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FAST ELECTROMAGNETIC BALANCE

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Abstract

Instead of reading the equilibrium value, the deflection of the balance as a function time can be measured and the equation of motion $T=J\ddot{\alpha}+k\dot{\alpha}+C\alpha$ can be used to calculate the unknown torque T and to relate the other quantities in the equation to the actual instrument-constants. In this way, balance reading could be much faster and weighing errors due to faulty instrument and environmental influences can be smaller than those in equilibrium position. This enables the use of microbalances for the observation of fast chemical or thermal processes and to use it as fast checkweigher for control of sorting machines. In the present paper we present results from calculations of a simulation procedure.

Keywords: balance, electromagnetic balance, extrapolation, gravimetry

Introduction

Several decades ago when working in the field of magnetism we had to use a balance the sensitivity of which was only limited by Brownian motion. This balance was a very slow one. Therefore, instead of reading the equilibrium value we calculated the moment of force T from the equation of motion

$$T=J\ddot{\alpha}+k\dot{\alpha}+C\alpha \tag{1}$$

where J is the moment of inertia, k is the damping constant and C is the constant of the restoring moment and where α, is the angle of deflection of the beam, as a function of time. In this way, we could obtain faster results. We presented the method at the 3rd Conference on Vacuum Microbalance Techniques 1962 at Los Angeles [1]. Later we suggested that, with the help of a computer, this procedure could be made applicable also to the handling of conventional balances [2]. We found that balance reading could be at least ten times faster [3, 4]. Similar proposals were made by Horn for load cells [5, 6]. Later on we discussed several sources of error relevant for this method [7]. Weighing errors, either in-

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trinsic to the instruments or due to environmental influences, can be smaller than those occurring when waiting for equilibrium position [8].

Modern balances are damped or compensated and the equilibrium position is reached within several parts of a second. For most purposes this is sufficient, however, time resolution might be insufficient for the observation of a fast reaction by thermogravimetry. Also, in applications where sorting by mass is required, e.g. the sorting of pharmaceutical pills, the speed limitations of conventional check-weighers can affect the manufacturing process. In such cases, the principle mentioned could be successfully used to achieve faster balance readings.

Optical or electromagnetical reading of balance deflections lead to high precision and sensitivity. For the time being we shall suppose that there are no limits to either precision or sensitivity. This supposition leads, at first sight, to the conclusion that no electrical feedback should ever be used as this could only involve extra errors. However, the use of such a simple balance would very soon bring along unacceptable deflections and velocities of the balance beam. This can be avoided by separating the actual measurement-time from feedback-time.

Numerical simulation

The data we use in our example with which we shall demonstrate this separation procedure are taken from a commercially available electrodynamic beam microbalance made by C. I. Electronics (Fig. 1 and Table 1). At the centre of the beam a coil is attached which moves in the field of a stator coil with permanent magnet.

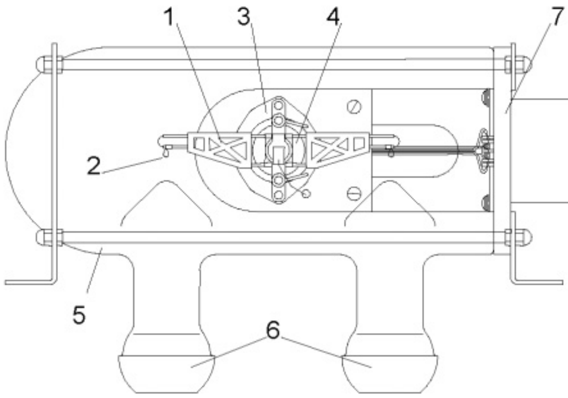

Fig. 1 Electrodynamic compensating beam microbalance of C.I. Electronics. 1 – balance beam (metal), 2 – bearings for sample/counterweight hangdown wire, 3 – permanent magnet with fixed coil, 4 – moving coil, 5 – glass casing, 6 – ground-in connection, 7 – metal flange with electrical connection

Table 1 Data of the balance and material parameters used

Symbol	Parameter	Value
l_{beam}	Total length of the beam	2·0.04 m
J	Moment of inertia of the beam, with no suspensions attached	10^{-7} kg m^2
f_0	Mechanical resonance of beam without electrical feedback	1 Hz*
C	Restoring constant	3×10^{-6} N m rad^{-1}
k	Damping constant	3×10^{-9} N m s rad^{-1}#
R	Resistance of the coil	2.3 kΩ
L	Coil inductance (measured with the coil mounted in the magnetic circuit)	200 mH

*Rather approximate, much higher with electrical feed-back
#Strongly dependent of form of scales and sample

During the time of measurement t_m without feedback variation we read the deflection, differentiate once and twice, and use the equation of motion:

$$T_x + T_c = J\frac{d^2\alpha}{dt^2} + k\frac{d\alpha}{dt} + C\alpha \quad (2)$$

where T_x is the torque to be measured (which is taken constant during t_m) and T_c is the compensating torque. We suppose that we know the values of J, k and C. So for the resulting torque T_m we use during the time of measurement:

$$T_m = -T_c + J\frac{d^2\alpha}{dt^2} + k\frac{d\alpha}{dt} + C\alpha \quad (3)$$

In the following period of feedback t_a we adjust T_c; apply a peak in the current to reduce the beam velocity; apply a combination of two pulses of opposite sign (equal magnitudes) to reduce the beam deflection.

This procedure is schematically demonstrated in Fig. 2. In this figure the quantities involved are plotted as a function of time in the case of a stepwise variation T_s of the torque T_x. For the clearness of the explanation we have, when drawing Fig. 2, separated the three adjustment steps in time. This causes a larger value of t_a what in practice would be considered to be disadvantageous.

In our example both T_x and T_c are supposed to be zero until t=0 and at this time T_x changes from 0 to the new value T_s ($<10^{-7}$ N m). Thereafter T_x remains constant (T_0), during the rest of the time in the example considered in Fig. 2. At $t=t_s$ (t_s=0.3 s) the measurement period is interrupted to adjust T_c with $T_c = -\left(J\frac{d^2\alpha}{dt^2} + k\frac{d\alpha}{dt} + C\alpha\right)_{t=t_s}$. Between t=0.3 s and 0.4 s the total torque is zero and so the angular velocity remains constant as the influence of k and of C is negligible and is given by:

$$\left(\frac{d\alpha}{dt}\right)_{t=0.3}=T_s\frac{t_s}{J}=0.75{\cdot}10^{-3}\ \text{rad s}^{-1} \tag{4}$$

where J is taken to be $2{\cdot}10^{-5}$ n m^2 including the contributions of the sample and of its suspension.

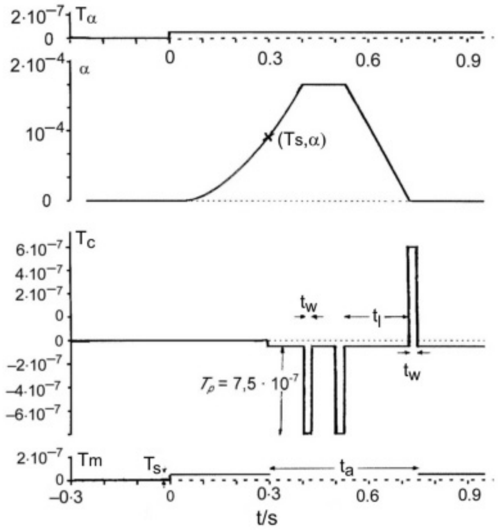

Fig. 2 Procedure to determine the mass change and to adjust the balance by means of current pulses. Description in the text

During t_a=0.5 s until t=0.79 there is no reading of T_m possible in this example. At t=0.4 s a single peak, height $T_p=-7.5{\cdot}10^{-7}$ N m, width t_w=0.02 s, is introduced to account for the first derivative of the deflection $\dot{\alpha}$ and to bring the balance at rest using:

$$T_p t_W = J\left(\frac{d\alpha}{dt}\right)_{t=0.4} \tag{5}$$

Between t=0.4 s and t=0.5 s the balance is at rest with the deflection

$$\alpha_p=\alpha_{t=0.4}=\alpha_s+0.1\left(\frac{d\alpha}{dt}\right)_{t=0.4}$$

At t=0.73 s and $t=0.5+t_l$=0.73 s two peaks are introduced to bring the deflection α_p back to zero. We have taken these peaks of equal height and width as the peak at t=0.4. For t_l we used:

$$T_p t_w t_l = J\alpha_p$$

At t=0.73 s the adjustments are finished and a new measurement period can start. In practice a much smaller value of t_a will be possible by applying an optimal combination of peaks used for T_c.

The method described requires that the current pulses through the coil (to produce the peaks in T_c) should be generated quickly, anyhow within t_a. However, this is limited by the self-induction L and the resistance R of the coil. The value of $\omega=R/L$ is therefore crucial. The angular frequency of the C.I. Instruments balance amounts to 11500 rad s^{-1} (f=1800 s^{-1}).

Therefore, it is reasonable to assume that we can pulse the current I through the coil during an interval of 10^{-2} s, justifying the qualification of subsecond wheighing.

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