WEIGHING GUIDELINES

V1, 09.01.2024

Contents

1. Introduction

In general, a good electronic balance is one of the most accurate and precise measuring devices in any laboratory or vault. The current generation of electronic balances report mass with 7 significant digits and determine that mass of gold bars with a readability to 0.0003 tr oz (for large gold bars).

The purpose of this guide is to provide some insight into how electronic balances work, factors that affect mass measurement, and discuss the best practices for mass measurement of precious metal bars.

2. How an Electronic Balance Works

Electronic balances with the best accuracy and precision use electromagnetic force restoration (EMFR) or electromagnetic force compensation. An electromagnetic device is used to counteract the force of gravity acting on the object on the balance pan. Current is measured to maintain the balance pan at the null (or zero) position. This is illustrated schematically in Figure 1, which shows the force of the object (being weighed) on the pan countered by a coil and magnet connected via beam and fulcrum. Current technology allows the EMFR device to be cut from a single piece of metal (typically aluminium) using precision machining which greatly reduces the number of parts used to build this device (Figure 2). The electromagnet and circuitry are attached to the block and the current (correlated to mass) is measured.

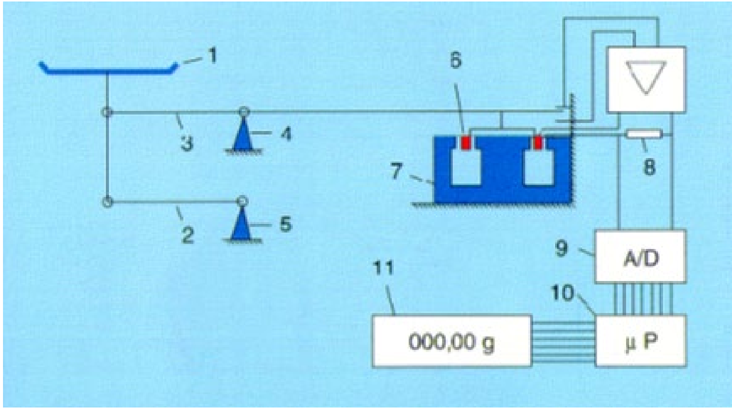

Figure 1. The schematic diagram of an Electromagnetic Force Restoration device is shown. The force of the object being weighed is countered by the force generated by an electromagnet. The balance pan (1) is at one end of two beams (2, 3) and the electromagnet (6, 7) on the other end with two fulcrums (4, 5) in between for the forces to balance out each other. An optical position sensor is used to verify that the zero position is maintained. The current is measured through a precision resistor (8) and digitized to a display (11) via an analogue-to-digital converter (9) and a microprocessor (10). (Figure from Sartorius [1])

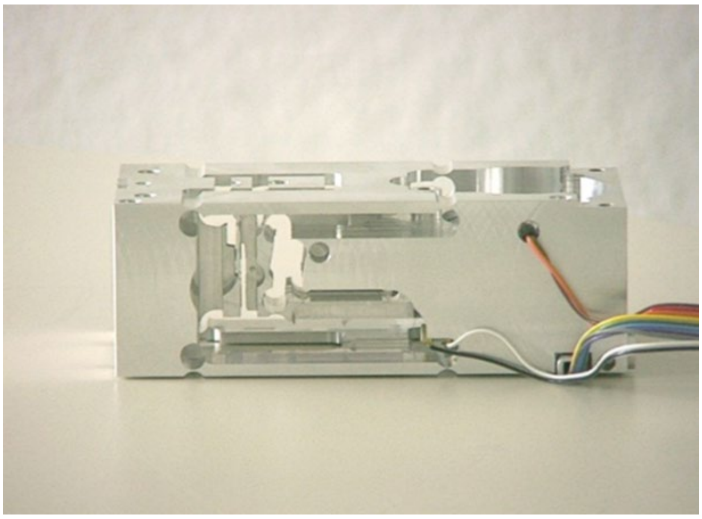

Figure 2. This is the photo of actual EMF device. It is precision machined from a single piece of metal. (Photo from Sartorius [1])

There is a linear relationship between the electrical current measured and the mass of the object placed on the balance (Figure 3) over the mass range of the device (i.e., 1 – 1200 g or 1 – 14,200 g). The metal block is manufactured in a way that this relationship is very reproducible (excellent precision) over time and through the linear response range of the device. This means that doing multiple mass measurements, of the same object, over time will give the same average result within a small standard deviation. Accuracy is established by calibrating the electronic balance with known weight standards through the range of the device. The linear current to mass relationship is stored within the memory of the device. This stored relationship must be verified by measuring the mass of an independent weight standard and comparing the result with its certified mass value.

The balance calibration occurs at the factory under ideal conditions. Analytical balances, generally, have a process where an internal weight is used to adjust the balance's response to changes in latitude and altitude (variations in gravity with location), temperature, humidity, and other environmental factors. This can be manually initiated or automatically triggered by changes in temperature or humidity. This adjustment should be verified by measuring a check weight assigned to the balance and compared to the acceptable range for the mass of this weight.

Some examples of electronic balances are given in Table 1. This shows the mass capacity, readability (lowest displayed mass unit), and the type of bar product to be weighed.

Range	Readability	Applicable to Measure Mass
1 210 g	0.001 g	Kilobar
14 200 g	0.01 g	Gold Large Bar
64 000 g	1 g	Silver Large Bar

Table 1. List of the capacities of selected electronic balances with noted readability and applicability to measure the mass of precious metal bars.

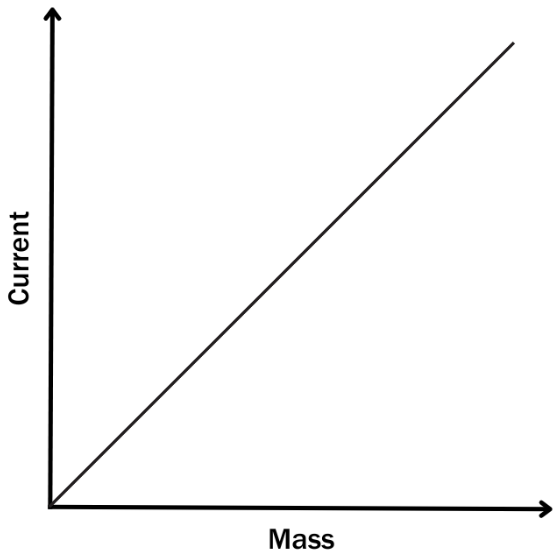

Figure 3. Mass vs Current for electronic balances.

3. Mass Traceability

Each good mass measurement or weighing can be traced through a chain of comparisons to an international mass standard.

3.1 New Definition of the Kilogram

In 2019, the definition of the kilogram was changed. It had previously been defined as the mass of a Platinum-Iridium cylinder (Le Grande K or primary kilogram) residing at the BIPM (International Bureau of Weights and Measures) in France. However, after years of comparisons to primary national kilograms, it was found that the Le Grande K was losing mass (very slightly). After many years of research, the kilogram was defined in terms of the Planck constant ($6.62607015 \times 10^{-34}$ $kg \cdot m^2 \cdot s^{-1}$) and the measurements are done on a Kibble Balance [2]. At present, there are five accredited Kibble Balances located in Canada, France (2), Switzerland, and the United States. The mass value of a kilogram is measured by one of these Kibble Balances with an associated uncertainty. This is considered to be a primary mass determination method used for measuring mass of national kilogram standards.

3.2 Unbroken Chain of Comparisons for Mass Traceability

Establishing the accuracy mass or weight measurements is done through comparison of known mass standards. Each of the weight standards must have a certificate indicating the mass of the standard with an uncertainty and a statement of traceability to the kilogram standard. Traceability is defined as the "property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually through an unbroken chain of comparisons all having stated uncertainties" [3].

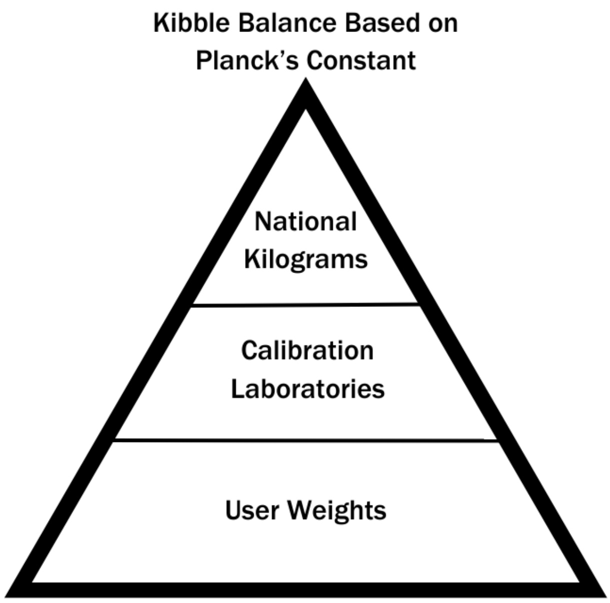

Figure 4. Mass traceability pyramid starting from the primary assessment of mass (Kibble balance based on Planck's constant) to comparison to kilograms held by National Metrology Laboratories then to Calibration Laboratories and then finally to User Weights.

The mass traceability pyramid depicted in Figure 4, shows the comparison chain starting with kilograms made of a Platinum-Iridium alloy from each nation's metrology laboratory being measured by a Kibble Balance. From there accredited calibration laboratories have sets of weights measured against the National Laboratories' mass standards. For each weight standard or set of weights measured, a certificate is issued indicating the mass and uncertainty for each weight as well as a statement indicating to which National kilogram the mass comparisons can be traced. This process is repeated for user weights sets or single weights measured by calibration laboratories.

Within each National Mass Laboratory and each Calibration Laboratory, there is another hierarchy of mass standards. This starts with the master weight or weight sets calibrated by the level above (Kibble Balance or National Laboratory). The next level is a reference weight or set of weights which are calibrated against the master weight or weight set within the institution. The reference set in turn calibrates the working set of weights that are used daily and recalibrated at regular intervals (certificate issued with measured mass with an associated uncertainty).

3.3 Weight Standards

Weight or mass standards are critical components in the traceability chain. They must be relatively inert, stable materials that do not change mass under normal handling conditions. Weight standards made of stainless steel meet these criteria. The International Organization of Legal Metrology (OIML) is an intergovernmental treaty organization that has developed weight classes that define the quality of weight standards [4] in terms of:

- Accuracy (closeness to nominal values and error limits)
- Material and Density
- Shape
- Surface Roughness (reduce attraction of dust and humidity).
- Low Magnetic Properties (reduces effect on mass measurement devices)

The weight classes go from highest to lowest: E_1, E_2, F_1, F_2, M_1, $M_{1\text{-}2}$, M_2, $M_{2\text{-}3}$, M_3. There is an associated cost with weight quality however weight standards are excellent long-term investments.
Once obtained, weight standards must be properly handled:

- Store in clean covered container.
- Handle with clean cotton gloves (direct contact with hands leaves oil residue that affects mass over time).
- Avoid drops and knocks.
- Re-calibrate at regular intervals (1 or 2 times per year) and update mass values in the monitoring software.
- Use the certified mass value as indicated in the certificate.

Most good weight manufacturers will provide a certificate of mass values for newly purchased weights. However, it is prudent to have the weights re-measured by an accredited mass calibration laboratory on a regular schedule (annually or twice yearly). This depends on the importance of the mass measurements and the laboratory schedule.

The certificate reports mass as conventional mass which assumes that: weights have a density of 8000 kg/m^3, the air density is 20^oC, and the air density is 1.2 kg/m^3. This accounts for air buoyancy effects which for vast majority of laboratory mass measurements has no real effect on the measured mass values recorded. At the international and national laboratory levels masses are measured in vacuum and reported as absolute mass values (in vacuum) where this type of accuracy and precision are required.

4. Factors Affecting Mass Measurement

Electronic balances work very well but must be set-up correctly within a proper environment to provide the best possible results. The following sections describe the optimal settings.

4.1 Balance Levelling
A balance must be level otherwise the force acting on the load cell (measuring) mechanism will be at a different angle than when the balance was completely level and calibrated. For example, if one side of the balance is raised by the thickness of a business card (400 µm) then the mass of a kilogram gold bar will be lower by 1.8 mg (will read 999.998 g vs 1000.000 g) [adapted from reference 1].

Most balances have a level indicator so that the balance can be manually adjusted to be on the level by screw threads on the corner legs attached to the device. The indicator must be checked before using the balance. More automated units have sensors alerting the operator to the balance not being level.

4.2 Environment
The environment surrounding the electronic balance will impact the quality of the mass measurements. The following items need to be considered in the physical set-up of the weighing area and in the daily operations [1, 5, 6, 7].

4.2.1 Vibration
Vibrations from the building, carts and people moving by need to be minimized to ensure high quality weighing. The best results occur with the balance located in a separate room with minimal traffic (people and machinery). The following should be implemented:

- Place the balance on a weighing table designed to be at an ergonomic height for the operators and made of marble or granite (not metal or wood). The heavy weighing table acts as an inertial dampener and minimizes vibrations transmitted to the balance. Cork pads should be set between the floor and the table legs to act as shock absorbers between the table and the building floor, which also acts to minimize vibration.
- Most electronic balances have settings to minimize vibrations through lengthening the read time and measurement averaging.
- If it is not possible to isolate the balance in a separate room, then weighing should only be done when there is no traffic (people or lifts/carts) going by the weighing area. Also, metal carts and forklifts are usually magnetic and moving them by an electronic balance changes the magnetic field surrounding the balance and will affect the measurements.

4.2.2 Temperature
Temperature is a definite factor in mass measurements. The environment must be at a stable temperature otherwise the thermal equilibrium of the balance will be disrupted and cause weighing errors. This means that balances must not be in direct sunlight (from windows) and must not be located near outside walls of buildings. Operators are also a heat source compared to a balance at room temperature. People must not be too close to the balance nor stay near the balance unless doing weighing operations. Best results are obtained when the temperature of room is set at one temperature all the time and operators wear lab or protective coats to reduce their radiated heat toward the balance.

All the materials to be weighed must be at the same room temperature as the balance and check weights. Temperature differences of materials weighed will alter the temperature of the balance through physical contact and by generating air currents that might alter the forces acting on the balance (hot materials – up drafts resulting in lower mass value; cold materials – down draft resulting in higher mass values).

4.2.3 Air Flow
Air has mass; one cubic meter of air has a mass of about 1 kg. If one fans air towards an empty balance pan, generally a change in the balance display is observed. A good work environment requires some air flow in the room. It must not however affect the balance mass measurement. This must be evaluated both for an empty balance and with a gold bar on the balance pan. Fluctuations in mass displayed with an empty balance will affect the zeroing point of the balance (zero mass) and of course changes in mass with a gold bar will affect the final mass. These will be observed as errors and/or increase in mass variability (uncertainty).

There are ways of minimizing the affect of air flow:

- Reduce or re-direct air flow from building ventilation away from the balance(s).
- Enclose the balance within a draft shield that allows weighing operations.
- Use a balance with a small balance pan or a mesh pan – both minimize the surface area in contact with the air.

4.2.4 Humidity
Like temperature, humidity should be kept constant between 40 – 60% relative humidity [6]. If humidity is high, then moisture re-adsorption may occur if samples are stored in a lower humidity environment (increasing mass as moisture is adsorbed). High humidity may also cause water condensation within the balance mechanism which will not be good for the longevity of the device and may impact the internal counterweight used for updating the calibration of the device (inaccuracy). On the other hand, too low humidity (< 40% relative humidity) can lead to the build up of static electricity within and around the balance which will affect the performance of an electronic balance.

4.2.5 Static Electricity
As noted in the previous section, low humidity can lead to a build up of static electricity within and around the balance. Since the balance measures current, a build up of static electricity may affect this measurement.

How to minimize or eliminate the effect?
Here are some of the most effective methods [6]:

- Maintain humidity in the laboratory or in the weighing area between 40 – 60%
- Ground the balance.
- Use an ion source inside the balance chamber to discharge the static charge.

4.2.6 Pressure Changes
Hinged doors opening into the room or out of the room change the pressure in the room and generate a force change in the air that will be measured by the balance (will alter the mass of a gold bar being measured or the zero point if being set). Sudden start ups of the building ventilation and air tube sample delivery systems will also cause sudden changes in pressure. The smaller the room the bigger the effect. These are random events and can be minimized by installing sliding doors into the weighing room, having continuous building ventilation, and not having air tube delivery systems in the same room as electronic balances.

4.3 Maintenance and Cleaning
Electronic balances like any other sensitive measuring device must be properly maintained to ensure that the most accurate and precise mass measurements are obtained. There are steps that should be followed to maintain the electronic balance(s):

- Daily Maintenance
    - Check the level of the balance and ensure the balance does not move from pressure applied to each of the corners of the balance frame. If this occurs, a complete re-leveling

must be done so that the balance is level and there is no corner-to-corner movement (rocking).
    - Clean the balance (pan, surrounding surfaces, and the display) and check that there is no visible damage to the balance.
    - Check the computer connection to the balance to ensure that mass data is transferred automatically and accurately.
    - Warm-up the balance before weighing operations. The balance has mechanical components, and they should be moving freely.
        - Place the check weight on the balance pan, let the display settle, take the check weight off the pan, and repeat the process 4 – 5 times.
        - This warm-up should be done when there has been a gap of 4 hours from the last measurement.
    - The maintenance noted above may need to be done more frequently than daily depending on the number of bars weighed.

- Annual Maintenance by factory trained technicians.
    - Thorough cleaning and check of all moving parts.
    - Sensitivity and Linearity Check
    - Precision and Accuracy Check (using technician's weight set)
    - Check balance eccentricity by placing weight on center and four corners of the balance pan (if large enough).
    - Produce a report of compliance that fulfills ISO 17025 and ISO 9000 requirements.
    - Can be done more frequently depending on the importance of the mass measurements, the number of measurements done annually, and the state of the electronic balance.

5. Best Practices

5.1 Physical Set-Up of the Weighing Area

The physical set-up of the weighing area should be in a separate area with sufficient space to allow for the movement of materials (i.e., bars on carts and people) while keeping vibrations, temperature, humidity, and pressure fluctuations to a minimum. The area should have a supply of clean air (no dust) but without the air flow affecting the electronic balance(s). These factors are discussed in section 4.

5.2 Best mass measurement practices

5.2.1 Proper Weight and Bar Handling

Clean cotton gloves must be worn when handling calibration weights or check weights. This prevents transference of dust, oil, or sweat to these very important mass standards.

Although bars are not meant to have sharp edges, protrusions or friable sides, such bars may still be encountered from time to time. These conditions may make a bar difficult to handle, especially with precision when loading or unloading weighing scales, so care must be taken to avoid physical injury or damage to the bar or scale. If mechanical means are available to load the scale, they should be used, or at the very least, protective gloves should be worn.

All objects (weight standards and bars) must be placed gently onto the centre of the balance pan to avoid a mechanical shock to the weighing device. This is quite easily accomplished for large gold bars where operators can manually set these bars on the balance pan puck on gold bullion balances without concern for pinching fingers. For kilo bars, setting them on a flat balance pan can be more of a challenge and lead to inadvertent short drops from time to time. One solution is to have a tared slotted holder on the balance pan upon which operators can set a kilobar without pinched fingers or leading to drops. Heavier silver bars also present a challenge however affixing a tared roller top onto the balance pan permits silver bars to be rolled onto the balance thus eliminating the risk of dropping the bars onto the balance.

All objects to be weighed must be placed in the centre of the balance pan to ensure even distribution of the weight onto the load cell. If the check weight needs to be moved off centre (towards a corner of the balance pan) to obtain an acceptable value, then this indicates there is a problem with the balance, and it must be repaired.

5.2.2 Balance Function Set-Up

Electronic balances have some built in and/or automated functions that improve the weighing process. Since many laboratories capture and process data through a Laboratory Information Management System (LIMS), balances are configured to output mass data through one or more data ports on the balance. Good quality balances also have a function that automatically sends data to LIMS when the first stable reading is obtained (recommended). The same transfer protocol should be used for all balances in the laboratory.

The internal software of the balance can be set to display the mass in a variety of units (g, kg, oz. tr oz, …). The software can also be set to account for the stability of the environment by doing time averaging to minimize the effects of vibration and/or air flow. By selecting a less stable mode, the balance will take more time to average several mass measurements. If a more stable mode is selected, then the measurement will take less time. One can also choose auto re-calibration if the temperature or other factors change too much, or this can be done manually. There is also a function for putting the balance into sleep mode after a period of inactivity.

5.2.3 Balance Warm-Up Weighing

Balances must be powered on 120 minutes before use if completely powered off (unplugged) or be kept in standby mode when not in use. As noted in section 4.3, an electronic balance has mechanical parts which need to be engaged prior to taking high quality measurements. The practice of putting the check weight on and off the balance 4 – 5 times with the balance settling between is highly recommended. Once this is complete, the device should be ready to measure the check weight to start the weighing session.

5.2.4 Check Weight

The accuracy of any electronic balance must be verified daily (if not several times a day, depending on throughput) by measuring the mass of an independent weight standard with a known mass value and uncertainty. It is important to use a check weight of the same mass as what is being measured.

Example:
A 400 troy ounce stainless steel weight should be used as a check weight for weighing 400 troy ounce gold bars. The certificate value of weight from an accredited calibration laboratory indicates that the mass of this weight is 400.0012 ± 0.0003 troy ounce. The uncertainty is established for the check weight by the calibration laboratory using a mass comparator which measures mass with lower readability than a regular electronic balance.

The check weight is typically measured at the beginning, middle, and end of a batch weighing to ensure the balance is measuring correctly throughout the whole batch of bars being weighed. Some operations measure the check after “x” number of weighed bars based on the number of bars that they would be willing to re-weigh if the check weight measure is outside acceptable limits.

What are acceptable limits?
It depends on the performance of the balance in the environment in which it is operating. This can be determined by measuring the check weight over the course of several shifts at hourly intervals and recording the values to obtain an average and standard deviation. One can use an acceptable limit of ± 2 x (standard deviation) or ± 3 x (standard deviation). Too small an acceptable limit and you will be re-calibrating frequently. Too large an acceptable limit and risk of bias (inaccuracy) increases. Many companies have automatic data capture systems which permit the check weight to be identified and have the acceptance limits stored. The system permits a batch of bars to be weighed only if the check weight falls within the acceptance limits at the prescribed intervals.

What happens if the check weight value is outside the limits?
The operators should first check the balance (level, dust, and clean debris), then re-weigh. If no improvement, then re-calibrate using the internal re-standardization common to most modern electronic balances (see balance manual for details). In this procedure a sealed internal weight is connected to the load cell and re-adjusts the calibration of the balance. After this procedure, the check weight must be re-measured to determine whether the re-calibration was effective.

5.2.5 Check Weight Control Chart

The results from the check weight measurements can be both tabulated and graphically displayed. The graphical display is usually referred to a control chart. An example of control chart is shown in Figure 5. The vertical axis indicates the measured mass of the check weight. The horizontal axis indicates the time (hours, shifts, or corresponding measurement number) of the measurement. There are five lines displayed: check weight mass calibrated value (single line), working range with values ± 2 x (standard deviation) from the calibrated value, and the control limits ± 3 x (standard deviation) from the calibration value, as depicted in Figure 5.

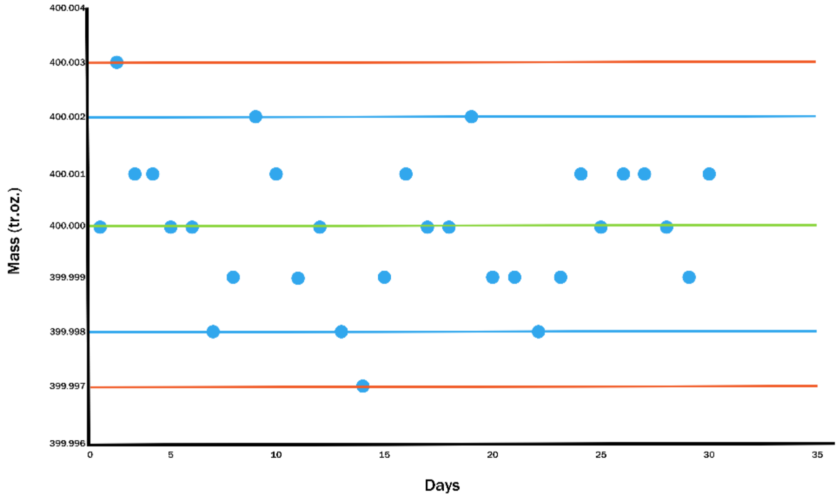

Figure 5 – Check Weight Control Chart, where the green line is the calibrated mass value for the check weight. The working limits [± 2(standard deviation)] are shown in blue and the upper and lower control limits [± 3(standard deviation)] are shown in red.

In the short term (1 -3 days/shifts), the control chart will indicate whether the electronic balance was measuring correctly with acceptable limits. The data collected on a longer-term basis (weekly, monthly) will indicate the balance trends such as consistent trending low or high within the acceptable limits. The control charts should be reviewed weekly or bi-weekly to spot any trends before they become an issue.

5.2.6 Bar Inspection

In the normal course of operations, precious metal bars are inspected for quality and defects. The bars must also be completely dry. Bars that retain water from the manufacturing process will change mass over time which is a problem. Caution should be exercised as wet bars can also present handling challenges and some cooling fluids can act as an irritant on skin. Suspicious bars should be further dried before being weighed.

5.2.7 Independent Duplicate Measurements

Some organizations use the results from two independent electronic balances to determine the mass of the bars. This has some benefits:

- Independent verification of the measured mass of each bar
- Useful in identifying bars that contain water. There should be a noticeable difference between the first and second weighing.
- Identifies a problem with a mass measurement from one balance immediately and track the problem to the bars quickly.
- If one balance goes down, there is already another balance functioning that can be used (with more frequent checks) until the other balance is repaired.

It is not uncommon to even have spare balances available for critical weighing operations. This is because repairs can take weeks to be done and the purchase of a new electronic balance may take weeks depending on the type of balance, your location, your internal procedures, and time of year (i.e., Christmas holidays).

6. LBMA Good Delivery (GDL) Rules

For all weighing the LBMA recommends that, for the weighing of gold and silver, all weights used for calibration, weighing, and checking should be made of stainless steel. This guide provides a summary of the weighing and rounding rules. For a complete explanation of the rules and examples, the reader is directed to the most up to date LBMA Good Delivery Rules on the LBMA website [8].

6.1 Weighing Gold Bars

6.1.1 Equal Arm Balances

It is the practice of LBMA and the market to weigh gold bars in multiples of 0.025 of a troy ounce and therefore this is the smallest weight used.

For a gold bar to 'turn the scale', it is necessary for the bar to cause the indicator needle on the beam balance to move a minimum of two divisions in favour of the bar when the correct weight is placed on the scales.

A division on a gold beam balance corresponds to 0.001 of a troy ounce. A gold bar must therefore weigh at least 0.002 of a troy ounce over the stated multiple of 0.025 for a Bar to be said to 'turn the scale'. If a bar does not 'turn the scale' then the weight is reduced by 0.025 of a troy ounce. While it is recognised that other procedures for weighing exist, the above procedure will be used in determining the weight of gold bars delivered into the London market.

6.1.2 Weighing Gold Bars – Electronic Balances

The mass measurement from an electronic balance should be recorded in troy ounces or recorded in grams/kilograms then converted to troy ounces. Then to comply with the rounding rules, the value of 0.002 tr oz must be subtracted from the measured value (in troy ounces). The rounding rules then apply to the subtracted weight as noted in the following table.

Measured Mass, tr oz	Subtract 0.002 tr oz	Reported Rounded Weight, tr oz
412.024	412.022	412.000
412.026	412.024	412.000
412.028	412.026	412.025

What about converting from grams or kilograms to troy ounces?

The LBMA uses the following conversion factors:

1 troy ounce = 0.0311034768 kg.
1 troy ounce = 31.1034768 g

When converting from kilograms or grams, one should be mindful of the fact that the final converted weight must have the same number of significant figures as the measurement. For example: a gold bar is measured at 12.5622 kg or 12562.2 g and using the above conversion factors the bar weighs 403.884 tr oz One can get more numbers after the decimal place from a spreadsheet or a calculator, but these are somewhat meaningless because there is a variation of at least ± 0.001 tr oz in measured value.

What about a bar whose mass is just at the turning point – which way do you go?

There are a couple of different ways to prove how the bar should be rounded:

- Do multiple weighing with the same balance and a different balance (at least 2 measurements from each balance). Take the average and calculate the standard deviation.
- Use a new generation balance that reports mass to 0.0003 tr oz. This gives more information as to the mass of the bar, i.e., 412.0273 – 0.002 = 412.0253 tr oz → rounded value 412.025 or 412.0269 – 0.002 = 412.0249 tr oz → rounded value 412.000

6.2 Weighing Silver Bars

Electronic balances used for weighing silver generally show the weight in troy ounces to two decimal places. Due to uncertainty in the second decimal digit, the recorded weight will be reduced to the next lower 0.1 troy ounce division if the second decimal is less than 5. On that basis, a bar showing a weight of 1000.95 on the scale would be recorded as 1000.9 troy ounces whereas a bar showing as 1000.94 would be recorded as 1000.8 troy ounces.

7. References

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