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AUTOMATED BALANCES OF THE SECOND GENERATION

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ABSTRACT

In automatic weighing a Lorentz-force is commonly used to compensate for the force to be measured. In this procedure the compensating force is adjusted such that it brings back the balance beam to its equilibrium position whenever the force to be measured varies. To avoid instabilities of the feedback system, the high frequencies are usually blocked in the feedback system applying low pass filtering. This involves loss of information present in the high frequency part of the (compensating) force signal. On the basis of the equation of motion of the balance, an analysis is given which provides a correction procedure improving the high frequency performance of automated balances.

INTRODUCTION

In weighing, the time t_m necessary for a measurement is always an important parameter. For instance, the theoretical detection limit, m, due to thermal noise proves to be proportional to t_m (see ref.1). In practice this means that when choosing or developing a balance for a given purpose, one should not only start from the accuracy wanted, but also from the highest frequency expected in the mass signal.

In the present paper we will discuss a method to get a quicker response from an automated balance. We shall start from the schematic of an automated balance as shown in Fig.1

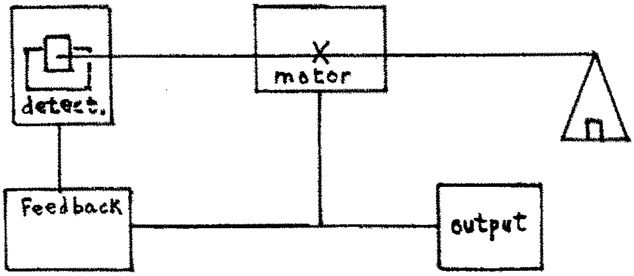

Fig.1 Diagram of the balance system

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Let α be the deflection of the balance, measured (e.g. optically) by the detector. The output of the detector is, via the feedback circuit fed to the motor. This word motor is with an increasing frequency used by scientists when referring to the compensating mechanism usually consisting of a combination of magnet and coil. As compensating force the Lorentz force is used caused by the current I through the coil. For practical reasons the feedback mechanism is designed such that high frequency mass variations are not accounted for. This might well lead to a characteristic time of the balance of the order of a few seconds.

It is the purpose of the present paper to advocate the possibility to make corrections so as to decrease the measuring time by using an on-line computer.

THEORY

For the equation of motion of the balance we use

$$J\frac{d^2\alpha}{dt^2} + K\frac{d\alpha}{dt} + C\alpha = C_1 I + m g \ell \qquad (1)$$

where J is the moment of inertia

α is the deflection of the beam

K is the damping constant

C is the torsion constant including a restoring couple due to gravity

C_1 is a constant concerning the Lorentz couple

I is the current through the motor

m is the mass to be measured

g is the acceleration due to gravity and

ℓ is the beam length.

In this equation m_x, α and I are time dependent.

It is the task of the feedback mechanism to make and keep the value of α as small as possible by adjusting the value of I. When α is zero, the LHS of Eq. (1) vanishes and leaves us with a simple expression for m as a function of I. Specially in the case that m contains high frequency terms the condition $\alpha = 0$ will not be satisfied constantly so that for these high frequencies I cannot be taken as the best measure for m. Corrections, however, can be made by using the complete Eq. (1). This implies that for the calculation of m, not only the values of I should be used but also those of α. The calculations, including determination of $\frac{d\alpha}{dt}$ and $\frac{d^2\alpha}{dt^2}$ can be performed by means of a digital computer.

EXPERIMENTS

For preliminary experiments we used a Cahn 2000 microbalance combined with an Apple IIc personal computer. We simulated high frequency signals m(t) by letting fall small weight pieces from different heights onto one of the scales. Each fall produced a combination of a step function and a delta function in m(t). The latter was caused by the transfer of momentum when the weight piece collides with the scale. This transfer satisfies

$$\int F(t)dt = m_w (2hg)^{\frac{1}{2}} \quad (2)$$

where F(t) is the force with the shape of a delta function

m_w is the mass of the weight piece and

h is the height from which the mass piece falls

The experiments were carried out with m_w = 2 mg and m_w = 5 mg with h = 5 mm and h is 20 mm. Each measurement was repeated several times. The constants J, K and C were fitted to the responses measured. In Fig.2 the expected combination of step + delta function (a) is compared with the normal response of the balance (c) and the response recalculated with the computer (b).

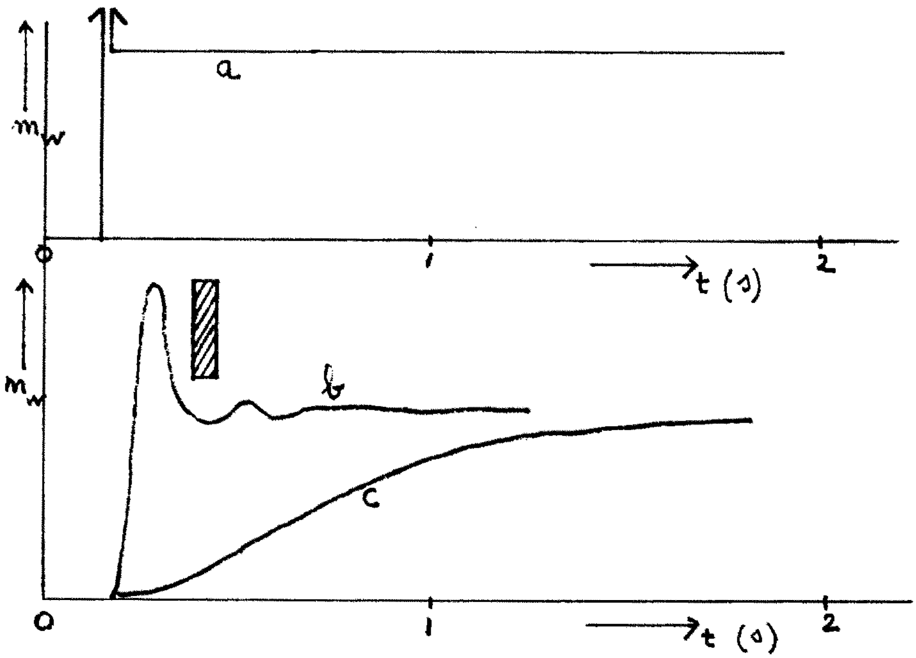

Fig.2. For explanation see text.

It has to be mentioned that, concerning the α measurement there exist quite some possible points in the feedback circuitry, to get the information from. It is not certain that we already got the best choice. In Fig.2 the expected area of the delta function calculated with Eq. (2) is shown as a shaded area. The agreement with the areas of the measured peaks is within the rather large measurement error. This latter error is mainly due to the error in measuring h which amounts to 30%.

From Fig.2 we conclude that after the corrections the balance allows measurement of effects which take a few tenth of a second. It has to be mentioned that the apparent dip immediately behind the peak in Fig.2(b), could at least in order of magnitude be accounted for by the underpressure caused by the airstream which accompanies the weight piece that falls onto the balance scale.

REFERENCES

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