

focus on Laboratory Products

Integrated Electrostatic Detection in Analytical Weighing

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Various examples of routine laboratory work show that electrostatic charges exert forces on the material to be weighed, thus causing significant falsification of measurement results. Recent advances in weighing technologies allow the user to reduce these shortcomings. An integrated sensor for measuring the electrostatic forces during normal operation in an analytical balance is presented and shown that errors over four orders of magnitude ranging from a few μg to several mg can easily be detected.

Introduction

An electronic analytical balance measures not directly a mass but the force of its weight. The uncertainty of this force depends on the technical specification of the instrument but also of many environmental effects like temperature variations, air drafts, evaporation or water adsorption of the object being weighed. In addition, the presence of electrostatic forces plays an important role in the accuracy of weighing data. Following a brief introduction to the physics of static electricity, this article describes how electrostatic charges arise and dissipate, how modern analytical balances detect their presence, and how large the measurement errors can be.

Static Electricity

Friction is the most common way to generate electrostatic charges on a weighing vessel. Typical laboratory actions that cause items to become charged are for instance, the dry rubbing of a glass beaker with a cloth or touching a measuring flask with disposable gloves. Even unpacking a laboratory vessel from a plastic bag or filling it with loose material is sufficient to generate a measurable electrostatic charge.

These charges can be expressed by Coulomb's Law [1], states that electrical charges exert a mutual force F_E expressed as:

$$F_E = \frac{1}{4\pi\epsilon_0\epsilon_r} \frac{Q_1Q_2}{r^2} \quad \text{or simplified to} \quad F_E = k_e \frac{Q_1Q_2}{r^2} \quad [1]$$

where: k_e is Coulomb's constant

Q represents the individual charge on two separate objects

r is the distance between the objects

ϵ_0 & ϵ_r are the absolute and relative dielectric constants

The balance measures the vertical component of the electrostatic force and interprets it as a weight corresponding to a mass of Δm , given by:

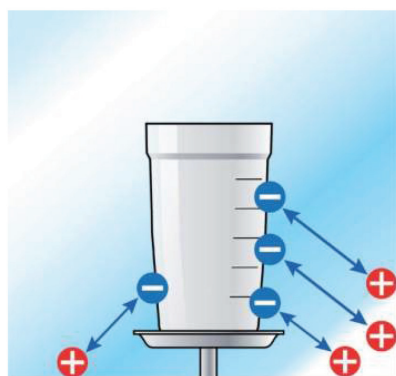
$$F_E = g \Delta m \quad [2]$$

where g is the gravitational constant.

Thus, combining [1] and [2], and resolving the equation for the total effect on the weighing result the equation becomes:

$$\Delta m = \frac{1}{g} * k_e \frac{Q_1Q_2}{r^2} \quad [3]$$

Figure 1. Shows the field lines between a negative charge on the measuring flask and the induced positive charge on the balance housing. According Coulombs law, the two charges attract each other. The vertical component of the resulting force adds itself to the force of the weight and thereby influences the weighing result.



Dissipation of Charges

Charges do not stay forever on flasks or the measuring goods, they dissipate over time. Surface conductivity of the insulator materials is the most important factor affecting the dissipation rate of electrostatic charges: the higher the surface conductivity, the faster the electrostatic charges can drain away and hence not affecting the weighing result. Surface conductivity is highly dependent on humidity and the degree of contamination. During wintertime, in heated rooms with a relative humidity of less than 45%, the risk for measuring erroneous data due to the presence of static electricity is significant and therefore the operator has to act carefully to achieve reliable results. The following measures illustrate this phenomenon; (Figure 2a and Figure 2b) 2a on a glass flask and 2b on a Teflon vessel and show the measuring error in function of time. A glass flask is unable to become charged at 80% relative air humidity, whereas for Teflon containers even when the air humidity is high, significant weighing errors are observed over several minutes.

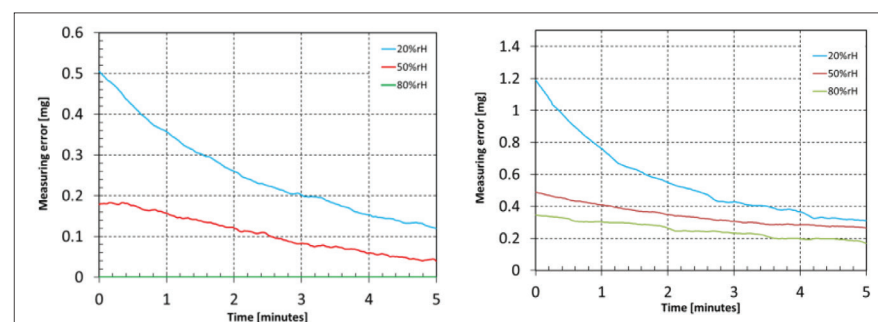


Figure 2a. Measuring error in mg as a function of time at 3 different relative air humidity ranges; from 80% to 20% for a glass flask

Figure 2b. Measuring error in mg as a function of time at 3 different relative air humidity ranges; from 80% to 20% for a Teflon vessel

Detection of the Electrostatic Force

The latest generation of analytical balances have weighing cells integrated with electrostatic detection, which operate without disturbing the normal measuring cycle. A concentric electrode is mounted close the grounded weighing pan. A square wave with an amplitude of $\pm 60\text{V}$ and a frequency of 1.2Hz is applied during the standard detection phase. The positive half-cycle of the square wave generates positive charge carriers on the electrode. If the material to be weighed is free of charge carriers, no electrostatic forces according the equation [1] will arise; the weighing cell measures the true weight of the sample. If the sample is negatively charged, there is a transient attractive force between the negatively charged material to be weighed and the electrode. The weighing cell registers the vertical component of this force, creating a result that exceeds the true mass. This case is illustrated in Figure 3a. The electrostatic field changes sign in the subsequent half-cycle, due to negative charge carriers being generated on the electrode. Now there is mutual repulsion between the material to be weighed and the electrode (Figure 3b) and the measurement result becomes less than the effective mass. With a lock-in amplifier and adequate signal processing the signal to noise ratio can be improved, allowing the sensor to accurately measure only the excitation frequency of the charge generation. Thus, this measuring method can measure the very small perturbing forces created by static electricity in a few seconds without disturbing the user.

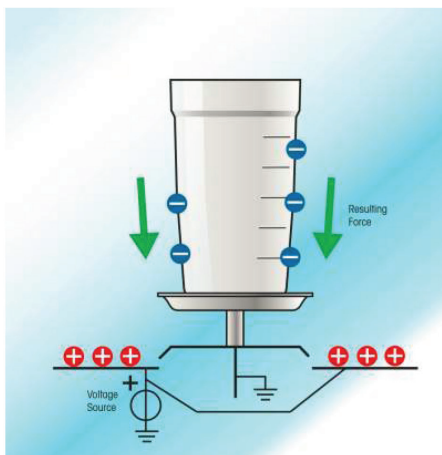


Figure 3a: There is an attractive force acting between the container and the electrode. The vertical component of this force adds itself to the weight, thus increasing the measurement result

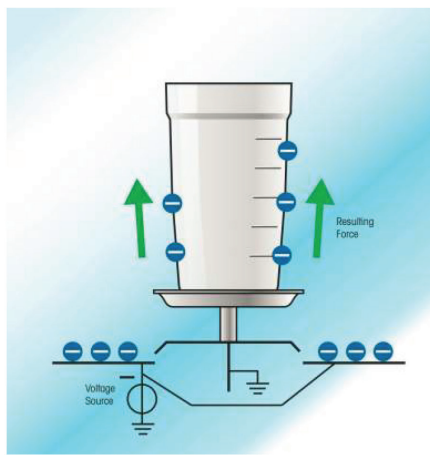


Figure 3b: There is a repulsive force acting between the container and the electrode. The vertical component of this force adds itself to the weight, thus decreasing the measurement result. The difference between cases a and b is used to derive the weighing error caused by electrostatic charges

The potential measurement error is determined from the difference between the two values, using a correlation factor (Figure 4). Figure 4 shows measurements that illustrate this relationship.

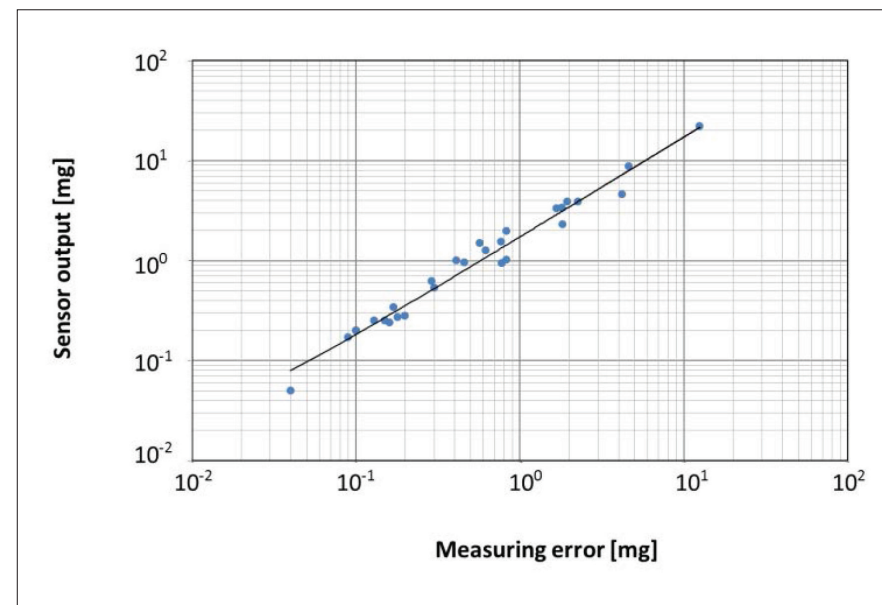


Figure 4. Measurements show excellent correlation between the true weighing errors over several decades. The points represent measurements performed using a variety of weighing vessels placed at different positions on the weighing pan and carrying various levels of charge. The charge sensor is calibrated such that the true error does not exceed the indicated error.

Conclusion

Analytical weighing is biased by many effects that introduce uncertainty for the data. Such influences include air drafts, temperature differences and, as demonstrated here, electrostatic charges. Low sample mass with relatively large insulating containers are extremely sensitive to the above described phenomena. Balance manufacturers address this issue with a new innovative technology and offers to users integrated electrostatic detection. Automatically detecting perturbation due to electrostatic charges makes balance operation simpler and more reliable, as well as constituting an important step forward in weighing technology.