Volume measurement block designed by adaptive algorithm

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Abstract. Volume is one of the most important parameters for mass measurement in the air. To measure the weight volume parameters of the hydrostatic technique volume comparator, for the shape and height parameters had strict requirements. Research on the mass and processing of the special weights usually exceeds the size range and cannot be measured. For the problem of volume measurement, a design method of volume measuring block based on adaptive algorithm is presented. To effectively improve the ability of volume measurement by volume comparison method, eliminate the limitations of large size and low-density weights in the volume comparator, extend the measuring capacity of volume measuring system. Meet the requirement of measuring volume parameters of mass measurement process and improve the accuracy of volume measurement.

1. Introduction
Volume is one of the most important parameters for mass measurement in the air[1]. The Researching of the present mass volume measurement focus on six accepted methods for the determination. The hydrostatic technique method which comparing the test weight with a reference weight both in air and in a liquid of known density, is the most accurate method[2][3]. The hydrostatic technique method commonly used to a volume comparator, such as VC1005. To measure the weight volume parameters of the hydrostatic technique volume comparator, for the shape and height parameters had strict requirements. Research on the mass and processing of the special weights usually exceeds the size range and cannot be measured.

For the problem of volume measurement, a design method of volume measuring block based on adaptive algorithm is presented. Ensure that the test weight can be placed horizontally to the volume comparator position for volume measurement. The technical characteristics of the algorithm based on density and volume weight of the comparator to be measured, adaptive calculates the required volume measuring block size. Besides, the method can effectively reduce the air bubble of the bottom groove of the weight in the placing process.

2. The designs
The volume measuring block used for volume measurement, requiring the surface to be machined into a groove for stabilizing test weight. Figure 1 is sketch map of the volume measuring block. Figure 2 shows an initial block of material to be machined into figure 1. The base of the initial block is Bw×Bd square, and the height is H (also can be a circle with a radius of R). The arc of the initial block is a part of the circular arc, and the weight of the cushion can be tightly jointed with the outer side of the test weight cylinder. The test weight diameter is R. Because the test weight is measured in the liquid (density is ρl), limited to the maximum capacity of the volume comparator measurement (Max) and electric weighing range (τ), so the mass of the block (m_b) also need according to the size and mass of
the test weight to be corresponding adaptive adjustment. Usually choose JF1 stainless steel material machining block, its density is 8000 kg/m$^3$. The volume, $V_d$, so the mass, $m_d = \rho_d \times V_d$.

The volume of the test weight, $V_t$; the density of the test weight, $\rho_t$; the mass of the test weight, $m_t = \rho_t \times V_t$. The volume of the reference weight, $V_r$; the density of the reference weight, $\rho_r$; the mass of the reference weight, $m_r = \rho_r \times V_r$.

The designs of the volume measuring block shall satisfy the following conditions:

\[
\begin{align*}
    m_t - \rho_t \times V_t &\leq Max \\
    m_t - \rho_t \times V_t + m_d - \rho_d \times V_d &\leq Max \\
    (\rho_t \times g - \rho_1 \times g) \times V_t + (\rho_d \times g - \rho_1 \times g) \times V_d &\leq \tau \\
    w &\leq B_w \\
    0 < h < H
\end{align*}
\]

Where: $m_t$, $m_r$, and $m_d$ are the masses of the test, reference weights and block, respectively; $V_t$, $V_r$, and $V_d$ are the volumes of the test, reference weights and block, respectively; $\rho_t$, $\rho_r$, and $\rho_d$ are the densities of the test, reference weights and block, respectively; $\rho_l$ is the density of a liquid used for volume measurement; $\tau$ is the electric weighing range of the volume comparator; $Max$ is the maximum capacity of the volume comparator; $H$ is the height of the initial block.

In Figure 3, the height of the block, $H$, the width of the top of the block, $w$. In Figure 1, $w = B_w$. In Figure 3, $w < B_w$. The rest of the block after cutting is treated as a cube with a groove. When the cutting width is equal to $B_w$, the volume measuring block continues to be cut, and the width of the block will not change and the height changes.

The cutting depth, $\text{dep}$ the height of the initial block after the cutting is $h$:

$$h = H - \text{dep}$$

In the cutting process, the arc angle corresponding to the sector ABC is $\theta$:

$$\theta = 2 \arccos \left( \frac{R - \text{dep}}{R} \right)$$

The area of the sector ABC consists of a triangular shape and a crescent shape:

$$S_{\text{fan}} = \pi R^2 \times \frac{\theta}{2\pi}$$

The area of the triangle:

$$S_{\text{delta}} = \frac{1}{2} w \times (R - \text{dep})$$

The area of the crescent:

$$S_{\text{cut}} = S_{\text{fan}} - S_{\text{delta}}$$
The volume of a part that has been cut off:

\[ V_{cut} = S_{cut} \times B_d \]

Due to the adaptive algorithm, the initial can be seen as a cube, as shown in Figure 4. The volume of the cube:

\[ V_{block} = Bw \times Bd \times H \]

The volume of the block after cutting:

\[ V = V_{block} - V_{cut} \]

The absolute value of the difference between the possible volume and the desired volume in the parameter space of the adaptive algorithm:

\[ DV = |V_{exp} - V| \]

Where: \( V_{exp} = V_d \)

Through the parameter space, search for the index which indicates the difference between possible volume values and the expected volume value is the minimum and then take advantage of this index to find the corresponding height value (H) and cutting depth (dep).

\[ [H_{index}, \text{dep}_{index}] = \min\{DV\} \]

\[ H = \min\{DV, H_{index}\} \]

\[ \text{dep} = \min\{DV, \text{dep}_{index}\} \]

The steps mentioned above give a complete calculation method of the volume measuring block. The processing parameters of the block can be determined by the steps described above.

3. Application analysis

The hydrostatic technique comparing the test weight with a reference weight both in air and in a liquid of known density \([1]\). This method in this paper as an example of the application steps of description and analysis.

The test weight is combined by gravity and buoyancy in the liquid, \( F_t \):

\[ F_t = (\rho_t g - \rho_l g)V_t \]

The volume measuring block is combined by gravity and buoyancy in the liquid, \( F_d \):

\[ F_d = (\rho_d g - \rho_l g)V_d \]

Total force, \( F_{total} \):

\[ F_{total} = (\rho_t g - \rho_l g)V_t + (\rho_d g - \rho_l g)V_d \]

The total force and the standard weight shall be compared in the liquid and shall not exceed the maximum range of the electronic balance.

\[ \frac{(\rho_t g - \rho_l g)V_t + (\rho_d g - \rho_l g)V_d}{(\rho_d g - \rho_l g)} = \frac{(\rho_t g - \rho_l g)V_t - (\rho_d g - \rho_l g)V_t}{(\rho_d g - \rho_l g)} \]

Where, the volume of the test weight \( V_t \) is the theoretical value. The \( V_d \) is obtained by the above equation, and the square or round dimensions at the bottom of the block are known, and then the H and dep can be obtained by the adaptive algorithm. So we can do the machining according to the size and get the volume measuring block.

Figure 5. Weight use mass measurement Block
Fig. 5 is an example of a weight use mass measurement Block. First, the test weight to be measured lies flat on the volume measuring block, and the standard weight is consistent with the nominal value of the test weight to be measured. Test and standard are simultaneously placed in a liquid for comparative measurements to obtain $V_{\text{total}}$. Secondly, the test weight is removed and the standard weight is replaced with the measured value of the volume measuring block, and $V_{\text{st}}$ can be obtained by measuring in the liquid. Finally, test weigh volume is calculated, $V_t = V_{\text{total}} - V_{\text{st}}$. Through the above steps to complete weight volume measurement.

4. Calculation example
Take 1 kg aluminium alloy weight as an example, which density is about 2700 kg/m$^3$, radius is 40 mm, the height is 98.08 mm. The volume comparator (such as VC1005) usually measuring the maximum height of 90mm, so this weight can't be measured. Therefore, it is necessary to place the weight on the volume measuring block to be measured in the equipment.

$$V_d = \frac{(\rho_r g - \rho_l g)V_t - (\rho_r g - \rho_l g)V_i}{(\rho_d g - \rho_l g)}$$

Where:
$\rho_r = 2.7$ g/cm$^3$, $\rho_d = 8$ g/cm$^3$, $\rho_r = 8$ g/cm$^3$, $\rho_l = 1.0$ g/cm$^3$, $V_t = 370.4$ cm$^3$, $V_r = 125$ cm$^3$. Through calculation,

$$V_d = 35.0529 \text{ cm}^3$$

This value is the theoretical design of the volume measurement block design target value, then the block can only change height $H$ and groove cutting depth $\text{dep}$. Using the above adaptive algorithm, the bottom dimension is designed to be 50×50 mm square, so the height variable $H$ and groove depth variable $\text{dep}$ are obtained. In actual machining process, the machining accuracy also needs to be considered. The machining accuracy is set to 0.005 mm, which is the stepping parameter of the control algorithm in adaptive algorithm.

The adaptive algorithm gives the spatial domain of all feasible solutions, in which the optimal machining size is:

$$H = 14.01 \text{ mm}, \ \text{dep} = 7.645 \text{ mm}.$$

5. Conclusions
The design method of volume measuring block based on adaptive algorithm is presented. The method comprises the following steps: using an adaptive algorithm to calculate the volume measuring block; using the measuring block, cylinder or OIML shape weight lying placed to the block; using mass comparison method to calculate the test weight volume is to be measured in liquid. When measuring, the test weight is placed horizontally on the volume measuring block, and the volume of the weight to be measured is measured by the hydrostatic technique method. This simple method is effective to solve the problem of volume size limit comparator.

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7. References
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