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Research Article

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50 kg high capacity mass comparator and its performance test

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ABSTRACT

The calibration of heavy mass standards is a difficult, demanding, and time consuming process. Loading and unloading of heavy mass standards is strenuous work as well as placing of the weights in the center of the weighing position by human. With the improvement of the technique and customer's requirements, it is necessary to establish the mass standard of 50 kg weight. A high capacity automatic comparator with readability of 0.1 mg has become available in National Institute of Metrology (NIM). Performance analysis of this mass comparator is shown in the paper. Then three class E_1 50 kg weights are measured on this new equipment, the measurement result and uncertainty are given out as well as experience in use.

Key words: High capacity; mass comparator; performance analysis; mass dissemination

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INTRODUCTION

Recently, a new generation of computer controlled comparators-AX64004, particularly designed for the calibration of high capacity weight, has become available. This equipment can automatically execute all steps involved in disseminations, including the moving of the weights and the necessary comparisons, requiring neither manual intervention by the operator, nor custom auxiliary weights [1].

Fig. 1: AX64004 comparator installed in NIM and crane used for lifting weight

The requirements of high-capacity mass dissemination to calibrate weights and weight sets in the nominal range of a few kilograms up to 60 kg are first discussed by Reichmuth and Richard in [2]. Now there are several national metrology institutes and independent commercial mass metrology laboratories equipping this comparator. For example: troemner is an independent calibration laboratory in the United States that can provide calibrations with this type of balance [3]. Primary Standards Laboratory of Sandia National Laboratories also maintains this kind of balance [4]. In KlodianDhoska's master thesis [5], he used this kind of comparator to get experience in the field of high accuracy mass measurements. In [6], the calibration of multiples of 1 kg is carried out using a fully automatic mass comparator with maximum capacity of 64 kg and resolution of 0.1 mg. In Jan.26th2010, China's first AX64004 was settled in Shanghai verification and testing technology institute [7].

Form all these documents and websites ,we can see that the requirements of high-capacity mass dissemination are very popular, like Estonia[8], 50 kg comparison of Euromet from 2004 to 2007 [9] and CCM.M-K3.1 comparison of 50 kg mass in 2009 to 2010[10].

50 KG AUTOMATIC MASS COMPARATOR

There are several mass comparator used for 50 kg weight, like Schenk FW18(1 mg resolution),Sartorius CC50000S\C50000S\CC50001S-L\(1 mg resolution) ,Mettler-Toledo PK60 MC(10 mg resolution), SMU 100 kg (1 mg resolution), and Mettler-Toledo AX64004(0.1 mg resolution). All these equipment are listed in CCM.M-K3 50 kg mass comparison report.

AX64004 is an automatic mass comparator which is based on computer operation, has four positions for weight alternator [6]. This electronic mass comparator is from Mettler Toledo, Switzerland, and specially used for large precision weights from 10 kg to 60 kg (weighing capacity is 64 kg, with remarkable high resolution of 0.1 mg and a typical standard deviation of less than 0.4 mg [5].

The AX64004 comparator weighing system comprises [5]: weight handler; balance controller; handler controller; temperature sensors; 4 glass cylinders (individual draft shields, designed for conventional 50 kg normal significantly with larger dimensions); cables connecting to weighing unit; computer control software; crane used for lifting 50 kg weights. That is all for fully automatic performance and reporting of comparative weightings. Besides, it has a modern and fast weighing system with switching weights (250g-steps). Comparator's substitution weight set is shown at the bottom of equipment. The weight partition provides combinations of substitution loads from 0 to 64 kg in increments of 250 g. With the weighing cell's electrical range of 260 g, this allows for an overlapping weighing range from 0 to 64 kg. Also kept with this set is a calibration weight of 250 g [2].

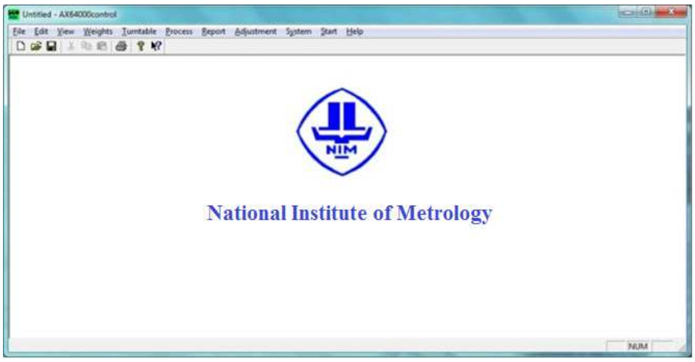


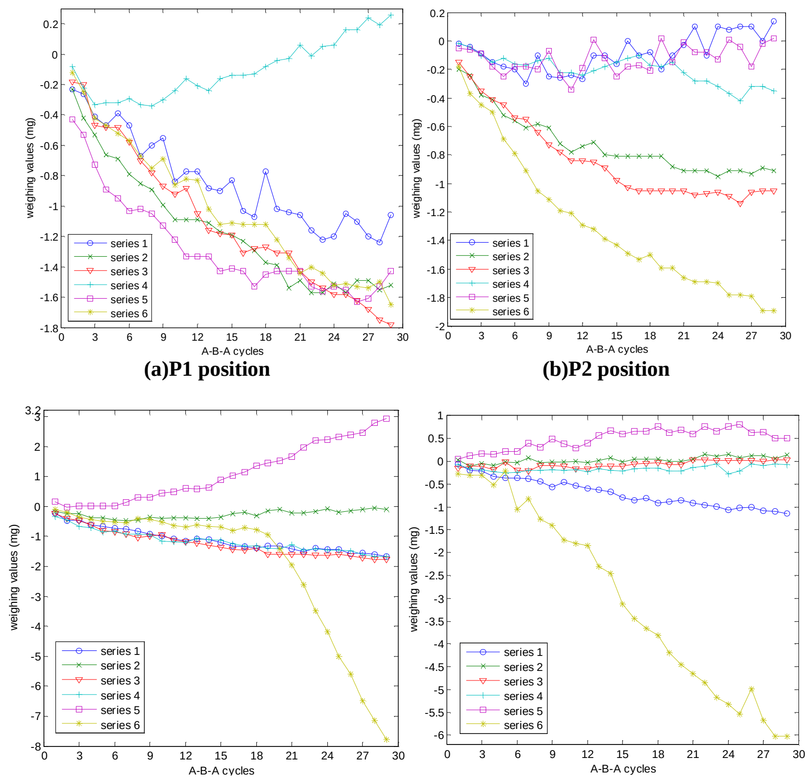
Fig. 2: Computer control software designed by NIM and MT

It features a four-place turntable for automatic weight ex-change, which is shown in the foreground in Fig1. The weighing platforms, equipped with individual draft covers, offer enough space to accommodate weight combinations according to any weighing scheme. METAS has given out an example on large object calibration without draft shield [2]. Besides, the weights self-center mechanism can reduce the eccentric load errors.

The comparator's display unit and a laptop PC to control the comparator, is visible on the right in the background. Computer control software with NIM's logo shown in Fig 2 is designed by National Institute of Metrology, China (NIM) and Mettler Toledo Corporation (MT).

PERFORMANCE TEST OF AX64004 MASS COMPARATOR

On Apr.29th 2013(Apr 29th 09:22:37 to May 3rd 13:14:34, and it is holiday from Apr 29th to May 1st), an equipment test was generated by AX64004 according to running an all comparison weighing processes consisting of 6 series of 10 A-B-A cycles weighment. And the running data was analysed. The comparisons are P1-P1, P2-P1, P3-P1, P4-P1, P2-P2, P3-P2, P4-P2, P3-P3, P4-P3, P4-P4, because the weighing scheme is A-B-A cycles, so we make all the comparison cycle to the same start point. Weighing data of P1, P2, P3 and P4 position are shown in figure 3. These measurement record obtained from 6 series of 10 comparisons between the same positions used one 50 kg mass standards.



(a)P1 position **(b)P2 position**

(c)P3 position **(d)P4 position**

Fig. 3: Measurement data from the same weighing positions

Table 1. Standard deviation of the same weighing position

Series No.	Standard Deviation (mg)			
	P1	P2	P3	P4
1	0.11	0.10	0.04	0.04
2	0.04	0.04	0.05	0.06
3	0.05	0.02	0.05	0.06
4	0.04	0.03	0.07	0.03
5	0.06	0.09	0.07	0.09
6	0.05	0.04	0.09	0.21

Table 1 is the mean (conventional) standard deviation of the same position, calculated from groups of 10 A-B-A comparisons (mark by circle, multiply sign, triangle, plus, square, star). Here in the weighing cycles, “A” represents weighing the reference weight and “B” represents weighing the test weight. The “A-B-A” cycle is normally used when calibrating class E and F weights automatically.The maximum value of each position is 0.11, 0.10, 0.09 and 0.21. All the values are better than the parameter shown in [6][2](0.4/0.2 mg), [5](0.29 mg).

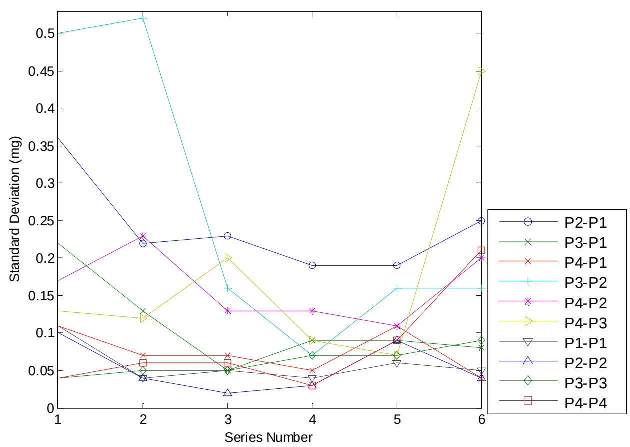


Fig. 4: Measurement standard deviation obtained from 60seriescomparisons between two weighment positions

Figure 4 shows the measurement standard deviation obtained from 60 series comparisons between two weighment positions. We can see that during P3 and P2 comparison , the standard deviations of first and second series are 0.50 and 0.52receptively, which are more higher than 0.4 mg. May be it is due to a transient at the beginning of the measurement, probably caused by acclimatization. Another reason for the data is eccentric load error. Although it has self-center mechanism, the 50 kg weight is too heavy and it is hard to center the weight at only a few centering process.

There is another high standard deviation (0.45 mg) happens to Series 6 between P4 and P3 position. It was almost the last comparison of the whole test, and holiday was finished. Human and environment reason can result to this value. Besides, the other measurement standard deviation almost remains smaller than 0.25 mg for the remaining measurements.

UNCERTAINTY EVALUATION OF 50 KG WEIGHTS

Three 50 kg test weights, which number are 197#, 199# and 200# receptively. Reference weights are as follows: 0012# 20 kg, 851#20 kg and 0012# 10 kg. The measurement uncertainties for these three weights are better than 1.0 mg, 2.0 mg (*k*=2) and 0.5 mg (*k*=2) respectively. Formula for the corrected value is show in Tab 2, and the corresponding values are in the Tab3.

Formula for the corrected value is show in Tab 2, and the corresponding values are in the Tab3.

Table2. Measurement group and measurement formula

Measurement Group	Measurement formula
1	$mc_{50} = mc_{20} + mc_{20} + mc_{10} + \Delta m_1$

Table3. Conventional value of 50 kg weight

Test	Balance Value (counts)	Sensitivity (mg/scale)	Mass difference(mg)	Air density (kg/m^3)	Air buoyancy corrected(mg)	Δm (mg)	Conventional corrected value of reference(mg)	Conventional corrected value of 50 kg weights(mg)
197	-4.07	1.0000077	-4.0700	1.1763	0.1434	-3.9266	5.433	1.5064
199	1.82	1.0000077	1.8200	1.1760	0.1448	1.9648	5.433	7.3978
200	-8.93	1.0000077	-8.9300	1.1758	0.1460	-8.7841	5.433	-3.3511

Uncertainty from the weighing process $u_w\left(\overline{\Delta m}\right)$

Table 4.Standard deviation of 10 times measurement per group (mg)

Group No	Standard deviation of measurement (ten ABBA cycles) $s\left(\Delta m\right)$	$u_w\left(\overline{\Delta m}\right)$
1	0.2929	0.0926
2	0.1575	0.0498
3	0.1152	0.0364

Uncertainty from the reference weight $u\left(m_r\right)$

In the measurement 0012# 20 kg ,851# 20kgand 0012#10 kg are reference weights, and from there expanded uncertainty U and coverage factor $k=2$, the following values are existing: $\frac{U}{k}=\frac{1}{2}=0.5$ mg, $\frac{U}{k}=\frac{2}{2}=1$ mg and $\frac{U}{k}=\frac{0.5}{2}=0.25$ mg.

$u_{\text{inst}}(m_{\text{cr}})$ is uncertainty from the mass variations of reference weight.Conventional corrected value of 0012# 20 kg in the old times are 3 mg, 1 mg and 1.28mg,then $u_{\text{inst}}(m_{\text{cr}}) = s(\Delta m) = \sqrt{\frac{1}{n-1}(\sum_{i=1}^{n}\Delta m - \overline{\Delta m})^2} = 1.0830$ mg .

Conventional corrected value of 851# 20 kg are 4.017 mg,5.317 mg,4.667 mg,3.933 mg and 5.3 mg,then $u_{\text{inst}}(m_{\text{cr}}) = s(\Delta m) = \sqrt{\frac{1}{n-1}(\sum_{i=1}^{n}\Delta m - \overline{\Delta m})^2} = 0.6675$ mg .Conventional corrected value of 0012# 10 kg in the old times are 1.4 mg, 0.2 mg and 0.19 mg, then $u_{\text{inst}}(m_{\text{cr}}) = s(\Delta m) = \sqrt{\frac{1}{n-1}(\sum_{i=1}^{n}\Delta m - \overline{\Delta m})^2} = 0.6957$ mg. Uncertainties of the three testing weights are $u_1(m_{\text{cr}}) = \sqrt{(\frac{U}{k})^2 + u_{\text{inst}}^2(m_{\text{cr}})} = 1.1928$ mg. $u_2(m_{\text{cr}}) = \sqrt{(\frac{U}{k})^2 + u_{\text{inst}}^2(m_{\text{cr}})} = 1.2023$ mg and $u_3(m_{\text{cr}}) = \sqrt{(\frac{U}{k})^2 + u_{\text{inst}}^2(m_{\text{cr}})} = 0.7393$ mg.

Finally the whole uncertainties of three reference weights are:

$$u(m_{\text{cr}}) = \sqrt{u_1(m_{\text{cr}})^2 + u_2(m_{\text{cr}})^2 + u_3(m_{\text{cr}})^2} = 1.8480 \text{ mg}$$

Uncertainty from the air buoyancy correction u_b

Uncertainty of the air buoyancy correction can be evaluated by:

$$u_b^2 = (V_{ref} - V_{test})^2 u^2(\rho_a) + (\rho_a - \rho_0)^2 (u^2(V_{test}) + u^2(V_{ref}))$$
$$+ 2\frac{\partial m_{test}}{\partial m_{ref}}\frac{\partial m_{test}}{\partial \rho_a} u(m_{ref}, \rho_a) + 2\frac{\partial m_{test}}{\partial m_{ref}}\frac{\partial m_{test}}{\partial V_{ref}} u(m_{ref}, V_{ref})$$

In which:

$$2\frac{\partial m_{test}}{\partial m_{ref}}\frac{\partial m_{test}}{\partial \rho_a} u(m_{ref}, \rho_a) = 2(V_{ref} - V_{test})(V_{ref*} - V_{ref})u^2(\rho_a)$$
$$2\frac{\partial m_{test}}{\partial m_{ref}}\frac{\partial m_{test}}{\partial V_{ref}} u(m_{ref}, V_{ref}) = -2(\rho_a - \rho_0)^2 u^2(V_{ref})$$

V_{ref*} is reference volume of the upper class reference weight. For the reason that the weight 0012# and 851# is trace back to national secondary prototype 121#, and the volume of 121# under 20℃ is 125.0773 cm^3, standard uncertainty is 0.0004 cm^3. Three groups air buoyancy correction uncertainty is shown in table5.

Table5 Uncertainty of air buoyancy correction(mg)

Measurement Group	u_b
1	0.0067
2	0.0067
3	0.0067

Uncertainty from the mass comparator u_{ba}

-Uncertainty due to the display resolution of a digital mass comparator

$$u_d = (\frac{d/2}{\sqrt{3}}) \times \sqrt{2} = (\frac{0.1/2}{\sqrt{3}}) \times \sqrt{2} = 0.0408 \text{ mg}$$

-Uncertainty due to the sensitivity of mass comparator

$$u_s^2 = (\overline{\Delta m_c})^2 (\frac{u^2(m_s)}{m_s^2} + \frac{u^2(\Delta I_s)}{\Delta I_s^2})$$

-Uncertainty from the mass comparator

Table6 Uncertainty from the mass comparator u_{ba}(mg)

Group	u_d	u_s	$u_{ba} = \sqrt{u_d^2 + u_s^2}$
1	0.0408	1.17926E-05	0.0408
2	0.0408	4.77038E-06	0.0408
3	0.0408	2.29099E-05	0.0408

Combined standard uncertainty
Combined standard uncertainty is shown in table7.

Table 7 Measurement uncertainty calculation on 50 kg weight(mg)

Group	Uncertainty Resources				Combined standard uncertainty
	Uncertainty from the reference weight $u(m_r)$	Uncertainty from the weighing process $u_w(\overline{\Delta m})$	Uncertainty from the air buoyancy correction u_b	Uncertainty from the mass comparator u_{ba}	
1	1.8480	0.0926	0.0067	0.0408	1.8507
2	1.8480	0.0498	0.0067	0.0408	1.8491
3	1.8480	0.0364	0.0067	0.0408	1.8488

The expanded uncertainty, *U*, of the mass of 50 kg weight is shown in table 8.

$$U(m_t) = ku_c(m_t) = 2 \times u_c(m_t)$$

Table 8Expanded Uncertainty (mg)

Weight Name	Standard Uncertainty *u*	expanded uncertainty *U*（*k* = 2）
197#	1.85	3.7
199#	1.85	3.7
200#	1.85	3.7

CONCLUSION

The repeatability of AX64004 comparator is always less than 0.4 mg(sometimes even better than 0.2 mg), which demonstrates that required environmental conditions indispensable for the running performance of this instrument. Only after satisfactory repeatability results are given, other characteristics can be tested and usefully determined. Besides, special care should to be given to suppress eccentric load error. For example, 50 kg kilogram weight is so heavy and big that, it cannot always be easily centered. To insure the safety on heavy weight and working people, a lifting device was mounted to move the weights from container to weighing pan[14].Then final test result of three 50 kg weights shows the expanded uncertainty is 3.7 mg.

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