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Analysis of the piston pressure gauge factor

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Abstract: *This paper introduces that the effective area of the tested sample can be calculated by calibrating the same piston manometer according to the same balance method, and analyzes the influencing factors of the calculated area under this method, as well as the influence of different influencing factors on the final result.*

Keywords: *piston type manometer, effective area of piston, influencing factors of effective area*

1. Introduction to the audit activities for the effective area measurement of piston pressure gauges

In the piston pressure gauge piston effective area measurement audit activity, if the two laboratories participating in the measurement audit calibrate the same tested piston pressure gauge according to the initial balance method, the two laboratories can respectively follow the JJG59-2007 "Piston Pressure Gauge". According to the relevant steps of Article 6.3.8.2 of "Verification Regulations for Type Pressure Gauge", measure the piston effective area of the tested piston pressure gauge sample, and calculate the $A_0^{'}$ value of the respective piston effective area by formula (1) and formula (2).

The effective area of the piston at each balance point of the piston pressure gauge given in JJG59-2007 $A_{i,0}{'}$ is:

$$A_{i,0}{'} = A_0 \times \frac{m_i^{'}}{m_i} \tag{1}$$

The formula: $A_{i,0}{'}$ - the effective area of the piston calculated by the tested piston manometer at the first i equilibrium pressure point, cm^2; A_0 - the effective area of the piston of the standard piston manometer, cm^2 ; $m_i^{'}$ - after the initial equilibrium point, the tested piston The mass of the special weight added by the first verification point of the standard piston pressure gauge relative to the balance point i , kg; m_i - After the initial balance point, the mass of the special weight added by the first verification point of the standard piston pressure gauge i relative to the balance point, kg.

The final calculation formula of the effective area of the piston given in JJG59-2007 is $A_{i,0}{'}$

$$A_0^{'} = \frac{1}{n}\sum_{i=1}^{n} A_{i,0}{'} \tag{2}$$

Participate in the measurement audit laboratory, calculate the effective area of each piston $A_0^{'}$, and then evaluate the uncertainty of each measurement result, and then calculate the E_n value of this measurement through the formula (3):

$$E_n = \frac{x - X}{\sqrt{U_{lab}^2 + U_{ref}^2}} \tag{3}$$

Among them x - the measurement results of the effective area of the piston in the participating laboratory; - the measurement result of X the effective area of the piston in the reference laboratory;

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U_{lab} - U_{ref} the uncertainty of the measurement result of the participating laboratory; - the uncertainty of the measurement result of the reference laboratory.

At that time $|E_n|<1$, the result was satisfactory; $|E_n|=1$ at the time, the result was suspicious; $|E_n|>1$ at the time, the result was unsatisfactory [1].

2. Analysis of the influence on the measurement results of the effective area of the piston

2.1. Analysis of the influence of the mass of the weight on the measurement results of the effective area of the piston

(1) Concept of vacuum quality and converted quality

It can be seen from formula (1) that the main factors affecting the measurement result of the effective area of the piston are the effective area of the standard piston and the mass of the weight loaded relative to the equilibrium point. Since the effective area of the standard piston is a fixed value given by the superior technical department after verification/calibration, the main factor affecting the measurement result of the effective area of the piston of the tested piston pressure gauge is the mass of the weight.

Quality is divided into converted quality and vacuum quality. The quality profession generally gives the converted mass according to the weight verification regulations, while the pressure profession mainly uses the vacuum mass of the weight. There is a deviation between the two. If the concept is confused and the application is incorrect, it will give the effective area of the piston. The calculation results bring some errors.

The vacuum mass of the weight refers to the mass value obtained by comparing the tested weight with the standard weight in vacuum, that is, the real mass value of the weight. The converted mass of a weight refers to the mass value obtained by comparing the weight with a standard weight in standard air under a predetermined condition.

In JJG99-2006 "Weight Verification Regulations", the definition of converted mass is: an object reaches equilibrium with a standard device of a predetermined density in air of a predetermined temperature and a predetermined density, then the mass of the standard device is the mass of the object. Converted quality. The conventional temperature (t_{ref}) is 20°C, the air density (ρ_0) is 1.2kg/m ^{3}, and the conventional density of the weight converted mass ρ_{ref} is 8000kg/m ^{3}.

Converted quality m_c. Relationship with vacuum quality m:

$$m_c = \frac{\left(1-\frac{\rho_0}{\rho}\right)}{0.99985} m \tag{4}$$

or
$$m = \frac{0.99985}{\left(1-\frac{\rho_0}{\rho}\right)} m_c \tag{5}$$

The introduction of the converted mass is to solve the problem that the weights with the same vacuum mass but different materials have different masses weighed on the balance due to different volumes and under the action of air buoyancy.

(2) Analysis of mass error of weights

When the weight adopts the converted mass, the air density will have an impact on its measurement result, and if necessary, the air buoyancy correction is required. Regarding the issue of air buoyancy correction, international recommendation R111 stipulates that the reference air density is 1.2kg/m ^{3}, and the range of deviation is ±0.12kgm ^{3}, which is only applicable to coastal plain areas. However, my country has a vast land area and complex terrain. Only in the provincial cities, there are 7 areas where the air density exceeds (1.2 ± 0.12) kgm3. Therefore, in different regions, there are differences in the calculation of the converted mass of weights, and special attention should be paid.

① Mass analysis of weights with air density in the range of (1.2±0.12)kgm^3

At present, the commonly used materials for domestic manufacture of special weights for piston pressure gauges are generally stainless steel (ρ =7800kg/m^3) and aluminum (=2700kg/ ρ m^3).

We know that in areas where the change in air density relative to the standard air density of 1.2kg/m^3 does not exceed ±10% (such as Beijing, the annual average air density ρ = 1.198kg/m^3), if the difference between the converted mass and the vacuum mass is not carried out For the weight of stainless steel material, the relative error introduced is 0.0004%, and the amount of influence is small. The relative error is acceptable for any grade of piston pressure gauge. Negligible: for aluminum weights

The relative error introduced is 0.0295%. The maximum allowable error of the special weight for the lowest grade 0.05 piston pressure gauge is ±0.02%, so the relative deviation between the vacuum mass and the converted mass of the aluminum weight is the displacement has exceeded the allowable error, that is, the relative error is negligible for piston pressure gauges of any accuracy class.

Therefore, in areas where the air density does not exceed (1.2±0.12) kg/m ^{3}, professional pressure measurement personnel should firstly analyze the relative error between the converted mass of the weight and the vacuum mass according to the weight material of the piston pressure gauge, so as to determine whether the conversion between the two is required. During the analysis, special attention should be paid to piston pressure gauges with aluminum chassis and weights.

② Mass analysis of weights whose air density exceeds the range of (1.2±0.12) kg/m ^{3} In areas where the air density exceeds (1.2±0.12) kg/m ^{3} The conversion with the vacuum mass will also lead to certain errors, which cannot even be ignored.

6.5.2.1 of JJG99-2006 stipulates that if the deviation of air density relative to ρ_0 =1.2kg/m ^{3} exceeds 10%, and the density of the checked weight deviates from the converted mass value of 8000kg/m ^{3}, the converted mass can be calculated according to Formula (6) is corrected:

$$m_{ct} = m_{cr} + m_{cr}C \pm \Delta I \times \frac{m_{cs}}{\Delta I_s} \pm m_{cw} \tag{6}$$

of which $$C = (\rho_a - \rho_0)\left(\frac{1}{\rho_t} - \frac{1}{\rho_r}\right) \tag{7}$$

The formula: - the converted mass of the m_{ct} tested weight after considering the air buoyancy correction; m_{cr} - the converted mass of the standard weight; C - the air buoyancy correction factor; ΔI , $\Delta I = I_{\text{Examined}} - I_{\text{standard}}$; m_{cs} -The converted mass value of the sensitivity weight added when verifying the weight; ΔI_s -Indication difference of the balance scale before and after adding the sensitivity weight: -In the m_{cw} comparison of weights, in order to balance the balance, in the lighter weight The converted mass value of the standard small weight added on the weighing pan.

In formula (7): ρ_t - the density of the tested weight; ρ_r - the density of the standard weight; ρ_a - the actual air density at the location; ρ_0 - the standard air density 1.2kg/m ^{3}.

In formula (6), ΔI the method for determining the positive and negative signs in front of the balance position item is: after adding a small weight to the balance plate on the side where the tested weight is placed, if the balance position reading of the balance can be made relative to that before the addition The algebraic value of the reading increases, the positive sign is taken before the balance position item, otherwise, the negative sign is taken: m_{cw} The method of determining the positive and negative signs in front of the standard small weight is: when the standard small weight is added to the left plate of the balance where the balancing object is located , take the plus sign in front of the standard small weight m_{cw} , and take the minus sign when it is placed on the right plate[2-3].

In the area where the air density exceeds (1.2±0.12) kg/m^3, whether it is necessary to carry out air

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buoyancy correction, JG99-2006 gives a clear regulation: if it is $m_0\left|C\right|$ less than one-ninth of the maximum allowable error of the weight, it is not necessary to carry out air buoyancy correction. Buoyancy correction, but to put this part of the error into the air buoyancy uncertainty for calculation.

Therefore, in areas where the air density exceeds (1.2 ± 0.12) kg/m ^{3}, for weights of different materials, it is necessary to carry out specific analysis according to the local air density through formula (6) and formula (7) and determine whether it is necessary or not. Make an air buoyancy correction to ensure the correct converted mass value is obtained.

(3) Precautions when applying the formula for calculating the effective area of the piston of the piston pressure gauge

The effective area of the piston at each balance point of the piston pressure gauge given in JJG59-2007 $A_{i,0}^{'}$. Strictly speaking, its use is subject to preconditions, namely: the measurement range, material (including the rods, cylinders, weights) should all be the same, only the accuracy levels will vary. In addition, according to the definition of pressure and Archimedes' law, the mass $m_i^{'}$ sum in formula (1) m_i actually means the effective mass value loaded on the piston, that is, it should be $\left(1-\frac{\rho_a}{\rho_{\text{Weight material}}}\right)$ the product of the respective vacuum mass values and. Therefore, after the quality major gives the converted mass value of the weight material, if necessary, the converted mass needs to be converted into the vacuum mass value by formula (5), and then the vacuum mass value is $\left(1-\frac{\rho_a}{\rho_{\text{Weight material}}}\right)$ multiplied, and then substituted into formula (1), calculate the effective area of the piston at each equilibrium point. Otherwise, if the vacuum mass value of the weight is directly applied to the piston effective area calculation, the error will be increased. It can be seen from the above analysis that the calculation of the effective area of the piston is of great importance to the application of the mass of the weight. Only with a clear concept and correct application can the influence of the mass of the weight on the measurement result of the effective area of the piston be effectively reduced.

2.2. Analysis of the influence of the selection of the standard piston pressure gauge on the measurement results of the effective area of the piston

It is allowed to use a standard piston pressure gauge with a small measurement upper limit and a tested piston pressure gauge with a large measurement upper limit. It is also mentioned in 6.2.1.1 of Knife G1086-2013 "Verification Regulations for Gas Piston Pressure Gauge" that the effective area of the piston of the standard should be larger than or close to the effective area of the piston of the tested piston pressure gauge.

Theoretically, since the pressure is inversely proportional to the area, if the same pressure value is generated, more small weights (g Therefore, the large area piston can subdivide the mass value of the small weight added relative to the equilibrium point, that is, the large area piston is relatively better than the small area piston in terms of discrimination.

In a certain experiment, a piston pressure gauge with a measuring range of (0.5~22.1) MPa, an effective piston area of 0.1961572cm^2, an accuracy level of 0.005, and a measuring range of (0.1~4.41) produced by DHI Company of the United States was used. MPa, the effective area of the piston is 0.9804649cm^2, and the accuracy level is 0.005. The same accuracy level is 0.05, the measuring range is (0.1~6) MPa, and the standard Weighing a liquid piston manometer with an area of 0.5cm^2, the experimental standard deviations of the obtained piston effective area were 2.86×10^{-5}cm^2 and 1.14×10^{5}cm^2, respectively.

The size of the experimental standard deviation characterizes the dispersion between the measurement results. Therefore, using a piston manometer with a small range and a large area to transmit a 0.05-grade piston pressure gauge, the experimental standard deviation of the calculated effective area of the piston is relatively small, and the dispersion of the measurement results is good.

Therefore, when choosing a standard piston pressure gauge, it is better to choose a standard piston pressure gauge with the same or smaller measuring range as the tested piston pressure gauge, so as to

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reduce the influence of the standard piston on the measurement result of the effective area of the tested piston.

3. Measurement method and uncertainty evaluation method for effective area of piston

3.1. Analysis of the influence of measurement methods and uncertainty evaluation methods on the audit results of piston effective area measurement

The measurement audit activity is a technical activity involving both parties. The difference in measurement methods and uncertainty evaluation methods between the two parties will also E_n affect the calculation results of the values. To ensure the validity of the measurement audit results, close attention must also be paid to the following two aspects.

6.3.8 of JJG59-2007 stipulates that when verifying the effective area of the piston, install the tested piston pressure gauge and the standard piston pressure gauge on the same calibrator (or install the standard piston pressure gauge and the tested piston pressure gauge through the piping is connected). Therefore, it is best for both laboratories involved in the measurement audit to maintain the same installation method (or connection method). When the installation methods are inconsistent, pay close attention to important technical indicators such as the sealing performance of the installed piston calibration system and the piston descending speed.

In E_n the calculation formula of the value, the uncertainty of the measurement result is E_n an important factor that affects the calculation result of the value. In the process of evaluating the uncertainty of the measurement result of the effective area of the piston, there are many influence components. Due to the differences in the technical ability and work experience of professionals, the understanding of the influence components is different. Therefore, in the uncertainty evaluation process, participation in the methods for evaluating the uncertainty of the measurement results of the two laboratories in the measurement audit are different. In order to effectively reduce the influence of the uncertainty evaluation results E_n, it is recommended that the higher-level technical institutions participating in the audit provide a unified template for measurement uncertainty evaluation, or the higher-level technical institutions should assess the uncertainty of the lower-level metrology technical institutions participating in the measurement audit. Process guidance and technical checks.

3.2. Conclusion

Piston pressure gauge piston effective area measurement audit activity is a difficult technical activity in the pressure measurement professional measurement audit project. During the measurement review process, the laboratories of both parties shall ensure the correct selection of standard piston pressure gauges, the correct application of weights, and the unification of measurement methods and uncertainty assessment methods, and ensure that the laboratories of both parties shall ensure that during the whole measurement review process Maintain good technical communication between them, so as to effectively ensure that the process of measurement audit activities is smooth and the results are accurate and reliable.

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