situ calibration device for magnetostrictive liquid-level meter is designed. The structure and working principle of the device are described, and the experimental test and error analysis are carried out for the parts of the in-situ calibration device. Finally, according to the modern instrument and error theory, the accuracy of the calibration device is assessed, and the field calibration experiment of magnetostrictive liquid-level meter is carried out. The theoretical analysis and field experiment results show that the calibrated device can meet the in-situ calibration requirements of the magnetostrictive liquid-level meter with a range of 0–6 m and a precision of 1 mm.

1 Introduction

In the process of oil trade, usually by oil-level height changes before and after the trade indirectly calculated the volume of trading in oil, the oil surface height measurement is the key in the process of oil trade [1]. With the rapid development of high and new technology such as microcomputer, ultrasonic, radar, laser, electron and sensor, more and more advanced equipment are developed. In the measurement of liquid level, the traditional manual sounding method is gradually replaced by the advanced-level meter equipment [2]. The magnetostrictive liquid level meter is widely used in oil fields [3], oil refineries, industrial control, chemical industry and ship and oil depot because of its high accuracy, large measuring range, simple operation and easiness to maintain [4].

At present, after the completion of the magnetostrictive liquid level meter installed only on the level zero and the maximum range for verification, and not on the whole range test, the parameters of the liquid level gauge is still using the parameters of the test in the laboratory. During the transportation of the liquid level gauge, problems such as guide rod bending and floating ball deformation may occur, and the perpendicularity after on-site installation is difficult to reach the accuracy of the laboratory [5], which ultimately results in the actual application accuracy of the liquid level gauge being lower than its nominal accuracy. This is an urgent problem to be solved. In order to solve this problem, a magnetostrictive liquid-level calibrator is designed to ensure the accuracy and reliability of the liquid-level meter in practical application.

2 Structure and working principle of the magnetostrictive liquid-level meter in-situ calibration device

Precision rangefinder is used as the length standard in the magnetostrictive liquid level gauge in-situ calibration device. The basic principle is that the range reference value is obtained by the precision rangefinder, and a liquid level value is simultaneously measured by the magnetostrictive liquid level meter. The range reference value is compared with the liquid level value, and the calibration result is obtained through software analysis [6]. The design and working principle of the calibration device will be described in detail below.

The code and name of each part of the device are as follows: 1 – floating ball lifting device, 2 – camera, 3 – roof, 4 – electronic level, 5 – reflecting prism, 6 – magnetostrictive liquid-level meter, 7 – level gauge display, 8 – precise rangefinder (built-in electronic level), 9 – two dimensional shift base, 10 – TLINK controller, and 11 – PC. Fig. 1 shows the schematic diagram of the calibration device in the left side, and the right image is the field calibration chart.

We can see from the diagram, the floating ball lifting device through three feet to support contact with the ground, telescopic rod with ground separation among lifting device, telescopic rod at the top with a circular bubble, measured by three feet to support before adjusting rod levelling circular bubble. The lifting device is operated by pneumatic lifting. In order to prevent the telescopic rod from slipping in the measurement process, the telescopic rod can be locked to a certain length, so as to avoid the measurement deviation caused by the slip of the telescopic rod. Due to the lifting device of machining error, telescopic rod gap between reason, lead to roof appeared in the process of ascension small tilt, leading to a prism in vertical direction movement, bring measurement deviation. In order to compensate the deviation caused by the tilt of the roof, an electronic level instrument is placed above the prism to measure the angle between the roof and the horizontal plane in real time [7]. The deviation value is calculated through the distance between the prism and the floating ball centre to compensate the ranging value of the precision rangefinder.

Floating ball in the direction of movement on the surface of the liquid is as the direction of the plumb line; therefore, the precision of rangefinder ranging axis direction should be plumb line direction, also due to the precision of rangefinder installation error and manufacture error and panning base causes ranging axis and
the vertical line is not parallel, in order to compensate the deviation on the impact of rangefinder built an electronic level, real-time measuring range axis angle, distance value reduction to the direction of the plumb line. Due to the tilt of the roof, the rangefinder cannot be precise in the centre of the prism in the calibration process, so the precision of the prism can be realised by installing the pan base at the bottom of the rangefinder. The calibration of the magnetostrictive liquid-level gauge is relatively dark, so the camera can collect the laser point and the centre of the prism through the camera to realise the visualisation. Each instrument is connected to a PC through a cable and a TLINK controller.

The PC terminal can send and collect the instructions of each instrument through measuring software, and the software can display and store the collected data in real time. System data have a distance, liquid-level value, angle and temperature, measurement software by multi-source data of joint adjustment, liquid-level value, and the reference value of the deviation value are obtained; finally the level value and deviation value for fitting and interpolation are obtained by the level in the whole range within the scope of the revised and the output correction table.

3 Calibration device error analysis and accuracy evaluation

3.1 Abbe error

Lifting device of the telescopic rod through the roof drives the floating ball and prism movement; the floating ball movement of the centre line of trajectory is not collinear with prism, roof occurred in the process of measuring swing, so the abbe error is caused [8], as shown in Fig. 2. When measuring the liquid-level gauge guide rod and prism centre distance \( L = 300 \) mm, the motion of the roof on the in-plane vertical direction Angle \( \varphi = 1'' \) is caused by the abbe error measurement uncertainty components

\[
u = L \times \sin \varphi = 0.001 \text{ mm}\]

3.2 Plane error of the base

In order to solve the precision problem of the rangefinder, the rangefinder is placed on the 2-D translation base, and the laser point is accurately adjusted by adjusting the two-dimensional shift base after the range finder is levelled. The translation base is shown in Fig. 3.

The base can be adjusted around the left and right by two handwheels. The translation range of the pedestal is 25 mm \times 25 mm and the height is 10 cm. In order to ensure flatness in the translation range of the base, this paper uses Leica AT901-B laser tracker [9] to test the flatness of the base, as shown in Fig. 4.

The ambient temperature in the laboratory is 22°C. Before the experiment, the base is placed on a stable platform, three supporting feet are fixed, a target is fixed above the base, and the laser tracker ball prism is placed on the target. At the beginning of the experiment, a point coordinate was measured every 5 mm and a total of 36 point coordinates were collected in the plane. MATLAB software is used to do the least square plane fitting and processing for point coordinates [10].

\[
z = -63.626343 - 0.013244x - 0.000039y \quad (2)
\]

The fitting results are shown in Fig. 5.

The distance between the observed points and the plane can be obtained, and the distance from each point to the fitting plane can be obtained, as shown in Fig. 6.

The root-mean-square error of the fitting plane is 0.0028 mm and the maximum error is −0.01 mm.

3.3 Stability error of lifting device

In the calibration process of magnetostrictive liquid-level meter, the extension rod extension of the lifting device can reach 6 m. Due to the machining error of the lifting device and the gap between the telescopic rod, it is easy to cause the sloshing at the maximum range of the lifting device, which leads to the poor stability of the whole calibration device. In order to test the stability of the lifting device, the stability experiment is carried out near the maximum range of the liquid-level meter. In the experiment, the measured value of the liquid-level meter and the range of the precision rangefinder are collected, and 50 sets of data are collected. The results of the experiment are shown in Fig. 7.

From the above picture, it can be seen that the readings near the maximum range of the liquid-level meter are unstable, the difference between the maximum and the minimum is up to 7 mm, and the repeatability accuracy of the measurement is obviously lower than the repeatability precision of the precision rangefinder. The error in the liquid-level gauge is 1.04 mm, and the error in the precision rangefinder is 0.14 mm. Therefore, the stability of the lifting device is obviously higher than that of the liquid-level meter.

3.4 Accuracy evaluation of in-situ calibration device for magnetostrictive liquid-level gauge

Here, the liquid-level gauge with a range of 0–6 m and a precision of \( \pm 1 \) mm is taken as the research object for in-situ calibration. According to the theory of metrology, the accuracy of the standard device should be higher than the 0.3–1 magnitude of the tested
equipment, so the uncertainty of the whole calibration device should be ≤0.33 mm, so the theoretical uncertainty of the in-situ calibration device should be evaluated [11].

i. The uncertainty component caused by the precision rangefinder
   The ranging accuracy of precision range finder can reach ±0.1 mm within 6 m range. Assuming that it obeys uniform distribution, the uncertainty component is
   \[ u_1 = \frac{0.1}{\sqrt{3}} = 0.06 \text{ mm} \] (3)

ii. The uncertainty component caused by the correction of the ranging axis.
   The axis tilt deviation of the rangefinder is compensated by the electronic-level instrument, and its angle measuring accuracy is ±1″. The range error caused by the maximum distance 6 m is 0.03 mm.
   Assuming that it obeys uniform distribution, the uncertainty component is
   \[ u_2 = \frac{0.03}{\sqrt{3}} = 0.02 \text{ mm} \] (4)

iii. Increase the uncertainty component caused by the stability of the device.
   The stability of the lifting device is measured to be ±0.14 mm by experiment, assuming that it is subject to uniform distribution.
   \[ u_3 = \frac{0.14}{\sqrt{3}} = 0.08 \text{ mm} \] (5)

iv. The uncertainty component caused by the flatness of the base.
   The test shows that the flatness of the pedestal is 0.0028 mm, assuming that it obeys uniform distribution.
   \[ u_4 = \frac{0.0028}{\sqrt{3}} = 0.002 \text{ mm} \] (6)

v. The uncertainty component caused by ambient temperature
   The uncertainty of temperature measurement is \( u_t = 0.2°C \), and the material expansion coefficient \( [12] \alpha = 0.000012°C^{-1} \) of the guide rod of the liquid-level meter, and the length of the length is 6 m, the uncertainty component of the length measurement caused by the temperature is as follows:
   \[ u_5 = \alpha \times u_t \times l = 0.01 \text{ mm} \] (7)

vi. The uncertainty component caused by Abbe error
   The distance between the guide rod and the centre of the prism of the magnetostrictive liquid-level gauge is \( L \) when the maximum value is 300 mm and the offset angle error is ±1″.
   \[ u_6 = 250 \times \sin 1'' = 0.001 \text{ mm} \] (8)

The uncertainty of components is independent of each component of uncertainty.
   \[ u_c = u_1^2 + u_2^2 + u_3^2 + u_4^2 + u_5^2 + u_6^2 = 0.11 \text{ mm} \] (9)

Taking \( k = 2 \), the expanded uncertainty is \( U = 2 \times 0.11 = 0.22 \text{ mm} \). The uncertainty of calibration results of the in-situ calibrated float type liquid-level gauge is \( U = 0.22 \text{ mm} (k = 2) \).

4 Field calibration experiment of liquid-level meter

After the device was completed, the field calibration experiment was carried out on the magnetostrictive liquid-level meter. The experimental site was selected in a shipyard in Jiangsu. The model was RDHL-A1, the range was 0–5.98 m, and the precision was 1 mm. The field test is shown in Fig. 8.

Field tests were carried out on the magnetostrictive-level gauge for uplink and downlink tests. After the test is completed, the deviation between the liquid level of the liquid-level gauge and the reference value of the calibration device is obtained, and the test data are shown in Fig. 9.

![Fig. 6 Base point coordinates error distribution diagram](image)

![Fig. 7 Folding map of lifting device](image)

![Fig. 8 Site test chart of liquid-level meter](image)

![Fig. 9 Field test data of liquid-level meter](image)
\[
\sigma_i = \sqrt{\frac{\sum_{i=1}^{n} v_i^2}{n-1}} 
\]

The error in calculating the middle error according to the formula:

\[
\sigma_i = 1.253 \frac{\sum_{i=1}^{n} |v_i|}{\sqrt{n(n-1)}} 
\]

order

\[
\frac{\sigma_i}{\sigma} = 1 + \mu 
\]

if

\[
|\mu| \geq \frac{2}{\sqrt{n-1}} 
\]

It shows that there are systematic errors in the observed values. In the experimental data, \(n = 22\), \(2/\sqrt{n-1} = 0.44\) mm and Table 1 are the results of the system error analysis of the liquid-level gauge.

### ii. Discrimination of gross error

Here, we use the \(3\sigma\) criterion to judge and eliminate gross error [14]. Table 2 is the test of data gross error.

### iii. Precision analysis

The calibrating device uses the precision ranging value as the reference value of the liquid-level meter, so the accuracy of the system is evaluated through the root-mean-square error. The RMSE = 0.10 mm is calculated and the accuracy of the liquid-level gauge is satisfied. The field calibration experiment of magnetostrictive liquid-level meter improves the measurement precision and efficiency, meets the requirements of the in-situ calibration of the liquid-level meter in the large capacity measurement of the ship's cabin capacity, and realises the unity of the in-situ calibration of the liquid-level meter and the traceability of the quantity value. It provides the in-situ calibration for the magnetostrictive liquid-level meter. A certain reference and reference significance.

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## 7 References

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