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THE DAMPING OF BALANCES*

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Abstract

The paper gives a survey of the history of damping methods for balances. Representation on Egyptian drawings demonstrate that the person performing the weighing shortened the measuring time by holding the suspension cords and touching the beam. By means of delimiters, the Romans constricted the deflection amplitudes. In the 19th century, the movements of precision balances were damped with a brush. For analytical balances, locking mechanism were developed, often combined with levers lifting the weighing scales and the beam in order to relieve the knife-edges. Half-arresting was used to curtail weighings. Air damping was invented by Arzberger in 1875, and eddy current damping by Marek in 1906. In electronic balances, lag, lead and filter elements and absorptive attenuators are used. For digital balances, the fast-reacting nullification of eddy signals is applied.

Keywords: attenuation, balances, damping, history of technology, weighing

Introduction

Conventional balances, of either beam or spring type, are systems which can easily be stimulated to undergo mechanical oscillations. Enhancement of the sensitivity of a balance simultaneously intensifies its tendency to oscillate and extends the time for equilibrium to be reached [1]. Two types of mechanical oscillations can be observed: oscillation of the balance beam around its swivelling axis or in the direction of the helical spring axis (one degree of freedom), and oscillations of the pans (two degrees of freedom). The two modes of motion are connected, influence each other and cause complex indications [2]. After stimulation, within an extended period of time, the movements decline and the balance comes to rest due to friction in the bearings or in the spring material, and due to friction in the surrounding air (Fig. 1, graph b). Insufficiently damped balances in vacuo may oscillate ceaselessly, because some stimulating disturbances are always acting, and friction by the residual gas is insignificant (Fig. 1, graph a).

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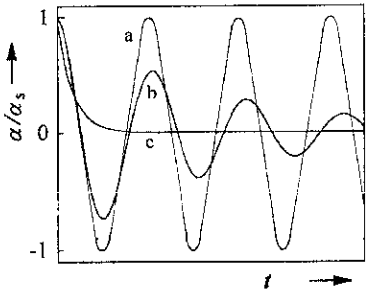

Fig. 1 Undamped (a) and damped (b) harmonic oscillations and aperiodic limit (c) of a balance. The diagram shows the course of the angular deflection as a function of time t, simplified for the case of pure beam oscillations and calculated using Eq. (1)

The movements of the balance hinder the observation of the equilibrium value and extend the measuring time. Balances have been in use for at least 5.000 years [3], and pictures 3.500 years old provide evidence that the operators tried to damp the balance. Since that time, a variety of methods have been developed for that purpose, which are all still applied today [4]. In principle, weighing can be curtailed in two ways:

– damping of the balance and observation of the equilibrium value at rest, or
– observation of the oscillating output signal, and calculation of the equilibrium value [5].

The present paper deals with the methods of damping the movements of the balance.

Capturing methods

Locking of the balance

The simplest method to quiet down the movements consists in arresting the balance by hand. This was already practised in Old Egypt, as demonstrated in many papyri and wall paintings. With one hand, the operator holds the hangdown cords of the weighing scale, and calms down the beam by touching it. This was necessary because the beam was suspended in such a way that it could not only swing in a vertical direction, but also rotate horizontally around its suspension. With his other hand, he touches a dangling plummet, part of the indicator system [6].

Ever since, oscillations of hand scales have been stopped by lowering the instrument so that one pan touches the desk. Further development resulted in devices with levers and gears or tackle line, which allowed the balance to be lowered (Fig. 2). Later, two discs were installed which could be lifted until they reached the pans (Fig. 3).

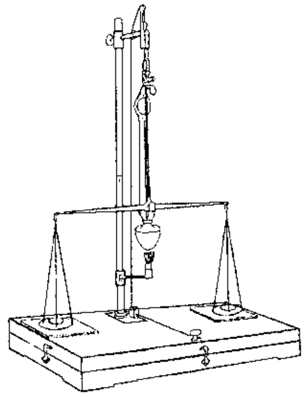

Fig. 2 The balance of Plattner (1833) could be lowered by means of a tackle line. With the brush, movements of the balance were damped. Movements of the weighing scales were stopped by touching the desk

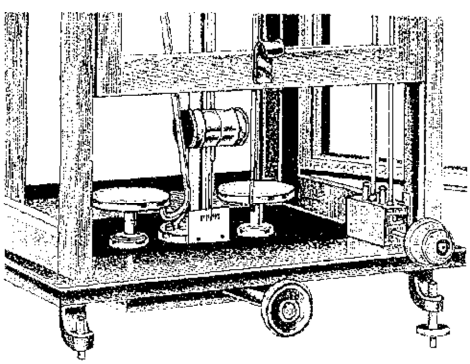

Fig. 3 Analytical balance of Spoerhase, Giessen (1932), with a horizontal air cylinder arranged at the pointer and with levers for arresting the weighing pans

The balance tube of a vacuum microbalance is sometimes equipped with a clamp which grips the hangdown wire, operated from outside. Hereby, oscillations can be stopped and simultaneously the sample is electrically grounded. Oscillations may be braked by inclining the balance tube a little within the flange and touching the sample pan. The compensation current of electrobalances may also be decreased so that the sample pan descends and touches the bottom. In this way, a thermal contact to the pan is achieved and the attainment of temperature equilibrium is speeded up [7].

For analytical balances, the locking mechanism is often combined with levers lifting the weighing scales and the beam in order to relieve the knife-edges. Today, even kilogram prototype comparators of extreme sensitivity with knife-edges are operated without locking and relieving [8]. Microbalances are mostly suspended in taut bands or springs, and relief of the beam is of minor importance and is applied for transport only.

Limitation of the oscillation amplitude

In order to curtail weighings, the Romans fastened a rectangular frame on a bracket at some distance from the scale beam axis to one or both ends. The beam is fed through this frame and in this way its motion is limited. From the beginning of the 19th century, high-performance balances were equipped with adjustable bars which gave some resistance to the swinging beam [9] (Fig. 4). In this way, fast corrections of the counterweight are possible. Modern electronic balances also dispose with delimiters for the beam: not to curtail weighings, however, but to protect the beam and its suspension.

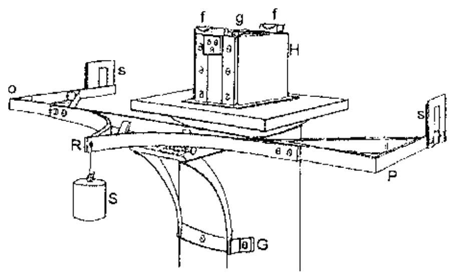

Fig. 4 Adjustable beam delimiters of the long-armed precision balance of Nathan Mendelssohn (1808)

Delimiter devices may be regarded as precursors of half-arresting, a method which came into use at the end of the 18th century. Hereby, the arresting lever was operated in such a way that the beam was allowed to swing only with restricted amplitude.

Dry frictional damping

Mechanical dampers are used as shock-resistors to protect the stand of the balance from spurious vibrations of the bottom. Damping the balance beam by means of dry boundary friction is not favourable because the static friction effect brings the indication to rest at an uncertain position.

Widely used within the 19th century was damping of the balance beam and the pans by means of a brush. As soon as the oscillations had nearly vanished, the brush was removed and the beam was allowed to swing freely and to find its rest position. This method may be regarded as a combination of half-arresting and damping using dry friction. In the balance of Plattner [10], damping of the balance by means of a brush was combined with arresting of the weighing scales by contact with the desk (Fig. 2).

Damping methods

We assume that the balance is well situated on a heavy stand and protected by dampers from shocks and vibrations from outside. Then, by handling, oscillations of the beam and additionally of the suspensed sample and counterweight are stimulated. In the following, we restrict ourselves to the movements of the beam, assuming the suspended parts to be at rest with respect to the beam [11] (Fig. 1). By the influence of friction within the bearings or in the spring material and by the surrounding air, the oscillations are damped. After initial disturbing effects, the angular movement of the beam around the new equilibrium can be described by the following equation of motion:

$$J\ddot{\alpha} + k_d\ddot{\alpha} + k_t\alpha = M \qquad (1)$$

with J the moment inertia, k_d the damping constant, k_t a directional quantity, α the angular deflection and M the turning moment. Damping by the surrounding air is low and friction in the bearings is minimized in order to obtain maximum reproducibility. Thus, k_d is very small for balances without special damping devices.

Damping may be defined as the application of reacting forces which are synchronous and proportional to the spurious oscillations and vanish as soon as the trouble signal becomes zero. Thus, damping in principle has no influence on the weighing result. However, damping devices themselves may be subject to environmental influences and in this way the weighings can be disturbed. Therefore, for the high-sensitive comparison of mass standards, no additional damping devices are applied.

In the 19th century, various damping methods for engine vibrations and for instrument indication were already known and could be adapted for the special

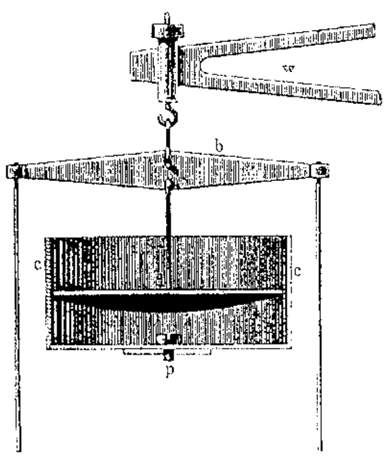

Fig. 5 Air damping according to Arzberger (1875). On one side of the symmetric balance, a plate is fastened to the pan support, which moves in a cylinder fastened to the casing

requirements of balances. Fast-acting damping of the balance beam oscillation allowed faster weighings and direct readings of the result, and permitted combinations with other measuring techniques.

Fluid damping

The first real damping device for a balance, air damping, was designed by Arzberger [12, 13] in 1875 (Fig. 5). It consisted of a plate suspended within the frame of the support of one weighing scale, which moved in a cylinder fastened to the balance casing. Further developments resulted in two cups packed into each other at low distance [14]. This device, in a variety of technical solutions, was successfully used to damp mechanical analytical balances [15, 16] (Figs 3, 6).

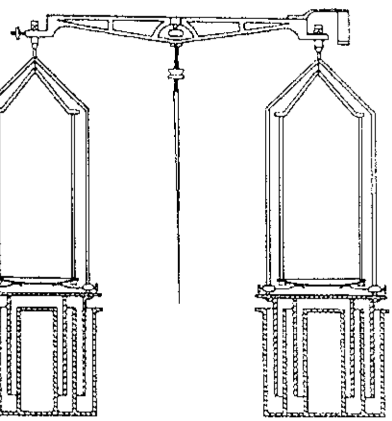

Fig. 6 Air damping according to P. Curie (1889), with two cylinders at the bottom of both scales. The counter cylinders are fastened to the desk

In vacuum, friction by the residual gas is insignificant. Kuhn *et al.* [17] recommended the introduction of some helium into the vessel at the beginning of adsorption experiments. The helium, as a scarcely adsorbing gas, can be pumped off quickly as soon as the oscillations end. The addition of helium also allows the performance of measurements in the pressure region of maximum Knudsen forces.

A special case of oil damping by means of rotating vanes in connection with a balance was reported by Poynting (Fig. 7). Damping by means of a vertically arranged vane moving through oil is widely applied for large mechanical balances and for rough weighings. Tripp *et al.* [18] immersed the bottom of a special tare pan of a Cahn microbalance in vacuum oil in order to damp vibrations. Since the beam of the compensating electrobalance is always at null, they observed no errors due to buoyancy or wetting effects and no decrease in sensitivity.

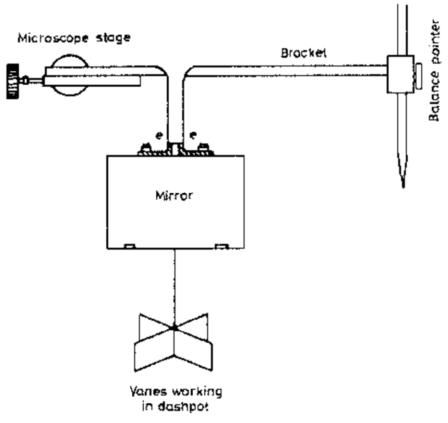

Fig. 7 Oil damping of a gravimetric instrument for determination of the mean density of the Earth according to J. H. Poynting (1891). On the right-hand side is the end of a 0.6 m long pointer which drives a bracket equipped with a mirror for microscopic observation. The mirror is damped by means of crossed vanes turning in oil

Eddy current damping

Very early, eddy current damping was applied for mirror galvanometers [19]. First, Marek [20] developed an analytical beam balance with eddy current damping (Fig. 8). Then, in the 1930s, in the USA, laboratory balances were equipped with such devices, whereas in Europe air damping was preferred.

Walker [21] damped the beam oscillations of a Gulbransen balance [22] by means of a thin plate of pure aluminium suspended on the aluminium suspension wire for the counterweight. Outside the balance tube, an external alnico permanent magnet was arranged, the poles of which encircled the aluminium plate. Kolenkow and Zitzewitz [23] fastened a copper vane on the beam. Mayer *et al.* [24] combined an eddy current device with automatic control of the balance.

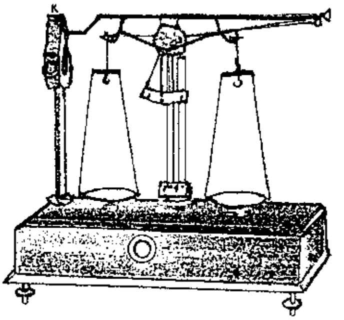

Fig. 8 Laboratory balance of W. Marek, produced by Nemetz Wien (1906), with eddy current damper

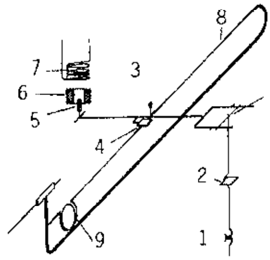

Fig. 9 Quartz torsion microbalance according to Mayer *et al.* with means for eddy current and electronic damping

Damping of the torsion UHV microbalance was accomplished in two ways: eddy currents and a delayed circuit by means of a permanent magnet plunging into a copper cylinder with coil (Fig. 9).

Electronic methods

Electronic damping

Electronic compensating balance [25, 26] used a feedback loop in which an error signal is amplified, producing the compensating force directly. In this case, not only the mechanical self-oscillations of the balance, but also those of the control loop should be considered [27]. Both oscillations can be influenced by means of lag, lead and filter elements in the control loop. Furthermore, absorptive dampers can be included in the indicating circuit. Mauer [28] stopped beam oscillations with an automatic analytical balance by phasing the beam position signal with a velocity damping signal obtained by differentiating the beam position signal. Cahn [29] equipped his electrobalance with an adjustable shunted capacitor in the indicating circuit in order to damp the oscillations of the signal [30]. For his suspension balance, Gast [31] inserted an RC circuit between the discriminator and the output amplifier which feeds the magnetic coil controlling the distance of the suspension magnet.

Digital methods

For digital balances, fast-reacting nullification of eddy signals and equilibration of the indicated values are applied. The digital indication can be disconnected and stopped either when the mass value does not vary for a given period of time, or as soon as a reliable mean value can be extrapolated.

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