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A METHOD FOR APPLYING MASS COMPARATOR CALIBRATION RESULTS IN THE UNCERTAINTY OF MASS VALUE TRANSFER

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Abstract:

This paper proposes a method for applying mass comparator calibration results to mass value transfer. On the basis of analysing the main factors affecting the calibration results of the mass comparator, according to the international recommendation OIML R111-2004 and the requirements of the national metrology verification regulation JJG 99-2006 for the balance, the calibration results of the repeatability, eccentricity and partial indication error of the mass comparator are applied to the uncertainty assessment of the mass value transmission. The results show that the method calculation can apply the calibration results calculated by the mass comparator to the calculation of the OIML R111-2004 conversion mass measurement, and can also meet the requirements of JJG 99-2006 for the uncertainty of the measurement instrument synthesis standard not exceeding the maximum allowable error of the quality of the weight being inspected, and the larger standard uncertainty or the three synthetic standard uncertainties on the mass comparator certificate are directly selected. All effectively avoid the loss of volume transmission accuracy and waste of resources.

Keywords: mass comparator; mass value transfer; balance; uncertainty assessment

1. INTRODUCTION

The mass comparator is a high-resolution electronic measuring device manufactured according to the principle of measuring the deformation and strain of elastic components, or the electromagnetic force feedback balance, and is the main measuring instrument for the transmission of weight values, which plays a very important role in the transmission of weight values [1].

Both the International Recommendation OIML R111-2004 and the national metrology verification regulation JJG 99-2006 "Weights" give the measurement instrument uncertainty calculation formula, while the national metrology verification regulation JJG 99-2006 "Weights" put forward specific requirements for the measurement characteristics of the measuring instrument (the uncertainty of the synthesis standard shall not be greater than one-sixth or one-ninth of the maximum allowable error of the quality of the corresponding inspected weights) [2]. Therefore, the calibration results of the mass comparator directly affect the selection of the volume transmission measuring instrument and the calculation of the uncertainty of the weight conversion mass measurement.

The main measurement characteristics of mass comparators are repeatability, eccentricity and partial indication error. According to the national calibration specification JJF 1326-2011, the calibration results also give the uncertainty corresponding to the three items. In this way, some staff in the uncertainty assessment take the synthetic uncertainty of the three as the uncertainty of the comparator, and some take the larger of the three as the uncertainty of the comparator, and the understanding is not uniform, resulting in the loss of quantitative accuracy and waste of resources.

Based on the above problems, based on the international recommendation OIML R111-2004 and the national metrology verification regulation JJG 99-2006 "Weights" for measuring instrument requirements, this paper analyses the main factors affecting the calibration results of the quality comparator, and gives the application method of how to apply the calibration results of the quality comparator repeatability, bias load and local indication value to the uncertainty evaluation of the mass quantity value transmission, and verifies the method and data and compares with other practices. The practicality of this method is given.

2. DESCRIPTION OF THE WORK

2.1. The Main Factors that Affect the Calibration Results of a Mass Comparator

Mass value transmission, first of all, to ensure the accuracy of the quality comparator calibration results, you need to consider the main factors affecting repeatability, eccentricity, local indication error calibration.

The main factors affecting repeatability are the precise positioning of the centre, as well as the impact force of the weight countertop and sensor when unloading weights [5], and the central position of each bearer C is shown in Figure 1.

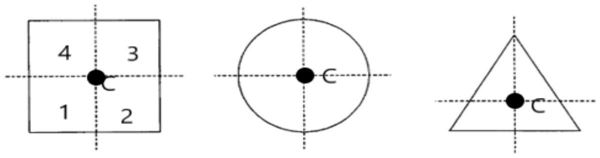

Figure 1: Schematic diagram of the centre position of the bearer

The eccentricity load error is often much greater than the repeatability error, and the key factor affecting the bias load also comes from the choice of the eccentricity load distance d_1 (the distance from the centre of the weighing pan to the centre of the weight), and the eccentricity load test results at different positions at each offset load distance See Table 1, where d_2 is the distance from the centre of the weighing pan to an angle [2], [4].

Table 1: Bias load test results at different locations at each offset load distance, in mg

d_1/d_2	1/6	1/3	1/2	2/3
Location 1	-1.40	-1.90	-3.85	-8.05
Location 2	-0.30	-0.35	-0.70	-1.70
Location 3	1.20	1. 25	3.10	7.80
Location 4	0.85	1. 05	2.70	7.25

The measurement data in Table 1 shows that the farther away from the centre of the weighing pan, the greater the error and the faster the error increases [5]. The trend of eccentricity load error with eccentricity position is shown in Figure 2.

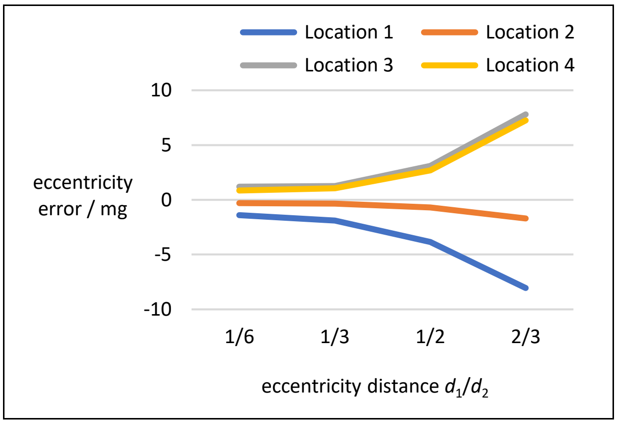

Figure 2: Eccentricity load error vs. eccentricity position trend plot

The component of the uncertainty of the local indication error comes mainly from the standard deviation of repeatability.

2.2. Calibration Results for Mass Comparators

In order to visually illustrate the calibration results of the comparator, this article takes the comparator with a maximum scale of 5.1 kg and an actual indexing value of 0.1 mg as an example, and according to the national calibration specification JJF 1326-2011 calibration requirements, the calibration results of the various measurement characteristics of the comparator at the 5 kg scale point are as follows:

Repeatability

Select a standard weight that meets the calibration comparator and cycle through the test in the $A_1A_2A_3$ to represent repeatable calibration results in standard deviations [6], as detailed inTable 2.

Table 2: Repetitive test data, in g

Reading *I*		**Phase contrast value Δ*I***
A_{11}	5 000.008 9	-0.005 65
A_{12}	5 000.003 0	
A_{21}	5 000.008 4	-0.006 65
A_{22}	5 000.001 8	
A_{31}	5 000.008 5	-0.006 50
A_{32}	5 000.002 0	
A_{41}	5 000.008 5	-0.006 35
A_{42}	5 000.002 0	
A_{51}	5 000.008 2	-0.006 50
A_{52}	5 000.001 7	
A_{61}	5 000.008 2	-0.005 85
A_{62}	5 000.002 1	
A_{71}	5 000.007 7	-0.006 05
A_{72}	5 000.002 0	
A_{81}	5 000.008 4	-0.006 55
A_{82}	5 000.001 5	
A_{91}	5 000.007 7	-0.006 25
A_{92}	5 000.001 6	
A_{101}	5 000.008 0	-0.006 80
A_{102}	5 000.001 1	
A_{111}	5 000.007 8	

The standard deviation s_P of repeatability is calculated from equation (1)

$$s_P = \sqrt{\frac{3n-1}{2n} \times \frac{\sum_{i=1}^{n}(\Delta I_i - \overline{\Delta I})^2}{n-1}} = 0.4 \text{ mg} \quad (1)$$

The expanded uncertainty U_{RP} of repeatability is calculated from equation (2)

$$U_{\mathrm{RP}} = 2 \times \sqrt{\alpha_\Gamma P_{\mathrm{t}}^2 + u_d^2} = 0.1 \text{ mg}, \quad (2)$$

where α_Γ is the amount of change in the uncertainty component of the temperature effect, P_{t} is the mass value of the standard weight, and u_d is the uncertainty caused by the resolution.

Eccentricity

The standard weights are placed in different positions on the comparator, represented by the maximum of the absolute values of the difference between the averages of each point and the midpoint [6], as detailed in Table 3.

Table 3: Eccentricity load test data, in g

Reading *I*		**Phase contrast value ΔI_f**
I_{01}	5 000.013 5	-0.001 90
I_f	5 000.011 7	
I_{02}	5 000.013 7	
I_{01}	5 000.013 7	-0.000 35
I_f	5 000.013 0	
I_{02}	5 000.013 0	
I_{01}	5 000.013 7	0.001 55
I_f	5 000.015 1	
I_{02}	5 000.013 4	
I_{01}	5 000.013 4	0.001 55
I_f	5 000.015 1	
I_{02}	5 000.013 7	

The maximum difference in eccentricity and associated expanded uncertainty are given by equations (3) and (4) respectively

$$E = \Delta I_{f_{\max}} = -1.9 \text{ mg} \quad (3)$$

$$U_{\mathrm{EP}} = 2 \times \sqrt{s_{\mathrm{P}}{}^2 + \alpha_\Gamma P_t^2 + u_d^2} = 0.9 \text{ mg} \quad (4)$$

Partial Indication Error

According to the characteristics of the use of the mass comparator, it can be calibrated with a small, relatively reasonable electronic display range due to error [6], as detailed in Table 4.

Table 4: Partial indication test data, in g

Reading *I*		**Phase contrast value *ΔI***
A1	5 000.015 9	0.500 00
A+m_{s}	5 000.516 2	
A2	5 000.016 5	
A1	5 000.016 5	0.499 95
A+m_{s}	5 000.516 6	
A2	5 000.016 8	
A1	5 000.016 8	0.500 60
A+m_{s}	5 000.516 8	
A2	5 000.015 6	

The calibration result of partial indication error and associated expanded uncertainty U_{sP} are given by equations (5) and (6) respectively.

$$E = m_{\mathrm{s}} - \overline{\Delta I} = -0.2 \text{ mg} \quad (5)$$

$$U_{\mathrm{sP}} = 2 \times \sqrt{s_{\mathrm{P}}{}^2 + \alpha_\Gamma P_P^2 + u_d^2 + a_s m_S^2} = 0.9 \text{ mg} \quad (6)$$

where a_s is the uncertainty caused by the small weight.

Calibration Results for Mass Comparators

The calibration result report of each measurement characteristic of the comparator at the 5 kg scale point is shown in Table 5.

Table 5: Calibration results report page

Calibration item	**Calibration result**	**Expanded uncertainty (*k* = 2)**
repeatability	0.4 mg	0.1 mg
eccentricity	1.9 mg	0.9 mg
partial indication error	-0.2 mg	0.9 mg
Maximum load = 5.1 kg The actual index value d = 0.1 mg		
Calibration Instructions: Test load weight P_{t} = 5 kg Calibration of local indication errors with a weight m_{s} = 500 mg		

The larger standard uncertainty of repeatability, eccentricity and partial indication is 0.45 mg, and the combined standard uncertainty of the three synthetic standards is 0.64 mg.

2.3. Uncertainty of Mass Comparator Transmission in Mass Transfer u_{ba}

According to the international recommendation OIML R111-2004 and the national metrology verification regulation JJG 99-2006 "Weights", the measurement instrument uncertainty calculation formula is given, and the measurement data of the repeatability, eccentricity and partial indication error of the mass comparator are brought into the relevant equation.

Uncertainty Due to the Sensitivity of the Balance

$$u_s^2 = \overline{\Delta m_{\mathrm{c}}}^2 \left(\frac{u^2(m_s)}{m_s^2} + \frac{u^2(\Delta I_s)}{\Delta I_s^2} \right), \tag{7}$$

where ΔI_s is the change in the indicator of the balance due to the sensitivity weight, $u(\Delta I_s)$ is the uncertainty of ΔI_s, and $\overline{\Delta m_{\mathrm{c}}}$ is the average mass difference between the test weight and the reference weight.

Taking 5 kg for an example, the average mass difference between the test weight and the reference weight is known $\overline{\Delta m_{\mathrm{c}}}$ = 3 mg.

The mass correction value of the E_1 grade weight 500 mg is 0.001 mg, and its uncertainty $u(m_s)$ = 0.001 3 mg which can be known according to Table 5, $u(\Delta I_s)$ = 0.45 mg, ΔI_s = 499.998 mg, brought in to obtain the uncertainty caused by sensitivity

$$u_{\mathrm{S}} = 3 \times \sqrt{\frac{0.0013^2}{500.001^2} + \frac{0.45^2}{499.998^2}} = 0.000\,9\ \mathrm{mg}\,. \tag{8}$$

Uncertainty Due to the Display Resolution of a Digital Balance

According to Table 5, it can be seen that d = 0.1 mg, so the uncertainty caused by the resolution can be calculated from equation (9)

$$u_d = \frac{d/2}{\sqrt{3}} \times \sqrt{2} = 0.040\,8\ \mathrm{mg}\,. \tag{9}$$

Acceptable Solution for the Uncertainty Due to Eccentricity

$$u_E = \frac{\frac{d_1}{d_2} \times D}{2 \times \sqrt{3}}, \tag{10}$$

where D is the difference between the maximum and minimum values from the eccentricity test performed according to OIML R76-2, d_1 is the estimated distance between the centres of the weights, and d_2 is the distance from the centre of the load receptor to one of the corners.

The partial load measurement of the comparator has a certain similarity with the weight transfer cycle mode, so the D value can be directly referred to the eccentricity of the comparator in Table 5, according to Table 5, it can be seen that D = 1.9 mg. Bring in to get the uncertainty of the eccentricity [7].

According to Table 5, it can be seen that D = 1.9 mg, and the uncertainty of bias load introduction can be obtained from equation (11)

$$u_E = \frac{\frac{1}{3} \times 1.9}{2 \times \sqrt{3}} = 0.182\,9\ \mathrm{mg}\,. \tag{11}$$

Uncertainty Due to Magnetism

The uncertainty due to magnetism is assumed to be zero.

Combined Standard Uncertainty of the Balance u_{ba} [4], [8]

$$u_{\mathrm{ba}} = \sqrt{u_s^2 + u_d^2 + u_E^2} \tag{12}$$

$$u_{\mathrm{ba}} = \sqrt{0.000\,9^2 + 0.040\,8^2 + 0.182\,9^2} = 0.19\ \mathrm{mg}\,. \tag{13}$$

According to the requirements of JJG 99-2006 for the uncertainty of the combined standard uncertainty of the balance, when the inspected weight is not corrected by air buoyancy, the uncertainty of the synthesis standard shall not exceed one-ninth of the maximum allowable error absolute value of the mass of the inspected weight [1]. The maximum allowable error absolute value for the E_1 class 5 kg weight is 2.5 mg, of which one-ninth is 0.28 mg.

The combined standard uncertainty of the balance is 0.19 mg, which meets the requirements for measuring the uncertainty of the instrument. However, if you directly select the certificate of repeatability, eccentricity and partial indication, the larger standard uncertainty is 0.45 mg or the standard uncertainty of the three synthetic standards is 0.64 mg, will cause a loss of quantitative transmission accuracy, waste of resources.

3. SUMMARY

In summary, the mass comparator should first try to avoid factors that affect its results in the mass value transfer; secondly, the quality comparator calibration results should not directly use any calibration in the mass value transfer uncertainty. The uncertainty of the results or the uncertainty of simple synthesis as the uncertainty of the mass comparator is recommended to be reasonable according to the requirements of the measurement instrument in R111. Analyse, judge, and then apply to the mass value transfer to ensure the accuracy of the mass value.

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