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INVESTIGATION ON DESIGN OF VOLUME MEASUREMENT SYSTEM OF WEIGHTS

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Abstract: To realize volume measurement of weights from 2 kg to 20 kg, three hydrostatic methods from annex B.7.4 of OIML R111-1 are described in this paper. Equipment with regard to volume measurement of weights from 2 kg to 20 kg having three operation procedures is designed and developed on the basis of three hydrostatic methods at National Institute of Metrology (NIM) in China. The equipment consists of robot arm for transferring weights, liquid bath, mass comparator, glass housing, two weight exchangers, two weight holders and controller. The equipment will enable to finish automatically operation of volume measurements according to each operation procedure.

Keywords: volume measurement; hydrostatic methods; robot arm; mass comparator

1. INTRODUCTION

There are several methods regarding volume determination of weights in OIML R 111-1 Edition 2004 (E). The most accurate measurement at all methods is method A including three methods with regard to hydrostatic comparison. Due to uncertainty budget of method A1 is better than those of method A2 and method A3, method A1 of annex B.7.4 in OIML R 111-1 Edition 2004 (E) is adopted as one measurement method of weights volume in the 'Weights Verification Regulation of China'. Mechanical mass comparator is used to mass determination of volume measurement of weights from 2 kg to 20 kg. The whole process of volume measurement is finished by hand of operator. On the one hand, it is difficult for one person to test weight volume of 20 kg under the circumstance of non-auxiliary transferring device. On the other hand, the readability and repeatability of mechanical mass comparator below 50 kg is lower than those of electronic mass comparator at the same level. For these reasons, it is very necessary for NIM to develop one volume measurement system with electronic mass comparator and auxiliary transferring device on the basis of method A1.

2. COMPARISON AMONG METHOD A1, METHOD A2 AND METHOD A3

The measurement procedures of method A1 are shown as a), b), c) and d) of figure1. Firstly, weighing mass of test weight (m_{ta}) in air and recording indication of mass comparator (I_{ta}). Secondly, weighing mass of reference weight (m_{ra}) in air and recording indication of mass comparator (I_{ra}). Thirdly, weighing mass of test weight (m_{tl}) in liquid and recording indication of mass comparator (I_{tl}). Finally, weighing mass of second reference weight in air and recording indication of mass comparator (I_{rl}). Note that determining the density of the liquid ρ_l in liquid bath and the air density ρ_a, ρ_{al} in air at the time of the test.

According to a), b), c) and d) of figure1, obtain equation (1) to (5) as follows:

$$m_{ta}g - F_{taB} = m_{ta}g - \rho_a g V_{ta} = I_{ta} g C_s \quad (1)$$

$$m_{ra}g - F_{raB} = m_{ra}g - \rho_a g V_{ra} = I_{ra} g C_s \quad (2)$$

$$m_{tl}g - F_{tlB} = m_{tl}g - \rho_l g V_{tl} = I_{tl} g C_s \quad (3)$$

$$m_{rl}g - F_{rl} = m_{rl}g - \rho_{al} g V_{rl} = I_{rl} g C_s \quad (4)$$

$$m_s g - \rho_a g V_s = I_s g \quad (5)$$

Where $C_s = \dfrac{1}{1-\dfrac{\rho_{as}}{\rho_s}}$ is obtained by the equation (5).

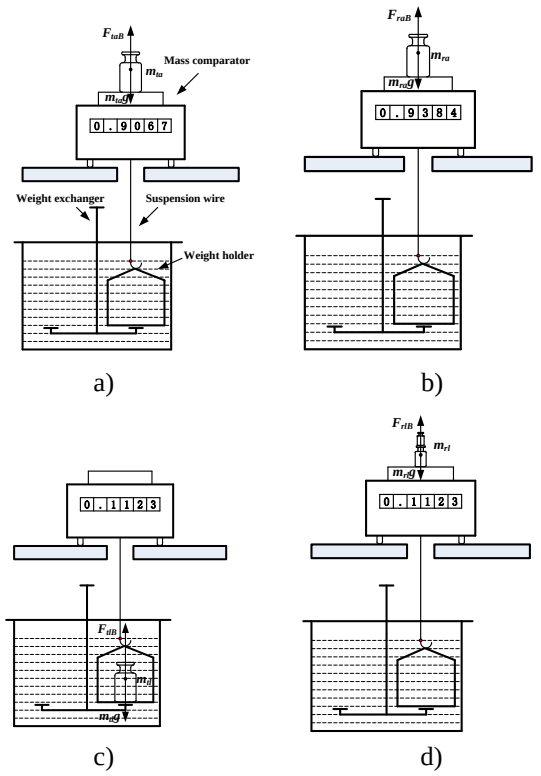


Figure 1 Measurement procedures of method A1

Equation (1) – Equation (2) is shown as follows:

$$(m_{ta}-m_{ra})-\rho_a(V_{ta}-V_{ra})=(I_{ta}-I_{ra})C_s \quad (6)$$

Equation (3) – Equation (4) is shown as follows:

$$(m_{tl}-m_{rl})-\rho_l V_{tl}+\rho_{al}V_{rl}=(I_{tl}-I_{rl})C_s \quad (7)$$

Where $m_{ta}=m_{tl}$, $V_{ta}=V_{tl}=V_t$, Equation (6) – Equation (7) is shown as follows:

$$V_t=\frac{(I_{ta}-I_{ra})C_s-(I_{tl}-I_{rl})C_s+m_{rl}(1-\frac{\rho_{al}}{\rho_{rl}})-m_{ra}(1-\frac{\rho_a}{\rho_{ra}})}{\rho_l-\rho_a} \quad (8)$$

Equation (9) and (10) are obtained by equation (6) and (7) respectively.

$$V_{ta}=\frac{(m_{ta}-m_{ra})-(I_{ta}-I_{ra})C_s+\rho_a V_{ra}}{\rho_a} \quad (9)$$

$$V_{tl}=\frac{(m_{tl}-m_{rl})-(I_{tl}-I_{rl})C_s+\rho_{al}V_{rl}}{\rho_l} \quad (10)$$

Where $m_{ta}=m_{tl}=m_t$, $V_{ta}=V_{tl}$, Equation (9) – Equation (10) is shown as follows:

$$(\rho_l-\rho_a)m_t=\rho_l m_{ra}-\rho_l\rho_a V_{ra}-(\rho_a m_{rl}-\rho_a\rho_{al}V_{rl})+\rho_l(I_{ta}-I_{ra})C_s-\rho_a(I_{tl}-I_{rl})C_s \quad (11)$$

$$m_t=\frac{\rho_l m_{ra}-\rho_l\rho_a V_{ra}-(\rho_a m_{rl}-\rho_a\rho_{al}V_{rl})+\rho_l(I_{ta}-I_{ra})C_s-\rho_a(I_{tl}-I_{rl})C_s}{(\rho_l-\rho_a)} \quad (12)$$

Equation (13) is obtained through equation (12) divided equation (8).

$$\rho_t=\frac{\rho_l[m_{ra}(1-\frac{\rho_a}{\rho_{ra}})+(I_{ta}-I_{ra})C_s]-\rho_a[m_{rl}(1-\frac{\rho_{al}}{\rho_{rl}})+(I_{tl}-I_{rl})C_s]}{[m_{ra}-\rho_a\frac{m_{ra}}{\rho_{ra}}+(I_{ta}-I_{ra})C_s]-[m_{rl}-\rho_l\frac{m_{rl}}{\rho_{rl}}+(I_{tl}-I_{rl})C_s]} \quad (13)$$

Where $C_a=1-\dfrac{\rho_a}{\rho_{ra}}$, $C_{al}=1-\dfrac{\rho_{al}}{\rho_{rl}}$, $\Delta m_{wa}=(I_{ta}-I_{ra})C_s$, $\Delta m_{wl}=(I_{tl}-I_{rl})C_s$

$$\rho_t=\frac{\rho_l(C_a m_{ra}+\Delta m_{wa})-\rho_a(C_{al}m_{rl}+\Delta m_{wl})}{(C_a m_{ra}+\Delta m_{wa})-(C_{al}m_{rl}+\Delta m_{wl})}=\frac{\rho_l(C_a m_{ra}+\Delta m_{wa})-\rho_a(C_{al}m_{rl}+\Delta m_{wl})}{C_a m_{ra}+\Delta m_{wa}-C_{al}m_{rl}-\Delta m_{wl}} \quad (14)$$

The measurement procedures of method A2 are shown as a), b), c) and d) of figure 2. Firstly, weighing mass of test weight (m_{ta}) in air and recording indication of mass comparator (I_{ta}). Secondly, weighing mass of reference weight (m_{ra}) in air and recording indication of mass comparator (I_{ra}). Thirdly, weighing mass of test weight (m_{tl}) in liquid and recording indication of mass comparator (I_{tl}). Finally, weighing mass of reference weight (the same as reference weight in air or different reference weight) in liquid and recording indication of mass comparator (I_{rl}). Note that determining the density of the liquid ρ_l in liquid bath and the air density ρ_a in air at the time of the test.

When the same reference weight is used for air and liquid measurement, $m_{ra}=m_{rl}=m_r$ and $\rho_{ra}=\rho_{rl}=\rho_r$, then:

$$\rho_t=\frac{\rho_l(C_a m_r+\Delta m_{wa})-\rho_a(C_l m_r+\Delta m_{wl})}{m_r\dfrac{\rho_l-\rho_a}{\rho_r}+\Delta m_{wa}-\Delta m_{wl}} \quad (15)$$

Where $C_a=1-\dfrac{\rho_a}{\rho_r}$, $C_l=1-\dfrac{\rho_l}{\rho_r}$.

When different reference weights are used for air and liquid measurement, $m_{ra}\neq m_{rl}$ and $\rho_{ra}\neq\rho_{rl}$, then:

$$\rho_t=\frac{\rho_l(C_a m_{ra}+\Delta m_{wa})-\rho_a(C_l m_{rl}+\Delta m_{wl})}{C_a m_{ra}+\Delta m_{wa}-C_l m_{rl}-\Delta m_{wl}} \quad (16)$$

The measurement procedures of method A3 are shown as a) and b) of figure 3. Firstly, weighing mass of test weight (m_{ta}) in air and recording indication of mass comparator (I_{ta}). Secondly, weighing mass of test weight (m_{tl}) in liquid and recording indication of mass comparator (I_{tl}). Note that determining the density of the liquid ρ_l in liquid bath and the air density ρ_a in air at the time of the test.

$$m_{ta}g - F_{taB} = m_{ta}g - \rho_a g V_{ta} = I_{ta} g C_s \quad (17)$$

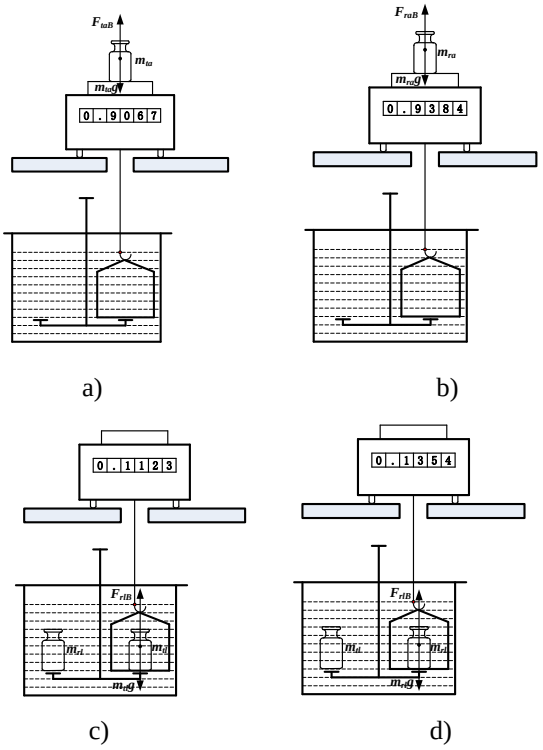
$$m_{tl}g - F_{tlB} = m_{tl}g - \rho_l g V_{tl} = I_{tl} g C_s \quad (18)$$

Where

$$C_s = \frac{1}{1 - \frac{\rho_{as}}{\rho_s}}, m_{ta} = m_{tl} = m_t, V_{ta} = V_{tl} = V_t .$$

Equation (19) is obtained through equation (17) divided equation (18).

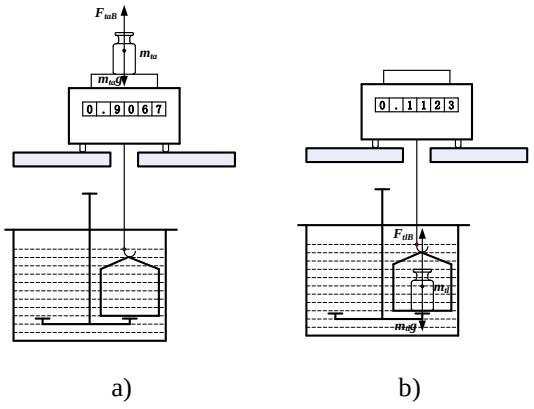
$$\rho_t = \frac{I_{ta} \times \rho_l - I_{tl} \times \rho_a}{I_{ta} - I_{tl}} \quad (19)$$



a) b)

c) d)

Figure 2 Measurement procedures of method A2



a) b)

Figure 3 Measurement procedures of method A3

3. EQUIPMENT OF VOLUME MEASUREMENT INCLUDING METHOD A1, A2 AND A3

The equipment for measuring volume of weights including method A1, A2 and A3 is being developed at NIM. The structure of equipment is shown as figure 4. It includes a robot arm for transferring weights, a liquid bath, a mass comparator with 26.1 kg of maximum capacity and 1 mg of readability, glass housing, two weight exchangers including in air and in liquid, two weight holders including in air and in liquid, and a controller. The robot arm is designed to move weights from ground to different positions in air and in liquid. It is convenient for operator to move weights from 2 kg to 20 kg in the measurement. Weight exchangers are installed in air and in liquid respectively. Weights are placed on weight exchangers by the robot arm. Weight holders are connected with the hook from bottom of mass comparator. They are used to support weights in the measurement.

Three programs for running automatically are written into the controller according to method A1, A2 and A3. It has a semi-automatic function to adjust initial positions of weight exchangers and move weights, which is convenient to move weights from ground to weight exchangers by means of auxiliary device.

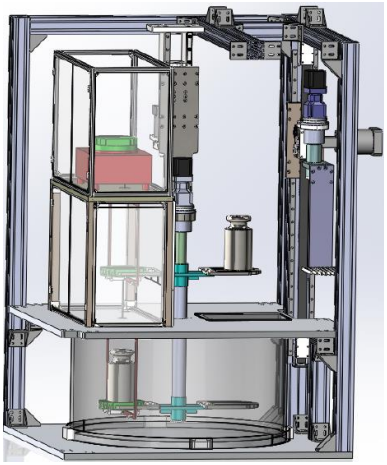


Figure 4 the structure of volume measurement system

4. CONCLUSIONS

Method A from annex B.7.4 of OIML R111-1 Edition 2004 (E) is introduced in this paper. Operation principles among method A1, A2 and A3 are compared by means of formula deduced. In order to improve measurement accuracy of weights volume and increase robot arm for transferring weights, an equipment for measuring volume of weights from 2 kg to 20 kg including method A1, A2 and A3 of annex B.7.4 of OIML R111-1 Edition 2004 (E) is being developed to meet technical requirements of volume measurement in 'Weights Verification Regulation of China'. The equipment will enable to perform automatically volume measurement of weights according to control program.

5. ACKNOWLEDGMENT

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