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INSTRUMENTS AND METHODS

Shipboard precision weighing*

J. L. Boucher,† H. P. Bougault† and J. Martinais†

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Abstract—Weights of about 1 mg to 1 g have been measured on board a ship with a precision better than 0·5% on a routine basis using an electromagnetic balance.

INTRODUCTION

Measuring a mass with a relative precision better than 1% is difficult on board a ship because of the various accelerations induced by the ship motions. Yet, in order to analyse rocks by X-ray fluorescence, or to determine the biochemical composition of zooplankton, masses ranging from about 1 mg (biochemical composition) to 1 g (rock analyses) have to be known with a relative precision better than 1%.

SETTING OF AN ELECTROMAGNETIC BALANCE ON BOARD

A conventional mechanical balance cannot be used for shipboard weighing because this type of balance usually has roughly the same period as the ship motions and the frame of the balance must be kept motionless because of its design.

In an electromagnetic balance, the torque resulting from the difference of mass between the two pans is compensated by an electromagnetic torque. Figure 1 illustrates the type of electromagnetic balance we used. The balance arm carries a shutter O interposed between a lamp and a pair of photocells C; a small displacement of the arm causes excess current flow through one photocell C. The current is amplified and sent through the coil which is rigidly attached to the beam, restoring it to its original position. Therefore, *the equilibrium position of the beam is related to the position of the frame of the balance and is maintained automatically without any operator action.* In addition, the balance has a short period and its damping is adjustable. These are important advantages for shipboard use.

The equilibrium position of the electromagnetic balance beam when the frame makes an angle α with the horizontal level is (Fig. 2):

$$(m + \Delta m)\,\gamma\, l \cos \alpha = m l \gamma \cos \alpha + KI,$$

where $m + \Delta m$: mass on one pan
m : mass on the other pan
γ : vertical component of the acceleration

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*Contribution no. 181 of the Département Scientifique, Centre Océanologique de Bretagne.

†Centre Océanologique de Bretagne, B.P. 337, 29273 Brest, France.

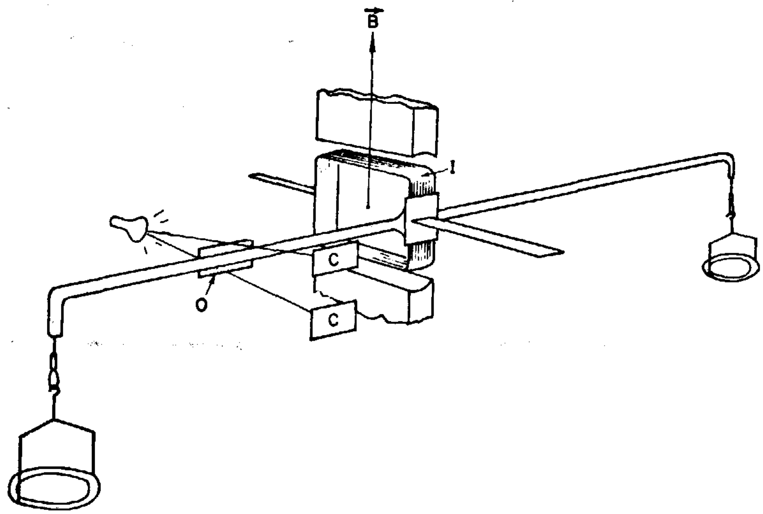

Fig. 1. Electromagnetic balance schema.

α : angle of the frame with horizontal level
KI : magnetic torque, I being the current intensity through the coil and K a constant of the balance
l : arm length

$$I = \frac{1}{K} \Delta m \, \gamma \cos \alpha.$$

A variation $\Delta\gamma$ of γ or $\Delta\alpha$ of α causes a variation of I, which is proportional to the value of Δm; consequently, we must minimize the variations $\Delta\gamma$ of the vertical component of acceleration; variations of the horizontal components of acceleration induce effects an order of magnitude smaller. We must also minimize the variations $\Delta\alpha$ of the frame angle with the horizontal level. In practice, we placed the balance on strongly damped gimbals near the neutral point of the ship and kept the difference of mass between each pan as small as possible using known counterweights. In this way possible cross-coupling errors can be neglected.

RESULTS AND DISCUSSION

Tests were conducted during three cruises of the R.V. *Jean Charcot* during 1972.* In a first experiment, we observed for several sea states, the equilibrium of the balance without any weight on the pans (Fig. 3). The observed variations of the current intensity show that although the balance is not in mechanical equilibrium ($\Delta m \neq 0$), the amplitudes of the variations are small enough to make mass measurements with the desired precision. In a second experiment we observed the equilibrium for several mass configurations (Fig. 4). As expected, the amplitude of the variation of current intensity through the coil increases with the difference of mass between pans. It appears, however, that the amplitude also increases with the magnitude of the weights placed on the pans, particularly in the range 500–1000 mg. This may be caused by

*Some tests made on a boat 10 m long show that the use of this balance is also possible on board smaller ships than the R.V. *J. Charcot* (74 m long, 2200 tons).

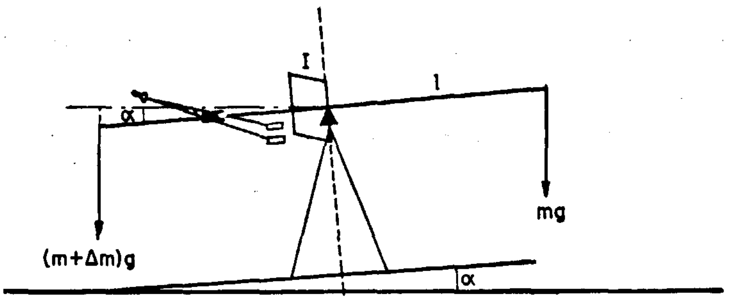

Fig. 2. Equilibrium position of the electromagnetic balance when the frame makes an angle α with the horizontal level.

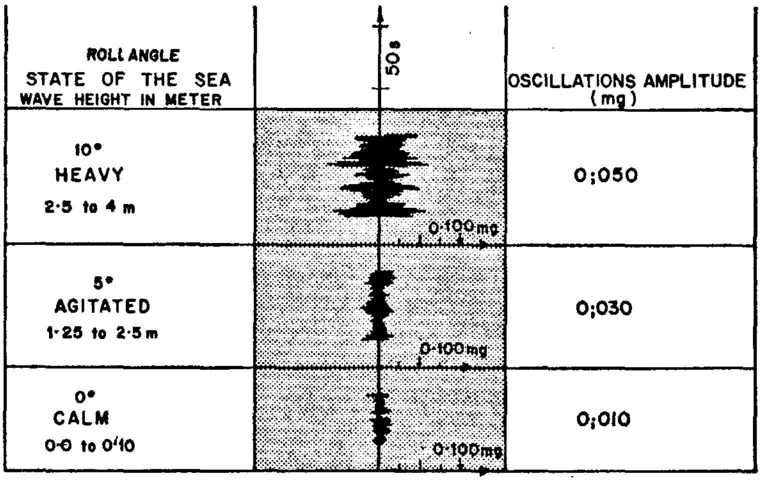

Fig. 3. Current intensity variations around the equilibrium position for the empty balance for minimum estimates of different sea states (and corresponding wave heights and roll angles); ship underway; beam perpendicular to the axis of the ship.

distortion of the beam which could increase the dissymmetry between the two arms of the beam. The observed variations, which are the sum of the variations due to the factors discussed above, have a maximum amplitude of 1 mg for a difference of mass of 50 mg between pans (500 mg on one pan, 450 mg on the other). Integrating this 'noise' during 20 s is sufficient to reduce, by a factor of 5, the error due to the oscillations about the equilibrium position and to evaluate a difference of mass of 50 mg with a precision of 0·2 mg. No differences were observed by alternating masses on each pan.

When measuring a mass of the order of 500 mg (for X-ray fluorescence analysis of rocks), the known mass put in one pan should not differ from the mass of the sample put in the other pan by more than 50 mg; the difference of mass between the two pans is measured by the intensity of the current through the coil. The error in the determination of the mass of the sample is the sum of the error due to the noise, the error in the measurements of the current intensity and the error of calibration current intensity versus mass. On a routine basis, it is easy to measure the sample mass with a

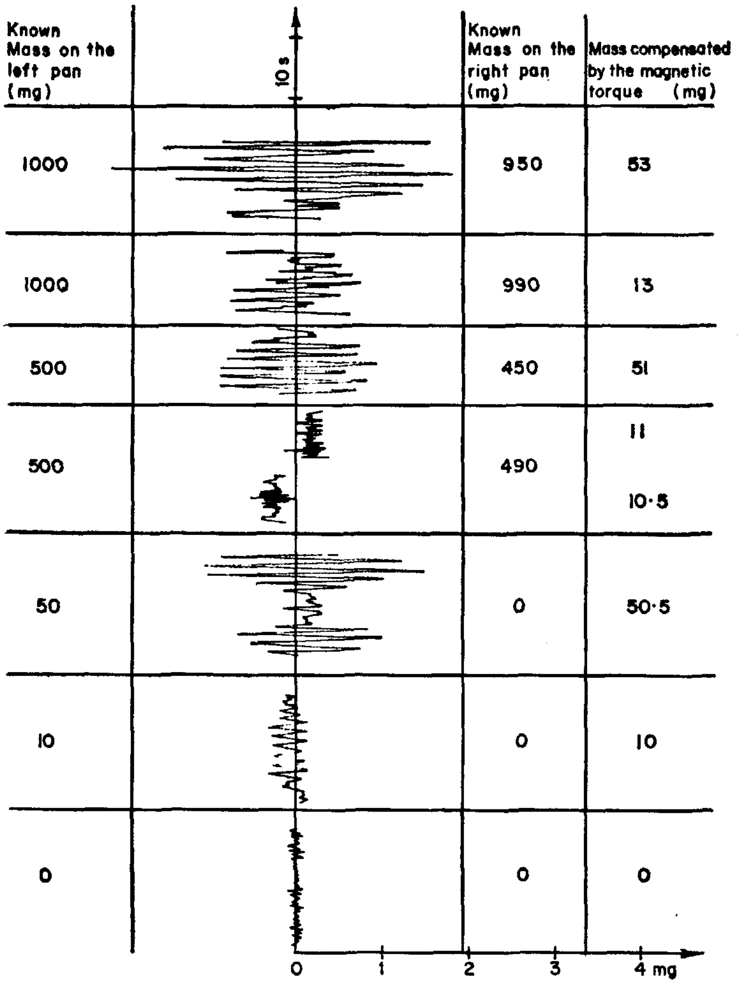

Fig. 4. Current intensity variations around the equilibrium position for different mass configurations; ship underway; beam perpendicular to the axis of the ship.

relative precision better than 0·5%; this precision could be improved considerably, if necessary, by recording over a long time and making a more careful calibration.

When measuring a mass of the order of 1 mg, the oscillations caused by the difference of masses placed on each pan are similar to those of the empty balance and can be neglected. The amplitude of the variations of the current intensity through the coil are proportionally the same as for the first case (for measurements of 1 g) and the relative precision is equivalent.

Finally, we note that the two balances we used kept a good zero stability, linearity and calibration stability throughout the whole period of three months corresponding to the three cruises during which the experiments were conducted.

CONCLUSION

It has been shown that a conventional electromagnetic balance is suitable for shipboard weight determinations, provided that a few special precautions are taken for its setting. Masses of 1 mg to 1 g can be weighed with a routine relative precision better than 0·5%. As a result, measurements of the biochemical composition of zooplankton and X-ray fluorescence analyses of rocks that were made routinely on board a ship compare favourably to the ones we obtained on land.

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