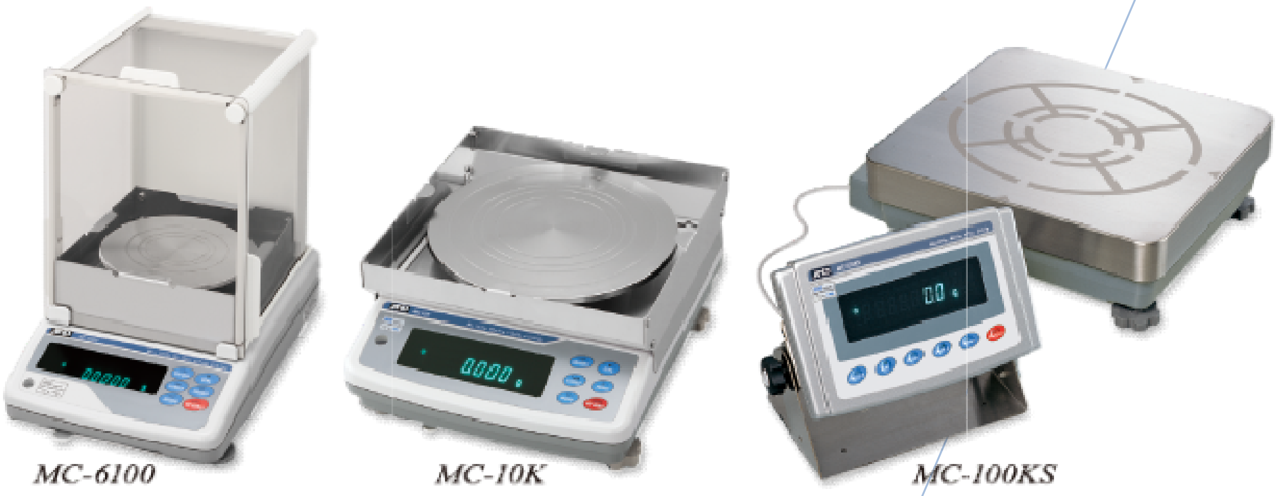
MC series of mass comparators

Accurate knowledge and usage to avoid trouble and maximize results



A&D Company, Limited

September 16, 2016

Table of Contents

1. Introduction

The MC series of electronic balances were developed for the purpose of weight calibration (mass comparison). Since sales began in 2010 this series has been well received among not only users who wish to manage weights in-house but also many people in service industries specializing in calibration. When used appropriately, the MC series enables extremely high precision measurement with superior cost performance.

That being said, without the proper understanding of the purpose and characteristics of the mass comparator and the correct installation, preparation and operation, you may fail to realize the full capability of and feel disaffected by the device. This document enables you to perform more accurate mass comparison by explaining the basic procedures and precautions for using the MC series.[1]

Meanwhile, the large capacity and high resolution of the MC series has allowed some users to find applications outside of mass comparison. However, even on such occasions, if you do not fully understand the main purpose and characteristics of the MC series or the meaning of its specifications you may draw false conclusions on phenomena that occur. Some considerations related to this point are detailed at the end of this document.

---

[1] Although this document mentions the typical methods of mass comparison there are no detailed instructions on calibrating weights. For procedures not covered here, strict requirements and recommendations, uncertainty calculation, etc., refer to standards such as OIML R111 and JIS B7609.

2. Balance fundamentals (explanation of terminology)

2.1. Zero point and span value

The zero point is the output of a balance before the target object is placed on the pan and is used as the base point of measurement. The span value on the other hand is the amount of change in the output due to the target object being placed on the pan and indicates the net weight of the object.

To obtain the span value, you need to subtract the display value at the zero point from the display value when the object is loaded. Under normal use you should set the display value to zero before each weighing with either the re-zero/tare key or zero tracking function[2] so that the measurement display value will be equal to the span value.

Ex.

Zero point	Measured value (full)	Span value
0.0007 g	100.0829 g	100.0829 g − 0.0007 g = 100.0822 g
−0.00012 g	19.99637 g	19.99637 g − (−0.00012 g) = 19.99649 g

2.2. Repeatability

Repeatability is the variation in the measured values when the same mass is loaded repeatedly by the same person under the same conditions (this is based on the premise that factors such as the operator, the target object, the measurement procedures, the environment and the balance itself influence the consistency of results).

Repeatability is typically expressed using the standard deviation (σ) calculated from a series of span values. For example, a standard deviation of 0.0004 g indicates that the results (span values) from a number of repeated weighings will fall within ±0.0004 g of their mean value with a probability of 68% (figure 1, next page).

---

[2] Balances equipped with zero tracking can automatically follow the zero point to maintain zero on the display.

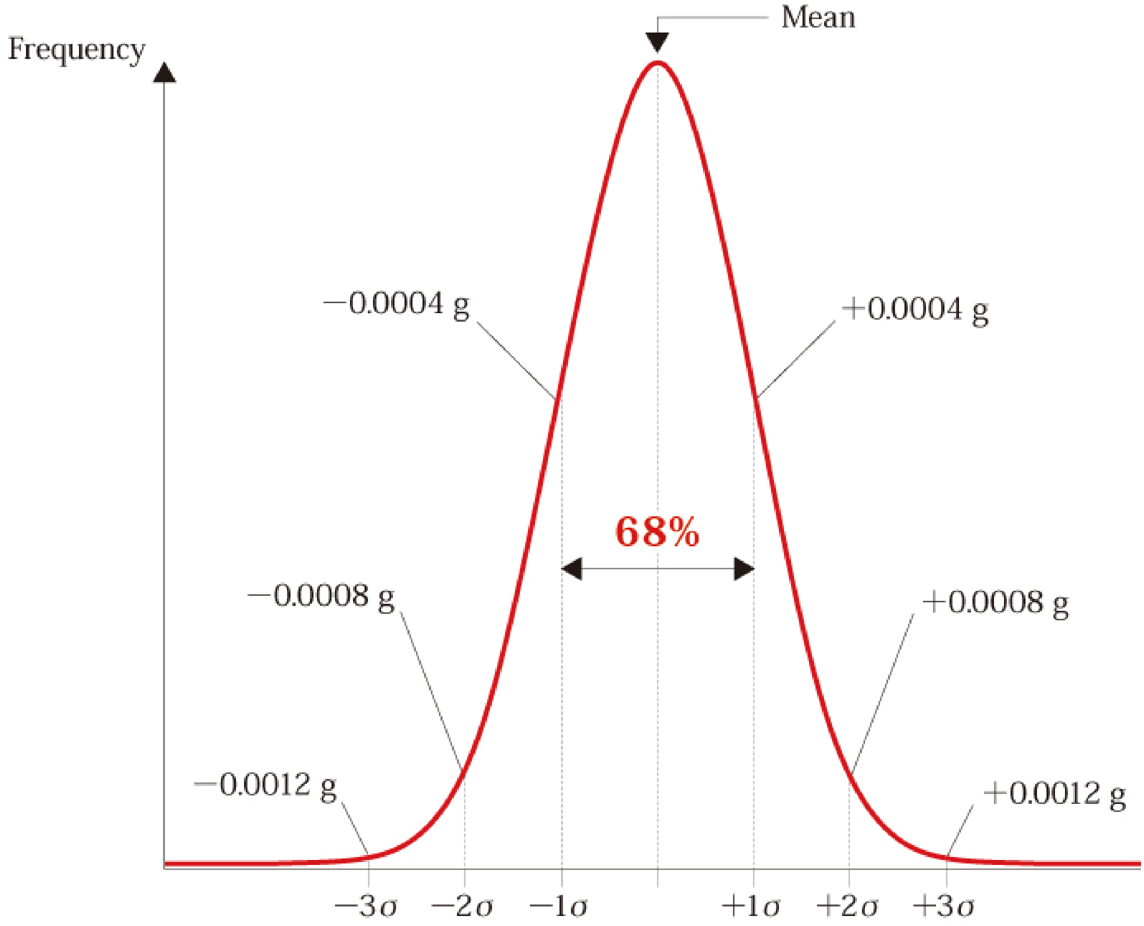


Figure 1. Assumed distribution when the standard deviation is 0.0004 g

2.3. Eccentricity (four-corner) error

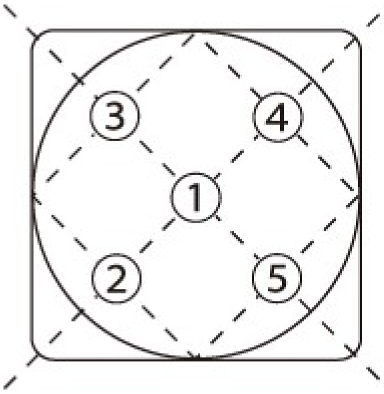


Figure 2. Positions for measuring eccentricity error

Eccentricity error represents the difference between the measured value of materials placed in the center of the pan and materials placed away from the center (four corners).

Eccentricity error is measured by performing sequential measurements with a single weight greater than 1/3 of the capacity of the device at the center of the pan and at the centers of gravity of 1/4 sections of the pan area (figure 2, previous page).

When eccentricity error is large, slight changes in weight placement can change measurement values leading to poor repeatability.

2.4. Zero-point drift

Both the zero point and span value will vary or “drift” in response to ambient temperature changes and other factors.

The purpose of weighing is to determine the span value. As a result, balance manufacturers generally specify the possible rate of such drift of the span value (sensitivity drift). However, virtually no manufacturers provide any specification for the drift of the zero point, which is much more susceptible to environmental changes than the span value.

A display value that drifts and never settles upon placing the target object is often a reflection of the zero point drifting while the span value remains fairly constant (figure 3). Zero tracking can only keep the display value at zero when the output is near zero; that is, at the start of each measurement.

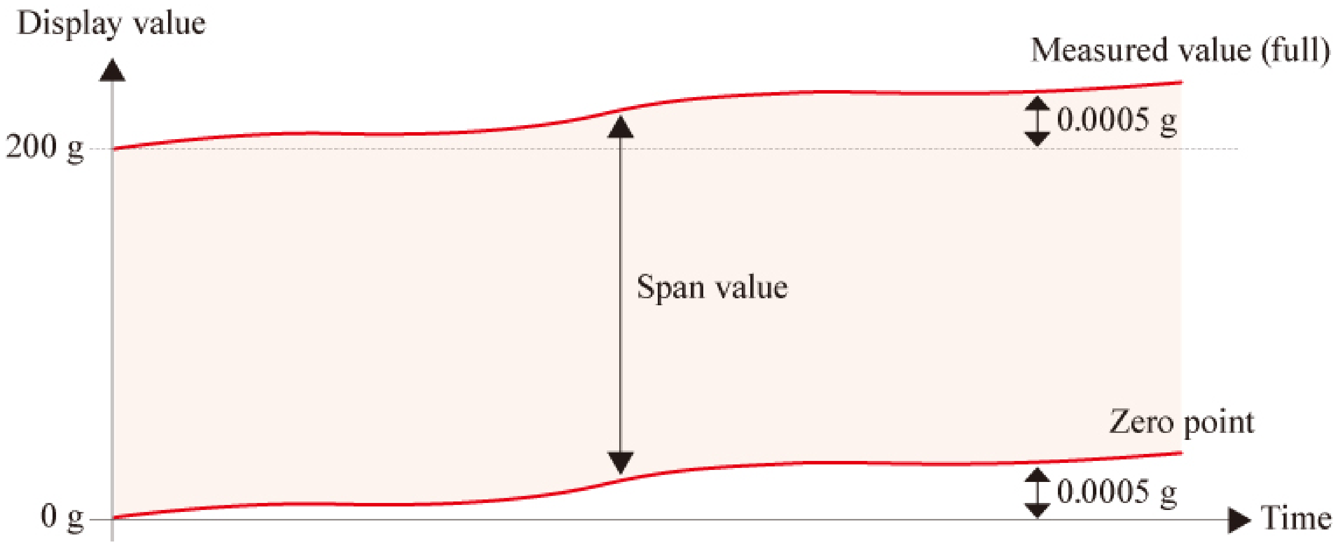


Figure 3. The span value remains fairly constant while the zero point may drift.

Drift is especially large when a balance is warming up (when internal temperature is rising due to power distribution) which requires caution as it can affect repeatability.

2.5. Uncertainty

Imagine for a moment that you are asked your weight. You weighed yourself the previous night after taking a shower and scale showed 62.6 kg. Would you say that 62.6 kg is without a doubt your “true weight[3]”?

Now, let's see. Before weighing yourself, how well did you dry off? Did you eat beforehand? When did you last go to the restroom? All of these factors can lead to variation in measurements. You also sweat during sleep. So if you had weighed yourself again in the morning you would have got a different value, wouldn't you? Of course, the accuracy of the scale cannot be ignored. Although digital scales have become more common recently, many of them have 100 gram scale intervals, which can lead to rounding error. Furthermore, older scales may be inaccurate due to their age.

However, even if you were not aware of these things, you know by experience that small variations are inevitable whenever you measure your weight. In other words, there is no way to ever know your “true weight”. So realistically, you will likely take a round number and say, “My weight is *about* 62.*5* kg.”

Uncertainty is a quantification of this ambiguous "about—", comprehensively considering various “uncertainty components[4]” such as eating before showering and weight rounding. It is probabilistically expressed as a standard deviation. In particular, uncertainty that defines an interval of two standard deviations (coverage factor k = 2: 95% confidence level) is known as "expanded uncertainty". Speaking in terms of the earlier example, if the expanded uncertainty was 0.74 kg, it can be estimated that your true weight has a 95% probability of existing in the range 62.6 kg ±0.74 kg.

To externally prove the traceability of a weight, etc., to the national standard of a

---

[3] Although there is the problem of defining “true weight” we will assume that it exists to simplify the concept of uncertainty with a familiar example.

[4] Typical uncertainty components associated with weight calibration include the uncertainty of the reference weight, the uncertainty of the air buoyancy correction, the uncertainty of the balance (repeatability, sensitivity, rounding error, eccentricity error, etc.).

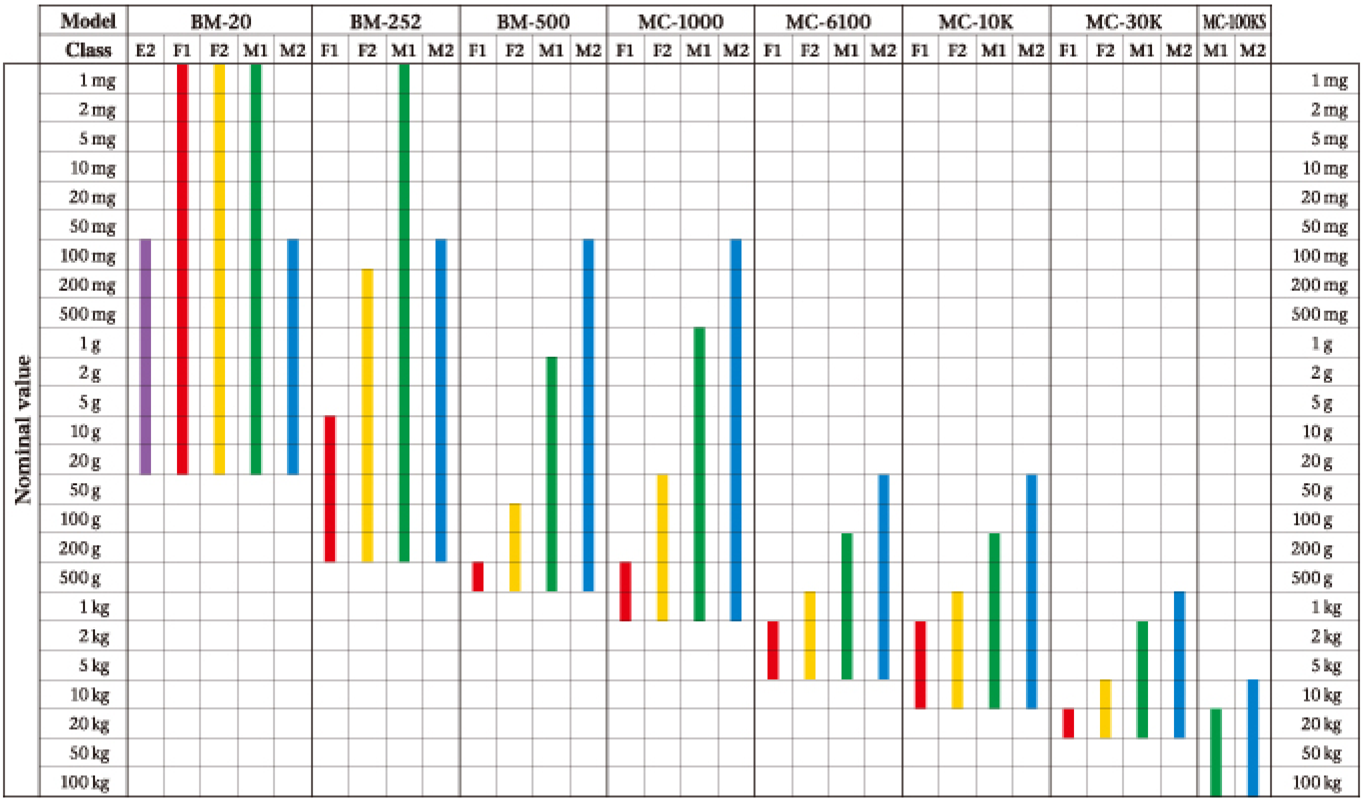
country, a calibration certificate needs to be issued by an ISO/IEC 17025 accredited laboratory that shows, in addition to the calibration value (nominal value + correction value), the uncertainty of that value.

3. Mass comparison

3.1. Selecting a mass comparator

When choosing the capacity and scale interval of a mass comparator take into consideration the class and nominal value of the weight to be calibrated (hereafter referred to as test weight). Ideally, select a model whose repeatability is not more than 1/6 of the maximum permissible error of the test weight.[5]

Based on the above, the recommended measurement ranges in each weight class for each model (including non-MC series models) are as shown below.



---

[5] The rationale for this is found in the OIML R111 standard "for each weight, the expanded uncertainty, U (coverage factor k = 2: 95% confidence level), shall be less than or equal to 1/3 of the maximum permissible error, δm ($U \leq 1/3\ \delta m$)" (OIML R111-1: 2004 5.2). Since the principal component of the expanded uncertainty, U, is the balance repeatability, σ, twice the repeatability can be substituted for the expanded uncertainty as shown by $2\sigma \leq 1/3\ \delta m$, which reduces to $\sigma \leq 1/6\ \delta m$.

However the above idea is an industry practice and not a rule that everyone must follow. Depending on the required management level of the facility, repeatability of not more than 1/3 (rather than 1/6) of the maximum permissible error of the test weight is often sufficient.

3.2. Installation environment

Mass comparators have greater sensitivity than general balances due to their intended purpose (calibration of weights for balance reference standards). They are therefore more susceptible to external disturbances (temperature, humidity, air pressure changes, drafts, vibration, etc.) making environment maintenance essential for obtaining expected repeatability.

Specifically, mass comparators should be installed on a rigid workbench and when necessary an external breeze break that covers the entire device should be used. Additionally, the temperature and humidity of the lab should be kept constant and measurement should be avoided on days with large changes in atmospheric pressure (such as when low pressure systems are passing through). Naturally, a barometer and thermo-hygrometer are necessary to manage the measuring environment and log data during calibration (the AD-1687 Weighing Environment Logger is useful for this).

For information on the ideal balance environment, refer also to the separately available booklet, “12 Tips You Can Use to Perform Stable Measurement With a Microbalance”.

AD-1687 Weighing Environment Logger

The AD-1687 allows you to monitor and record with dates and times chronological changes in temperature, humidity, atmospheric pressure and even vibration. Moreover, when connected to an A&D balance (including the MC series), it saves mass values sent from the balance together with these environmental data.

3.3. Setting and preparation

Use the auto-centering pan (excluding the MC-100KS) for the MC series to significantly reduce eccentricity error and resulting worsened repeatability. Auto-centering pans can automatically ensure that the center of gravity of the target object (weight) is brought to the center of the pan (figure 4).

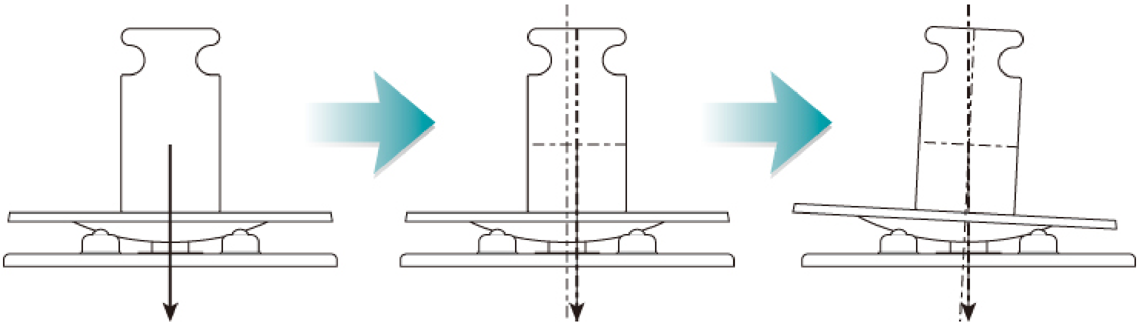


Figure 4. The center of gravity of the weight and pan are automatically aligned

Set the internal settings of the mass comparator as follows: COND = 2 (SLOW response), FIL = 1 (stabilization filter on) and TRC = 0 (zero tracking off). Turning the zero tracking function off is particularly important.

Plug in and allow the mass comparator 24 hours to warm up. At the same time, place and leave a weight equal to the capacity of the device (or the test weight if only one weight is to be tested) on the pan to let the sensor adjust to the weight.

The weight used as a reference standard (hereafter referred to as reference weight) and test weight must have sufficient time to adjust to the lab temperature. Heat stabilization times for weight class, size and difference between initial weight temperature and room temperature are specified in OIML R111 (OIML R111-1: 2004 B.4.3.1). However, allowing weights to sit at room temperature from the day before measurement is a practical alternative.

To avoid degradation, contamination, temperature change do not touch weights with bare hands. Wear gloves and handle weights with tweezers or a special weight fork or grip (for 10 kg and heavier weights using only gloves will have a negligible effect).

Tweezers

Fork

3.4. Direct comparison method

Described below is a method of finding the calibration value of a test weight by directly comparing its mass to a reference weight. Reference weights should have the same nominal mass but be of a higher class (e.g. for Class F1 calibration use Class E2 reference weights and Class F2 calibration use Class F1, etc).

Before starting mass comparison preload the mass comparator (load and remove either the reference weight or test weight a few times). At this time, prepare a timer and determine the read time (time to wait until the display is read after the weight has been loaded). When using a mass comparator that comes equipped with a breeze break (weighing chamber) avoid putting your hand in the chamber when loading weights.

Cycle ABA

A is the reference weight and B is the test weight.

(1) A1: Load A on the mass comparator. After P seconds read the display value then remove A.
(2) B1: Load B on the mass comparator. After P seconds read the display value then remove B.
(3) A2: Load A on the mass comparator. After P seconds read the display value then remove A.

P is the read time that you determined beforehand. Similarly, the intervals between measurements in steps (1)-(2) and (2)-(3) should be kept constant.

What needs to be noted here is the fact that drift is inherent in the balance. The cycles ABA (figure 5 on P.14) and ABBA (explained later) were devised to minimize the effect of drift and this is part of the reason why the read time and measurement interval should be kept constant.

Performing a tare (tare method) when reading the display in step (1) will make the subsequent values easier to read.

(4) Consider steps (1) to (3) as one cycle and then repeat as many times as necessary.[6]

(5) Find the difference in mass between A and B in each cycle (in this example 3 cycles).

$$\mathrm{C1} = \mathrm{B1} - \frac{\mathrm{A1} + \mathrm{A2}}{2}$$

$$\mathrm{C2} = \mathrm{B2} - \frac{\mathrm{A3} + \mathrm{A4}}{2}$$

$$\mathrm{C3} = \mathrm{B3} - \frac{\mathrm{A5} + \mathrm{A6}}{2}$$

(6) Calculate the average of the differences in mass.

$$\mathrm{D} = \frac{\mathrm{C1} + \mathrm{C2} + \mathrm{C3}}{3}$$

(7) With N as the nominal value and CV as the correction value of the reference weight, the calibration value of the test weight is

N + (CV+D)

---

[6] The minimum number of cycles for each weight class is described in OIML R111 (OIML R111-1: 2004 C.4.3).

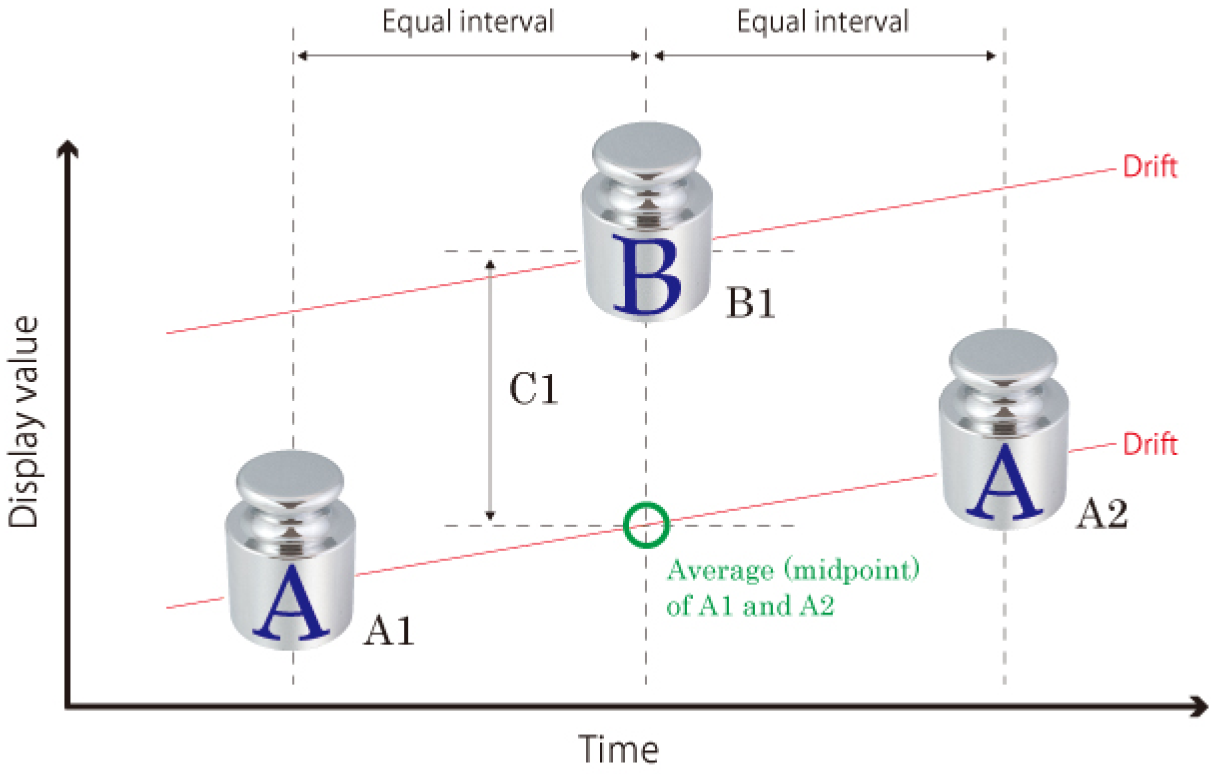


Figure 5. Removing the effect from drift (cycle ABA)

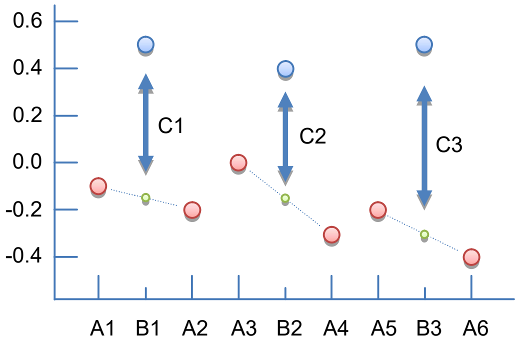
One measurement cycle of ABA (steps (1) to (3)) is represented along the time axis in figure 5. As you can see, even though balance drift occurs, if you read the display and measure at constant intervals, the midpoint of A1 and A2 will meet with the measuring time for B1 and allow for accurate mass comparison. (If the average of A1 and A2 is considered as the zero point relative to the B1 display value, the difference in mass between A and B, C1, can be considered as the span value.)

Ex.

MC-1000 (capacity: 1,100 g / scale interval: 0.0001 g) used to calibrate a 1 kg weight.

Cycle ABA performed with the tare method 3 times.

	A (mg)	B (mg)	Difference (mg)
1	A1 −0.1		
		B1 0.5	C1 0.65
	A2 −0.2		
2	A3 0.0		
		B2 0.4	C2 0.55
	A4 −0.3		
3	A5 −0.2		
		B2 0.5	C3 0.80
	A6 −0.4		
			D 0.67



Conventional mass[7] of reference weight A 1 kg −1.4 mg

Calibration value of test weight B 1 kg −0.7 mg

Cycle ABBA

This method compares the average of not only the reference weight A but also of two measurements of the test weight B. Similar to the cycle ABA this method also considers the effect of drift (figure 6 on P.17).

(1) A1: Load A on the mass comparator. After P seconds read the display value then remove A.

(2) B1: Load B on the mass comparator. After P seconds read the display value then remove B.

(3) B2: Load B on the mass comparator. After P seconds read the display value then remove B.

(4) A2: Load A on the mass comparator. After P seconds read the display value then remove A.

---

[7] Conventional mass is the value of a result of weighing in air. For a weight taken at a reference temperature of 20 °C, the conventional mass is the mass of a reference weight of a density of 8000 kg/m³ which it balances in air of a reference density of 1.2 kg/m³. (OIML R111-1: 2004 2.7)

P is the read time that you determined beforehand. Similarly, the intervals between measurements in steps (1)-(2), (2)-(3) and (3)-(4) should be kept constant.

(5) Consider steps (1) to (4) as one cycle and then repeat as many times as necessary.

(6) Find the difference in mass between A and B in each cycle (in this example 2 cycles).

$$\mathrm{C1} = \frac{\mathrm{B1} + \mathrm{B2}}{2} - \frac{\mathrm{A1} + \mathrm{A2}}{2}$$

$$\mathrm{C2} = \frac{\mathrm{B3} + \mathrm{B4}}{2} - \frac{\mathrm{A3} + \mathrm{A4}}{2}$$

(7) Calculate the average of the differences in mass.

$$\mathrm{D} = \frac{\mathrm{C1} + \mathrm{C2}}{2}$$

(8) With N as the nominal value and CV as the correction value of the reference weight, the calibration value of the test weight is

N + (CV+D)

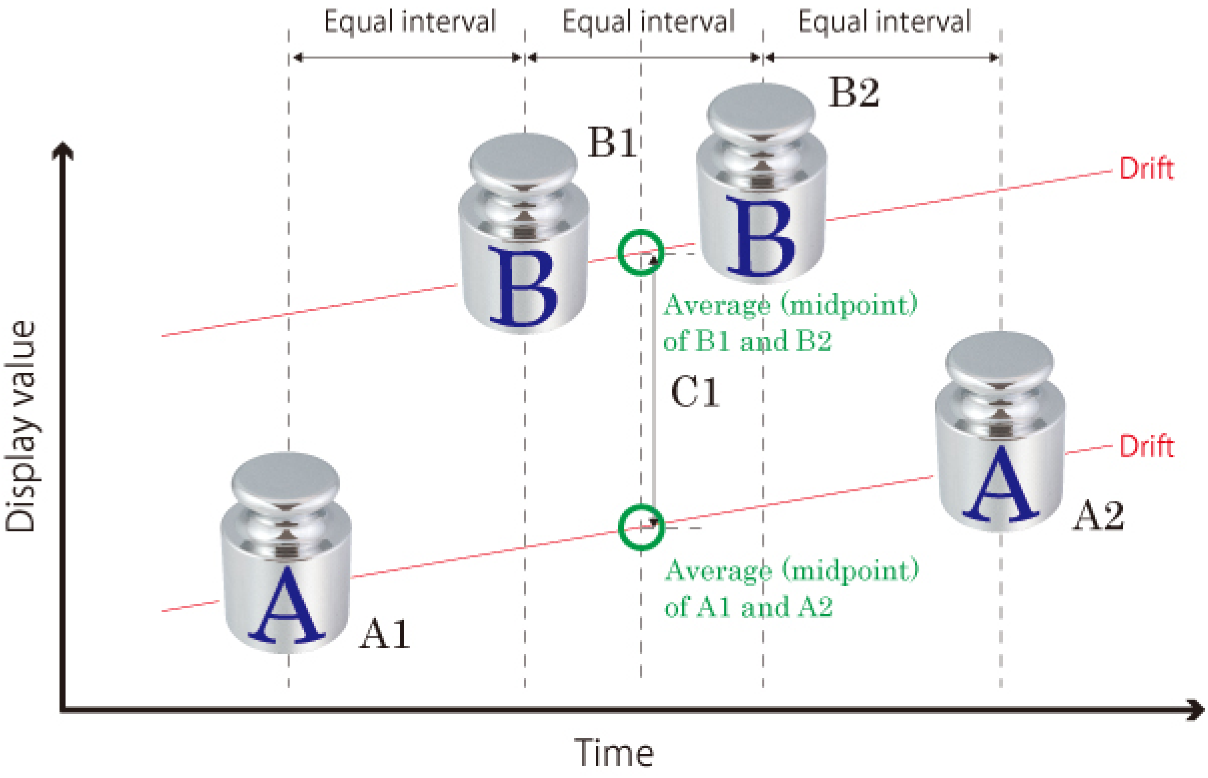


Figure 6. Removing the effect from drift (cycle ABBA)

4. Non-mass comparison related applications

4.1. Strengths and the limitations of the MC series

As previously stated the main purpose of the MC series is weight calibration, for which the resolution is enhanced. As a result, these balances can display one digit more than standard balances of the same capacity. Capitalizing on this feature, the MC series can be used effectively for applications where the actual measured/controlled net weight is extremely small relative to the total amount placed on the balance (including tare) such as measurement of wear volumes of metallic materials or fill levels of gasses.

However, as is apparent from the contents of this document thus far the proper procedure must be followed to fully draw out the performance of the MC series for high-accuracy measurements. Further, when comparing the MC series to balances with similar scale intervals (e.g. analytical balances with 0.0001 g scale interval and the MC-1000), the MC series has a larger capacity but weaker final digit stability.

4.2. Catalog specifications and actual variation

Let's take a look at what that means. First look at the MC series catalog specifications for repeatability shown below.

	MC-1000	MC-6100	MC-10K	MC-30K	MC-100KS
Capacity	1100 g	6100 g	10.1 kg	31 kg	101 kg
Scale interval (D)	0.0001 g	0.001 g		0.01 g	0.1 g
Repeatability (σ)*	0.0005 g	0.004 g	0.005 g	0.015 g	0.2 g

* In a favorable environment with an auto-centering pan (for the MC-100KS the automatic loader loads and removes from the same position)

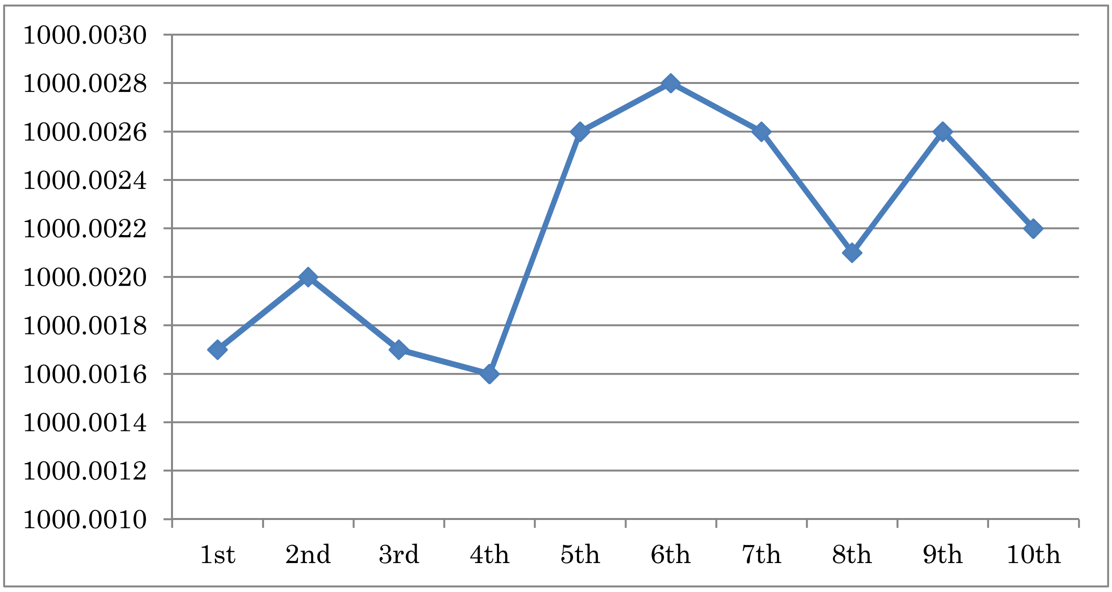
For example, A&D analytical balances with scale interval of 0.0001 g normally have a repeatability of 0.0001 g to 0.0002 g (1 d to 2 d) whereas the MC-1000 has a somewhat larger repeatability of 0.0005 g (5 d).

As explained on P.4-5, when the standard deviation is 0.0005 g results should fall within ±0.0005 g (±1 σ) of the mean 68% of the time for repeated measurements of the same weight by the same person under the same conditions.[8]

Here are the results of repeated measurements of a 1 kg weight using the MC-1000. The data is not very good but it meets the σ = 0.0005 g specification.

	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	Repeatability
Zero point	0.0000 g	0.0003 g	0.0000 g	0.0005 g	0.0002 g	0.0000 g	0.0006 g	0.0006 g	0.0005 g	0.0003 g	
Measured value (full)	1000.0017 g	1000.0023 g	1000.0017 g	1000.0021 g	1000.0028 g	1000.0028 g	1000.0032 g	1000.0027 g	1000.0031 g	1000.0025 g	
Span value	1000.0017 g	1000.0020 g	1000.0017 g	1000.0016 g	1000.0026 g	1000.0028 g	1000.0026 g	1000.0021 g	1000.0026 g	1000.0022 g	**0.000441 g**

The graph below displays only the span values.



How does it look? Although the standard deviation is 0.000441 g (< 0.0005 g) the amount of variation may be surprising (the difference between the maximum and

---

[8] Furthermore, 95% of values should fall within ±0.0010 g (±2 σ) and 99.7% within ±0.0015 g (±3 σ).

minimum values is 12 d). As you can see from this example, because standard deviation is the probability of the measurement as a whole, it is conceivable that values fluctuate greatly when you look at them individually. Keep in mind that the MC series has a large standard deviation with respect to scale interval which makes this effect especially pronounced.

Next is eccentricity error. As noted in the footnote in the table above, the MC series repeatability catalog specification includes use of an auto-centering pan or automatic loader. That is to say weighing is performed under conditions that eliminate eccentricity error. Or in other words, because the effects of eccentricity error are especially significant, the risk of worsened repeatability increases if you choose not to use an auto-centering pan or automatic loader..

Finally, as described on P.12-13, mass comparator usage (direct comparison method) assumes that drift will occur. Therefore, although the MC series tends to have greater drift compared to other balances with similar scale intervals this is not considered a problem. Of course, as with variation in measurement, drift can be greatly reduced with the correct installation environment and device setup and preparation.

For the reasons above, in applications other than mass comparison A&D recommends using the final decimal place of the MC series (e.g. 0.0001 g for the MC-1000) to confirm values at the next highest decimal place (0.001 g).