CE update [generalist]

Laboratory Balances: How They Work, Checking Their Accuracy

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After reading this article, the reader should understand the principle operation of the modern electronic balance and understand how to check the balance's accuracy.
Generalist exam 90401 questions and corresponding answer form are located after the "Your Lab Focus" section on p. 59.

- Modern electronic laboratory balances work on the principle of magnetic force restoration. In this system, the force exerted by the object being weighed is lifted by an electromagnet. A detector measures the current required to oppose the downward motion of the weight in the magnetic field.
- Accuracy checks of a balance involve testing for reproducibility, linearity, calibration, and cornerload.

Precision weighing is a necessity in laboratories of all types. Accuracy exceeding one part per million is commonplace now for masses in the range of 1 gram to 1 kilogram. Although the requirement for highly accurate weighing for the preparation of reagents, standards, and calibrators has diminished, many laboratories use precision balances for periodic checking of the accuracy of mechanical pipettors.

Principle of Operation

The principle of operation of a modern laboratory balance bears some resemblance to its predecessor—the equal arm balance. The older instrument opposed the torque exerted by an unknown mass on one side of a pivot to that of an adjustable known weight on the other side. When the pointer returned to the center position, the torques must be equal, and the weight was determined by the position of the moving weights.

The modern equivalent is called magnetic force restoration. In this system, the force exerted by the object being weighed is lifted by an electromagnet. The typical mechanism consists of a coil of wire suspended in a magnetic field. Because the magnetic field is radially oriented relative to the coil, the direction of current flow and the direction of the magnetic field are perpendicular at all points. The force exerted is therefore in the direction of the axis of the coil. The coil is supported by precision springs, which allow it to move in the direction of its axis. An optical sensor detects the position of the coil, and provides a feedback signal to an electronic amplifier. The amplifier automatically adjusts the current to maintain the position of the coil at a reference position (the "null" point). The amount of force exerted by the coil is directly proportional to the amount of current flowing in it. So, by measuring that current, the force can be calculated.

The equal-arm balance opposed 2 counteracting torques and caused the deflection of a needle to return to a reference position, whereas the electromagnetic force restoration system opposes the linear force exerted by the unknown against the adjustable and known linear force exerted by the coil at a specific spatial position.

Checking Accuracy

The College of American Pathologists (CAP) Laboratory Inspection Program requires that "the verification of accuracy of the analytical balance must be performed each time it is used for the creation of analytical calibrators and/or weighed-in controls from standard materials." as well as when gravimetrically checking the accuracy of pipets.[2]

Checking a balance is very similar in concept to the checks we do in the laboratory for other analyses. There are 4 components to the testing of a precision laboratory balance: *reproducibility, linearity, calibration,* and *cornerload.*

Reproducibility refers to the instrument's ability to repeatedly deliver the same weight reading for a given object. It is expressed as a standard deviation. Standard deviation, or reproducibility, is often an advertised performance specification for a laboratory balance.

Linearity is the characteristic which quantifies the accuracy of the instrument at intermediate readings throughout the weighing range of the instrument. The weighing range of the instrument is similar to the analytical measurement range (AMR) of a laboratory test. Since a laboratory balance will often be used to weigh items much smaller than the capacity of the instrument, this is a critical aspect.

Calibration refers to a comparison of the weight reading of a given mass standard, and the actual value of that standard. This measurement is often done at full capacity.

Cornerload errors are those errors associated with different positions on the weighing pan of the object being weighed. A given object should produce the same reading, regardless of its position on the weighing pan. This is a type of error that is unlike those usually seen in the clinical laboratory and is unique to the analytical balance.

How to Check Balance Accuracy

The tests for balance accuracy are similar to those done in the clinical laboratory for checking the accuracy and precision of analytical tests. However, because balances are special mechanical devices, there are some differences in the details of the reliability tests. Complete instructions with forms for collecting the test data[1] can be found at the Web site, www.labbalancerepair.com/test.doc.

Reproducibility Testing

Reproducibility testing entails repeatedly weighing a given object, recording the results, and analyzing those results. A test weight equal to, or nearly equal to, the weighing capacity of the instrument should be selected. Twenty pairs of readings should be taken for 2 data sets: "full-scale reading" and "zero reading." A detailed procedure is as follows.

1. Tare the instrument to read all zeros. Do not record the initial zero reading.
2. Place the test weight on the pan. Record the reading in the column labeled "FULL SCALE READING" .
3. Remove the weight (DO NOT REZERO), and record the reading under "ZERO READING"
4. Repeat steps 2 and 3 until lines 1 through 20 are all filled in.
5. Transcribe the 2 columns of numbers into a spreadsheet or QM statistical program.
6. Use the program to calculate the standard deviation and coefficient of variation (CV) of both columns of numbers.
7. Calculated standard deviations larger than allowed in the instrument specifications indicate that the instrument is either operating in an unstable environment (static, air draft, warm-up, vibration, etc), or that the instrument is in need of repair.

Linearity Testing

Linearity testing verifies the accuracy of the instrument at intermediate values of weight. Manufacturers often use the term "accuracy" in advertised specifications. This test is quite different from linearity testing in the clinical laboratory where we make a series of measurements over the AMR of the test. The balance linearity test measures the ability of the balance to accurately measure an added weight before and after a non-measured weight load has been placed on the balance. The procedure is as follows.

1. Use 2 weights, each of approximately one-half the weighing capacity of the instrument. It is imperative that these 2 weights not be interchanged within this procedure. Refer to the individual weights as "weight A" and "weight B."
2. Rezero the display. Place "A" on the pan (at the center), and record the reading on the "Linearity Chart" in a column marked "0% – 50%."
3. Remove "A" and place "B" pan near its center. Rezero the display with "B" still on the pan.
4. Again place "A" on the pan with "B" still on the pan. Record the reading under the column marked "50% - 100%."
5. Calculate the difference between the 2 (0-50 and 50-100) readings.
6. The difference should be less than the advertised tolerance for linearity or accuracy.

A common error in linearity (accuracy) testing is to simply place test weights on the weighing pan and observe

Laboratory Environment Cornerload Tolerances **T1**

	Resolution				
	.1 g	.01 g	.001 g	.000 1g	.00001 g
Capacity					
30 gram	-	-	-	2	5
100 g	-	-	2	4	10
300 g	-	2	4	10	-
1000 g	2	4	10	-	-
3000 g	3	6	-	-	-
10 Kg	4	-	-	-	-
30 Kg	12	-	-	-	-

Industrial Environment Cornerload Tolerances

	Resolution				
	.1 g	.01 g	.001 g	.0001 g	.00001 g
Capacity					
30 gram	-	-	-	4	10
100 g	-	-	4	8	20
300 g	-	4	8	20	-
1000 g	4	8	20	-	-
3000 g	6	12	-	-	-
10 Kg	8	-	-	-	-
30 Kg	24	-	-	-	-

The value for each combination of balance capacity and resolution is the greatest allowable difference between the highest and lowest reading of the cornerload test weights in the most right hand digits of the balance readout.

the difference between the indicated weight and the nominal value of the test weight. This process fails to account for the fact that test weights are imperfect and that the difference between the nominal value and the actual weight might be significant. This is especially true with analytical balances, where the balance may be more accurate than any standard test weight. The above procedure nullifies this problem by comparing the weight readings of the same object, both with and without a preload. The accuracy of the test weight is thus immaterial.

Calibration

Calibration of instruments is different from model to model and manufacturer to manufacturer. Generally, it is a simple procedure described in the user's manual which comes with the instrument.

Many instruments now include internal calibration weights, so calibration is as easy as pushing a single button. The user may ask, "How do I know the internal calibration weight is correct?" The answer is that the only way to know is to have an external standard for comparison, as required by CAP LAP Checklist question AGC.27540. The advantage of an external standard, whether it is used to calibrate the instrument or just to check the internal weight, is that it can be checked by a calibration laboratory and traced to national standards.

CAP LAP Checklist question AGC.27540 (a Phase II deficiency) requires that laboratories have the appropriate ASTM class weights for accuracy testing (the same as checking calibration as described in this paper). Standardized test weights are made to various levels of accuracy. CAP's requirements for the use of the appropriate ASTM class of weights are: "ASTM Class 1 weights are appropriate for calibrating high precision analytical balances (0.01 to 0.1 mg). ASTM Class 2 weights are appropriate for calibrating high precision top-loading balances with readabilities from 0.001 to 0.01 g. ASTM Class 3 weights are appropriate for calibrating moderate precision balances, from 0.01 to 0.1 g."[2]

ASTM class 1 is the most accurate weight class commonly available. Most weights in ASTM class 1 are accurate to 1 part in 400,000. Since analytical and microbalances are considerably more accurate (resolution of greater than 1 ppm), one might wonder how a standard weight can be used to test or calibrate analytical balances. The answer would be that the standard weight can itself be calibrated by a laboratory which specializes in that service. The characterization of the weight by such a laboratory will determine the actual value of the weight to a much higher degree of precision than required by the ASTM standard. Such a weight can be used to verify the accuracy of an internal calibration weight.

After placing a test weight on an operating instrument and finding that the displayed weight value does not exactly match the value of the test weight, many users have concluded that the instrument is miscalibrated. However, that conclusion is by no means certain unless the test weight has been calibrated and its correction from nominal value is known. The calibration weights internal to high quality laboratory balances are more accurate than commonly available test weights. In the absence of actual calibration data for specific weights, users should presume that internal weights are more accurate than external test weights. We therefore disagree with the CAP LAP policy of using ASTM class 1 weights for calibrating analytical (0.01 to 0.1 mg resolution) balances. ASTM class 1 weights are less accurate than most analytical balances. Many toploading balances would be poorly calibrated using class 2 weights for the same reason.

If the balance internal calibration is more accurate than the marked value of the weights then the user should check the calibration of the balance as described below. Why is it required to perform that checking of calibration each time analytical standards or calibrators are prepared or pipettors are checked for accuracy? This is a valid question. However, the requirement does exist and laboratories must have documentation that the checking has occurred. One suggestion is to perform the following "calibration verification" test. This test is referred to as "Accuracy Checking" in the CAP Checklist.

1. Select 5 or 6 weights over the AMR of the balance.

2. Tare the balance so that its reading is zero.
3. Weigh each of the standard weights and record the observed weight in a log. Use the same weights from the same weight set each time this test is performed.
4. Compare the observed weights with previous weightings.
5. The results are judged to be satisfactory if there has been no significant shift of the observed weights of the weights. If a single weight does not agree, reweigh it and confirm that there has not been a substitution of weights from a previous calibration verification.

If one has serious concerns about the calibration of the balance, a qualified balance repair service should be consulted.

Cornerload Testing

Cornerload testing verifies that the instrument delivers the same weight reading, regardless of where on the weighing pan the object being weighed is placed. Cornerload performance specifications are often not advertised. Typical tolerances are shown in **T1**.

1. Select a test weight close to the weighing capacity of the instrument.
2. Place the test weight in the center of the weighing pan. Then re-zero the display.
3. Move the weight one-half way from the center to the front edge of the pan. Record the reading on the "Cornerload Chart" under the heading "FRONT."
4. Repeat step 3 at the half-way locations for right, rear, and left edges, recording the readings in the appropriate spaces in the chart.
5. Cornerload tolerances are often not a component of advertised specifications. **T1** shows typical tolerances for instruments operating in both laboratory and industrial conditions. The laboratory environment presumes a specially built, leveled, rigid table and uninterrupted temperature control within 1°F. The industrial environment includes a sturdy table and uninterrupted temperature control within 4°F.

Handling Test Weights

The weights used to test laboratory balances are precision devices and need to be handled accordingly. When handling weights, avoid direct hand contact with weights by using clean gloves or special lifting tools. Hand contact with the weights can cause corrosion. Also avoid sliding weights across any surface, especially across the stainless steel weighing pan of the balance under test. Weights should be kept in a covered, protected box. CAP LAP Checklist question AGC.27560 (Phase II deficiency) says "Weights must be well-maintained (covered when not in use, not corroded)."

Environmental Conditions for Best Weighing Accuracy

In order to pass any test of reproducibility an instrument must be operating in an acceptable environment. A poor environment will degrade the results of a standard deviation (SD) test and falsely suggest that the performance is substandard. There are several aspects of the environment which impact the performance of a laboratory balance.

Temperature

The accuracy and overall performance of any laboratory balance is affected by the room temperature. For best stability and performance the room temperature should be regulated to within 1°F without interruption. The instrument should remain with power ON continuously.

Air Drafts

In the cases of measurements with resolution of .001 gram and less the force exerted by moving air is readily detectable. A shroud or enclosure around the weighing pan will shield the pan from these effects. Avoid plastic materials for draft shields because of potential static electricity interference problems.

Static Electricity

Static electricity exerts a mechanical force which is readily detectable by analytical and microbalances. An example of static electricity exerting a mechanical force would be lint sticking to clothing. Static will be a problem when it exists on the object being weighed, on the person using the balance, on draft shields, or on weighing vessels. Sources of static are carpets, Vibrum shoe soles, plastic draft shields, plastic weighing vessels, and melamine (Formica) table tops. Low ambient humidity exacerbates static problems.

You can test for a static problem easily. On an analytical balance place a metal enclosure (a coffee can works well) over the weighing pan, so that the pan is enclosed by the can but NOT touched by it. If the weight readings stabilize with the can in place, then static may be the cause of the instability. Notice that the coffee can provides an effective draft shield too.

Floor Vibration/Table Instability

Many laboratory balances are extremely sensitive to vibration or movement. If the weight readings change as you walk around the instrument, or if the readings change as you lean on the table or move objects on the table, then the table and floor are affecting weight readings. You can minimize these effects by using an especially sturdy table and minimizing movement. Users of microbalances often need specially built marble tables on concrete floors.

Conclusions

Although the high precision laboratory balance is used less now than in the past when many analytical reagents, standards, and calibrators were made rather than purchased, the balance is still an important laboratory instrument. Periodic checking of its accuracy and precision is an important part of the laboratory's quality management program. The procedures in this paper are straight forward ways to check on the balance's performance.

1. Testing your laboratory balance, IES Corporation. Available at: www.labbalancerepair.com/test.doc. Accessed on November 13, 2003.
2. CAP LAP Checklist question AGC.27540, College of American Pathologists. Available at: http://www.cap.org/lap/accstandards.html. Accessed on November 13, 2003.