The Non-contact Precision Measurement for Spherical Metrology Tank

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Abstract. As one metrology tool, sphere tank plays an important role in many industries, such as petrochemical industry, and it is necessary to carry out the research related with sphere tank volume calibration. The method of sample and analysis for three dimension data cloud was discussed, and the main content included data sample principle, noise reduction, gross error identification, radius fitting and volume calculation. One preliminary experiment was done to test this method. The experimental result showed that there was consistency between total station method and data cloud analysis method for the measurement on the level diameter of spherical tank with one difference 1mm, but one big difference occurred between the data from two methods.

1. Introduction

Liquefied gas volume is one important metrology method for commercial transaction in international trade, and the main measurement tool is spherical tank. Measurement of liquid levels and the use of the tank capacity table permit the assessment of volume of the liquid held in store or transferred. In order to be accepted for fiscal or custody transfer application, spherical tanks shall be calibrated carefully to ensure the accuracy of volume measurement of liquid contained [1, 2].

There are mainly three volume calibration methods used for vertical tank, which are strapping method, optical reference line method and optical triangulation method. The strapping method is the reference for other reference methods, and has been used for about 50 years. Based on the measurement of circumferences at each course by using strap, the diameter at each height can be calculated, and then the liquid volume in the tank can be determined [3]. For optical reference method, one vertical reference line is established by using an optical device. The circumference of bottom course is measured by strapping method, and the radial offsets of higher courses are measured optically [4]. The optical triangulation method also known as OTM is an extension of the optical reference line method. With two theodolites at a known distance, the target points on tank shell are determined by triangulation [5, 6].

With the requirement of improving calibration efficiency, the three calibration methods above cannot meet the requirement, because they all are not automatic measurement method.

The laser scanning method is one new approach for non-contact space geometry measurement, and can acquire large amount of information within short time. In this paper, one automated measuring system for liquid volume was researched based on laser scanning method. Distance measurement by laser ranging technology and angular measurement by optic-encoding principle was applied to acquire coordinate values of points in each course. Iterative method was used to deduce the radius at each course height. One comparison experiment was designed to validate the method discussed.
2. The non-contact precision measurement system

The measurement system for coordinates of points in tank shell is shown as Figure 1. The 3D laser scan instrument was installed firmly on the bottom of vertical tank, and adjusted to horizontal level.

During measurement, the laser is transmitted from the instrument to the surface of tank shell. According to the phase-shift principle, the distance \( r_p \) between point \( P \) and instrument can be achieved by Eq. 1

\[
r_p = \left[ \lambda (m + \epsilon) / 2 \right]
\]

Where \( r_p \) is measured distance; \( \lambda = \lambda_0 / n \) is wavelength of laser and \( n \) is the refractive index; \( m \) is the integral order of interference fringes; \( \epsilon \) is the partial order of interference fringes. Vertical angle \( \beta_p \) and horizontal angle \( \alpha_p \) for each point are acquired by optical grating [7,8]. Therefore, with the center of the instrument as original of coordinate and plumb-line as vertical axis, one rectangular coordinate was established as shown in Figure 2.

The coordinate value \((x_p, y_p, z_p)\) of point \(P\) in tank shell could be deduce by Eq. 2 based on the three parameters \(r_p\), \(\beta_p\) and \(\alpha_p\).

\[
\begin{align*}
x_p &= r_p \cos \beta_p \cos \alpha_p \\
y_p &= r_p \cos \beta_p \sin \alpha_p \\
z_p &= r_p \sin \beta_p
\end{align*}
\]

The method can be automated to scan the tank both horizontally and vertically. It is obvious that the 3D laser scan method is more sophisticated and advanced compared to all others, and is primarily an internal calibration technology.

3. The algorithm of radius fitting for measured points of each course

The algorithm of radius fitting for measured points of each course is very important for computation of vertical tank volume. According to technical requirement of OIML R71 [9], the vertical tank is regarded as ideal cylinder. Therefore, the core problem of data processing is the fitting of circle curve \((x - x_c)^2 + (y - y_c)^2 = R^2\), and deducing the equivalent radius \(R\) for each course at different height. The equivalent radius \(R\) is the most important parameter for volume computation, and algorithm based on iterative method was applied to carry out the research on fitting of \(R\).

The fitting of circle curve of data scanned from vertical tank is one problem of minimization of nonlinear objective function with multi variables in nature, to which calculation by iteration is one of
the most effective solutions. For this algorithm, there is no requirement for derivation of function, and it can be used whether the objective function is continuous and differentiable or not.

Firstly, the center of fitting curve \((x_{c0}, y_{c0})\) is initialized and set to \((0, 0)\) generally, and then the objective function \(f_{\text{obj}}\) is defined as Eq. 3

\[
f_{\text{obj}} = |R_m - R_{m-1}|
\]

(3)

Where \(R_m\) is the estimated value of radius when iterative step is \(m\). The iteration algorithm is as Eq. 4

\[
\begin{align*}
x_{c_m} &= \sum_{i=1}^{n} x_i / n - (R_m / n) \sum_{i=1}^{n} \frac{x_i - x_{c(m-1)}}{R_i} \\
y_{c_m} &= \sum_{i=1}^{n} y_i / n - (R_m / n) \sum_{i=1}^{n} \frac{y_i - y_{c(m-1)}}{R_i} \\
R_m &= \left(\frac{(x_i - x_{c(m-1)})^2 + (y_i - y_{c(m-1)})^2}{n}\right)^{1/2}
\end{align*}
\]

(4)

Where \((x_i, y_i), \ i=1,2,\ldots,n\) are the \(n\) points obtained from measurement. Calculate \(x_{c_m}, y_{c_m}, R_i\) and \(R_m\) until the new value of \(R_m\) differs from old one by less than \(\delta\), where \(\delta\) is the calculation threshold, and usually set to 0.1mm. If the iterative computation is finished, the latest values of \((x_{c_m}, y_{c_m})\) and \(R_m\) are regarded as the best fits of center and radius for sampled points on tank shell. Considering the 3D laser scanning instrument is installed near the center of tank bottom, the initialized value of \((x_{c0}, y_{c0})\) can be set by the Eq. 5 to accelerate the computation.

\[
x_{c0} = \sum_{i=1}^{n} x_i / n, \ y_{c0} = \sum_{i=1}^{n} y_i / n
\]

(5)

4. Experiment and Data Analysis

To verify the measuring method discussed above, a comparison experiment system was designed, in which one 1000m\(^3\) vertical tank with top roof and 8 courses was used as test object. The height and diameter of this tank is 8.9m and 12.0m respectively. Two series of radius in each course at different height (about 1/4 and 3/4 of course height) were measured by strapping method complying with the requirement of OIML R71. It took about 10 days to complete the strapping work. The calculated radius value obtained from strapping method is regarded as reference value. The laser measurement system was installed near the middle of tank bottom, and the configuration parameters were list in Table 1.

| Parameters of laser measurement system. |
|-----------------------------------------|
| Interval between sampled points | Maxima of Ranging | Maximal ranging scope | Angle measurement scope | Sampling Rate | Time-consuming |
| Value | 2 [mm] | ±2 [mm] | 80 [mm] | \(360^\circ \times 320^\circ\) | 120,000 [points/s] | 2 [min] |

The space distribution of measured points by laser scanning method was shown in Figure 3 and Figure 4.
The data of scanned points were processed by using iterative algorithm discussed to achieve the fitting value of radius at each course. The radius at equatorial plane is 6141.3mm, which is only about 1mm difference from traditional measurement method.

Based on the comparison experiment, it can be concluded that the radius value obtained from 3D laser scan method is well consistent with reference value achieved by manual method. It took less than one hour for the whole calibration in situ, so the work efficiency can be improved greatly by the new method.

5. Conclusions
According to the technical requirements of international legal metrology recommendations, one liquid volume measurement method for spherical petroleum tank metrology was presented, based on 3D laser scan principle, with measurement errors of distance and angle are 2mm and 2" respectively. Comparison experiment was carried out with manual method. The experimental results show that the local curve features of tank shell were described correctly.

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6. References
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