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RESTORING OF A BALANCE BY ELECTRIC PULSES

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Abstract

Restoring of the balance beam to its initial situation after a change of load can be effected by combination of forces of different kind. In former papers we discussed the possibility using the equation of motion of the balance to determine the mass to be measured. After the measurement the balance was restored by means of current pulses into the electromagnetic measuring system. In the present paper we discuss the application of electric pulses into an additional electrostatic system.

Keywords: balance, current pulse, electromagnetic balance, electrostatic, voltage pulse

Restoring by means of current pulses

Different methods of restoring the deflection of compensating balances can be applied [1–4]. In former papers we discussed the possibility of mass measurement using explicitly the equation of motion of the balance [5–8]. The procedure involved an arrangement to adjust the compensation force stepwise, so that during the intervals between the steps the equation of motion of the balance would be a simple one [9]. However, the stepwise adjustments of the compensating force make it necessary to use pulses as extra contributions to this compensating force to cope with large deflections and velocities.

The simplest way to realise such a procedure would be to use a permanent magnet and coil system for the compensating force. As described in detail in [8], during the time of measurement without feedback variation, we read the deflection and calculate the rest position by means of the equation of motion. In the following period of feedback we adjust the compensating torque, apply a pulse in the current to reduce the beam velocity and a combination of two pulses of equal magnitude but of opposite sign to reduce the beam deflection.

There arise, however, two difficulties:

- The coil in the vicinity of the permanent magnet has a self-induction which limits the realisation of short pulses.

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- Current pulses through the coil bring along extra contribution to the Joule heat in the coil. This is due to the fact that the current used is inversely proportional to the width of the pulse, while the Joule heat is proportional to the square of the current.

Restoring by means of voltage pulses

To cope with these problems we suggested using an additional electrostatic arrangement for voltage pulses as compensating forces [10]. For this extra arrangement a double capacitor could be used [11], Fig. 1. For its capacity we use:

$$C = \varepsilon_0 bx(1/d_1+1/d_2) \tag{1}$$

When the balance arm moves up and down the quantity x varies, we shall use Δx for this displacement; it causes a variation ΔC given by

$$\Delta C = \varepsilon_0 b(1/d_1+1/d_2)\Delta x \tag{2}$$

When the voltage V over the capacitor is kept constant it follows for the force F_C

$$F_C = 0.5V^2\mathrm{d}C/\mathrm{d}x = 0.5V^2\ {}_0 b(1/d_1+1/d_2) \tag{3}$$

Estimation: V=300 V, $d_1=d_2=10^{-3}$ m, ${}_0=10^{-11}$ A s V^{-1} m^{-1}, $b=10^{-2}$ m. It follows: $F_C=10^{-5}$ N.

For the width of the voltage pulses we use τ_b, for the distance between two pulses we use τ_a. For estimating purposes we start from a constant force F_x to be measured. This force causes after τ_C a velocity of the balance. To neutralise this velocity we need a pulse force with height F_x satisfying

$$F_x\ \tau_a = F_C\tau_b \tag{4}$$

For our estimations let us use: $\tau_a=10^3\tau_b$. It follows: $F_x=10^{-8}$ N. The result of our estimation is that we can use the pulse method in the microgram range.

It is of interest to calculate also the displacement Δu caused by the supposed constant force F_x during the interval τ_a which we take to be 2 s.

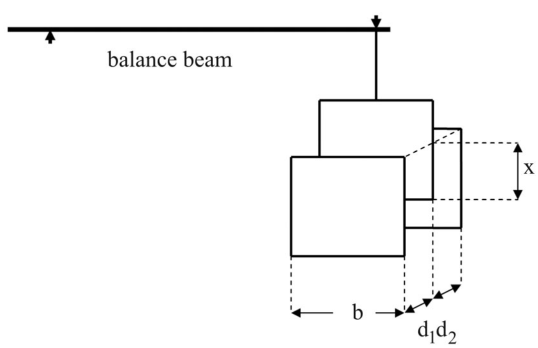

Fig. 1 Arrangement of a capacitor on the balance beam for restoring to its rest position by means of voltage pulses

$$\Delta u = 0.5F_x\tau_a^2/m^* \tag{5}$$

where m^* is the mass of the balance after correction for the rotational movement of the balance. Using our estimation together with $m^*=10^{-1}$ kg we get $\Delta u=2\cdot10^{-7}$ m. This result supports the assumption that a very sensitive displacement sensor is necessary.

Adjustment errors

As the electrostatic forces estimated above are small, it will be advisable to mount the capacitor near the end of the balance beam. This makes the position of the central plate susceptible to errors in the adjustment. What happens when the central capacitor plate is not exactly in the middle?

We take:

$$d_1 = d_0+\Delta d \tag{6}$$

$$d_2 = d_0-\Delta d \tag{7}$$

With Eq. (1) we get:

$$C=\frac{2}{1-(\Delta d/d_0)^2}\varepsilon_0 b\frac{x}{d_0} \tag{8}$$

In the present proposal the electrostatic compensation is only used for reducing the velocity of the balance deflection. The resulting value of the measured mass does not depend on the value of the voltage V used but is determined by the compensating current, the deflection and its first and second derivative. This reduces the importance of the error which we estimated in the above.

Conclusions

Electrostatic pulse shaped forces in addition to the Lorentz forces used for the compensation leads to faster adjustment of the balance to a rest position. This combination reduces the errors due to the heat production caused by the current through the coil.

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