Properties of Magnetism in Mass Standards

Editor's Note

Since this article was first published, the concern over magnetism in test weights has evolved to a new level. Unfortunately, a number of issues surrounding the measurement of magnetism in mass measurement has created frustration for mass calibration laboratories and for accreditation bodies. NCSLI recently met to bring together interested parties to discuss issues with the intent of coming to some resolutions on how to handle the various issues. As a result of these discussions a number of resolutions was adopted.

1. Laboratories should not include an uncertainty component for magnetism measurements in mass calibrations.
2. NVLAP's position is that for Echelon I and II measurements (corresponding to OIML R 111 classes E1, E2, F1, and F2) laboratories should
    1) State on their reports whether or not they are screening for magnetism
    2) State that no component is included in their uncertainty statement for magnetism effects
    3) Include a discussion/written agreement as to the laboratory's practice regarding magnetism screening (or lack of screening) as a part of normal contract review with laboratory customers.

So then, why does RLWS screen test weights for magnetic influences? Our dedication to provide you with the utmost value for your dollar. Should we fail to test for magnetism, we could inadvertently provide you with erroneous calibration data. This data would not be repeatable in your facility. Therefore the assurance and traceability of your own work could be jeopardized.

Our philosophy always has been and will always be to take care of the customer first.

By testing for magnetic influences prior to executing a test weight calibration, we continue to provide you with a quality of work unparalleled within the industry, keeping your needs first.

What Problems Can Magnetic Balances Cause?

When working with balances, magnetic field strength can be increased in a standard that has high susceptibility, even if the standard previously had a low or insignificant magnetic field strength. The solution seems obvious: don't expose the standard to a balance with magnetic properties. This is easier said than done. A balance with magnetic properties will reproduce its measurements as long as there are no other magnetic fields intersecting the balance's own field; thus, the magnetic field of the balance goes undetected. Introducing a standard into the balance's magnetic field, even one with very low field strength, has the potential to increase the magnetism of the standard. In this manner, a standard that formerly had no problems could potentially accumulate serious problems. To avoid this situation, the magnetic field of the balance and the magnetic susceptibility of the standard must be measured.

In 1994, a Magnetic Round Robin was performed by several metrology laboratories to test the effect magnetism has on weight measurements. This round robin was designed to show how close the laboratories' results would be after performing a calibration on 1 kg standards with known magnetic properties.

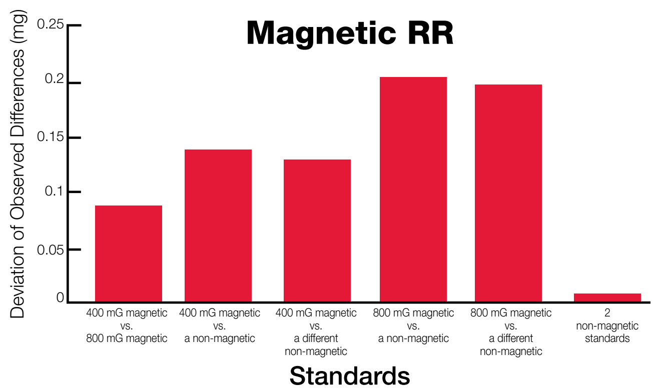
The balances compared and the approximate standard deviation of observed differences for these tests are shown below.

These tests show that a balance responds to magnetic properties of a mass regardless of the type of force the magnetic properties are exerting. However, the magnetic fields which are present in one balance are not necessarily reproduced in a different balance. Because of this phenomenon, it is difficult to reproduce the measurements from one facility to another. If this theory is true, the link of traceability for standards with magnetic properties is obviously broken because the magnetism causes an inability to reproduce consistent measurement results.

BALANCE COMPARISON	STANDARD DEVIATION
400 mG magnetic vs. 800 m non-magnetic	0.09 mg
400 mG magnetic vs. a non-magnetic	0.14 mg
400 mG magnetic vs. a different non-magnetic	0.14 mg
800 mG magnetic vs. a non-magnetic	0.2 mg
800 mG magnetic vs. a different non-magnetic	0.2 mg
Non-magnetic vs. another non-magnetic	0.3 mg

The graph below shows the results of the magnetic round robin, clearly showing the inconsistencies that can occur.

Results of magnetic round robin.



How Does Magnetism Develop During the Manufacturing of Mass Standards?

The existence of magnetic properties during the manufacturing of mass standards warrants careful consideration. Due to the numerous possibilities of creating magnetic properties, it is difficult to produce a mass standard from austenitic (virtually non-

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magnetic, highly corrosion resistant) stainless steel completely free of magnetic properties.

On April 11, 1946, F. A. Gould from the National Physical Laboratory wrote in the Journal of Scientific Instrumentation: "Analytical weights of stainless steel have been on the market for several years. The kind of stainless steel used for their construction is one which purports to be reasonably non-magnetic, being of the austenitic variety; and up to the present time the 18/8 type of austenitic steel, that containing 18% chromium and 8% nickel, has been employed for this purpose in this country. The quality of the finished weights, however, has not been very satisfactory in regard to their magnetic properties, and some have been found permanently magnetized to an appreciable extent."

Mass standards are manufactured through a variety of methods, including turning, milling, and casting. Before beginning the manufacturing process, it is imperative to choose the proper materials. When choosing materials, the most important factors to consider are machinability, corrosion resistance, porosity, and magnetic properties. The magnetic properties generally develop when austenitic stainless steel is cold worked. Although cold working adds tensile strength, mass standards do not normally require added tensile strength.

Which Materials are Best for Manufacturing Mass Standards?

Three hundred (300) series stainless steels are often used to manufacture mass standards because their chemical composition is highly resistant to corrosion. Certain materials found within 300 series stainless steels such as iron, cobalt, and nickel may possess ferromagnetism. Ferromagnetism occurs when a small external magnetic field produces an alignment of atomic magnetic dipole moments, which in some cases can persist even when there is no external magnetic field. This occurs because the magnetism of these substances exerts such a strong force over a small region of space that the magnetism is found on surrounding materials, even when no external magnetic field exists. In addition, cold working these materials often changes the austenite to ferrite in the material.

Several tests were conducted by the National Physical Laboratory, United Kingdom, to evaluate the materials used for manufacturing weights. In one of these tests, finished weights of 18/8 steel obtained from several sources of supply were tested. About half of the weights in these tests exhibited a magnetic permeability of 1.02 or less, but the remainder of the weights showed higher magnetism. Several weights showed a permeability value of 1.1, and one showed a high permeability value of 2.6. Some of this material was found to have become permanently magnetized to an elevated extent.

Because of the variety of austenitic steel which is available, additional tests were performed to help in the selection of a material with non-magnetic properties. These tests found that 18/8 materials were not satisfactory with respect to magnetic properties. Figure 3 depicts the magnetic permeability of different stainless steel compositions.

When comparing the processes required to manufacture mass standards or to manufacture the stainless steel to produce the standards, this chart provides a general idea of the magnetism problems which may occur. Most purchasing personnel are not aware of the problems of magnetism, so when the purchase of materials takes place, materials are requested by their manufacturing names, such as 310, 304, and 316.

These names are like recipes in that they give a process for heat treating the material and a range for the chemical composition. Most of these materials have a heat treating process that returns the materials to an austenite state after any cold working process. However, sometimes this heat treating process may leave the materials bent or twisted. So in order to supply vendors with the proper materials, a secondary process to straighten the materials must be performed. This process is still within the requirements for the materials, but the cold working during the straightening process leaves the materials with magnetic properties. This is most common in smaller size diameters.

Aside from the risk of the materials having magnetic properties from the start, weight manufacturers add to the possibility of elevating magnetism during the series of cold working processes necessary to produce the mass standard. Manufacturers must use either a saw or lathe operation to start the process. The removal of any metal in this fashion is considered a cold working process. Polishing and stamping are also cold working processes. These operations can and do produce magnetic properties in the standards.

CHEMICAL COMPOSITION									MAGNETIC PERMEABILITY	MAGNETIC PERMEABILITY AFTER COLD ROLLED TO GIVE A 33% REDUCTION IN AREA
C	Si	Mn	S	P	Cr	Ni	W	Cu		
0.03	0.57	0.55			17.45	11.9			1.003	1.10
0.14	0.6	0.58			19.8	12.96			1.003	1.005
0.07	0.24	0.44			10.33	20.7	1.73	2.14	1.015	1.04
0.09	0.23	0.44			10.3	20.26	1.79	2.20	1.013	1.021
0.13	0.19	0.36			9.72	20.28	1.55	2.39	1.021	1.045
0.10	0.26	0.42			10.85	20.71	1.83	2.13	1.016	1.043
0.10	0.26	0.48			10.42	20.77	1.57	2.32	1.012	1.021
0.09	0.22	0.39			10.41	20.17	1.67	2.19	1.014	1.024
0.10	1.71	0.78	0.017	0.011	24.27	20.40			1.002	1.003

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What are the Requirements for Magnetic Properties in Mass Standards?

The United States uses the American Society for Testing Materials (ASTM) specification E 617-917 for specifying the requirements of magnetic properties in laboratory weights and precision mass standards. This specification was replaced by the National Bureau of Standards (NBS) Circular 547, Section 1 in 1978 and recognizes the international recommendations of the Organization Internationale De Metrologie Legale (OIML) R111, edition 1994.

According to the ASTM E 617 specification, magnetic properties must be measured in magnetic field gradients because unshielded devices in the vicinity of the measurement can affect the accuracy of measurements. Higher grades of weights have lower magnetic susceptibility. Grades S, S', O, and P should not be more magnetic than 300 stainless steel.

The OIML international recommendations include requirements for magnitude of magnetic susceptibility. They state that the metal or alloy used for weights of classes E1 and E2 shall be practically non-magnetic (magnetic susceptibility K not to exceed K=0.01 for class E1, K=0.03 for class E2, and K=0.05 for classes F1 and F2).

How Can Magnetism be Avoided?

Although magnetism cannot be completely avoided, steps can be taken to control the effects of magnetism on the accuracy of weight measurements. The area where the weighing occurs should be tested with a gaussmeter for magnetism created by electrical wiring, motors, and any other components in the area. If the testing shows magnetism is present in the area, another location should be chosen for the measuring process.

A gaussmeter should also be used to test the balances for magnetism. Even if the standards have very low magnetic strength, the internal components of a balance may cause varying results. For example, if the components of the balance have a magnetic charge, the standard introduced to the balance will change the force exerted on the load device, causing inconsistent results from one device to another. Balances should be tested whenever there is any suspicion of magnetic problems, such as erratic weight measurements. The gaussmeter shows which part or parts of the balance are magnetized and need to be replaced.

The elimination of magnetism in mass standards is not likely to happen. However, if the proper steps are taken, the magnetism in mass standards can be significantly reduced. Starting with the manufacturing process, the proper methods and materials must be chosen. Then, the mass standards should be tested for magnetic properties. Finally, remember that the magnetism inherent in the environment, balances, and standards will cause some degree of inconsistency in mass measurements, no matter what preventive steps are taken.

How are the Magnetic Properties of Mass Standards Measured?

Although specific requirements for magnetic susceptibility are a good start, magnetic field strength is also a very important factor that needs to be measured. Susceptibility adds to the potential of an item becoming magnetized or further charged. Measuring the magnetic field strength of the standard shows whether or not the magnetism is significant enough to cause mass measurement errors.

Richard Davis of Bureau International des Poids et Mesures (BIPM) wrote an article entitled, "New Method to Measure Magnetic Susceptibility," in which he describes a process he developed for measuring magnetic susceptibility. The following pieces of equipment are used to perform the measurements:

Balance

The balance must have a 5 g capacity (to leave enough range in the balance to place the column and magnet on it and perform the measurement) and a resolution of ≥1 micrograms. The weighing chamber is a glass tube with a removable glass top. The original top is replaced with one made of an aluminum alloy because aluminum contains very little magnetism.

Magnets

Two high quality cylindrical magnets (constructed of neodymium-iron-boron) are used in this measuring process. Each magnet has a height of 2.5 mm and a diameter of 5 mm. The axis of magnetization coincides with the geometric axis of the cylinder. Two such magnets are combined to produce a cylinder of height equal to diameter.

Pedestal

The magnet sits on a tubular pedestal that is centered on the balance pan. Holes drilled through the wall of the tube ensure that the total mass of the magnet and pedestal is well within the capacity of the balance.

Bridge

Samples are centered on an aluminum alloy bridge that straddles the weighing chamber of the balance. The bridge must be designed so the span can be made level with respect to the balance pan. The span should be as thin as possible, with adequate mechanical rigidity. If the span sags in the middle, samples with a large diameter will be farther from the magnet than samples with a small diameter.

Gauge Blocks

It is convenient to place the bridge on non-magnetic gauge blocks so that it may be raised or lowered in precise 5 mm increments.

Magnetic Susceptibility Standard

The magnetic susceptibility standard can be the identical shape of the item being tested or a cylindrical shape that has been calibrated by known standards.

Once all of the equipment has been assembled, the distance from the center of the magnets to the top of the bridge must be calculated to determine the magnetic force. This can be done by using the known magnetic standard. After the distance is calculated, the samples that need to be tested may be introduced. The samples are calculated based on the distance from the magnets and the response of the balance. If the samples have different geometrical values, additional calculations must be performed to solve for the volume of magnetic susceptibility.