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A neutral-buoyancy float for measuring deep currents

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Abstract—Floats designed to stabilize themselves at a given depth, and fitted with means of sending out acoustic signals to indicate their position, have been made at the National Institute of Oceanography. Some current measurements were made with them on a recent cruise of R.R.S. "Discovery II".

INTRODUCTION

A body which is less compressible than sea water will gain buoyancy as it sinks ; if its excess weight at the surface is small, it may at some depth gain enough to become neutrally buoyant, when no further sinking will occur. Following the movement of such a float would give a direct measurement of the current at that depth, free from the uncertainties involved in using a conventional current-meter from an anchored ship. The possibility of using this method for measuring deep drift currents over a long period has been suggested in a recent note by STOMMEL (1955).

THE FLOAT AND ITS SIGNALLING EQUIPMENT

In the present design, tracking the floats is made possible by fitting them with acoustic transmitters, capable of sending out a short pulse every few seconds for two or three days. Besides having a sufficiently low compressibility, the float must provide enough spare buoyancy to carry this transmitter, and must not collapse at the greatest working depth.

Aluminium alloy scaffold tubing (alloy specification HE-10-WP, described in B.S. 1476 (1949)) has the required mechanical properties, and can be made into convenient containers for the electrical circuits and batteries. The compressibility of a long tube, closed at its ends, is (see, for example, NEWMAN and SEARLE, 1948)

$$-\frac{1}{v}\frac{dv}{dp} = \frac{R_1^2/\mu + R_2^2/k}{R_2^2 - R_1^2}$$

where R_1 and R_2 are the internal and external radii, v is the external volume, and μ and k are the rigidity and bulk moduli of the tube material. In Fig. 1 this compressibility is plotted against the ratio wall thickness : mean radius. The buoyancy and collapsing depth are also shown, the latter being calculated from formulae given in B.S. 1500 (1949). It can be seen that, by reducing the thickness-to-radius ratio of the standard tube to 0·16, the buoyancy can be doubled without seriously impairing the low compressibility or restricting the working depth. The outside diameter of the tubes was reduced uniformly, by solution in caustic soda, to make the ratio 0·16 ($\pm$ 0·01), and in this condition 6 m of tubing is needed for each float. For convenience in handling, this is made in two lengths of 3 m, one containing the transmitter circuit and batteries, and the other providing buoyancy.

Fig. 2 is a sketch of the float, with the end plugs shown in detail. The ends of the tubes are bored out to fit individual plugs ; this method of sealing scaffold tube has been tested to 4,500 m depth. The transmitter consists of a nickel scroll resonant at 10 kc/s, wound toroidally and energized by discharging a capacitor through a flash tube. Originally the transmitter was arranged so that, besides sending out a steady series of pulses, it would respond when it received a signal from the ship's echo-sounder. Since no current measurements were made with this arrangement, however, only the simple circuit is shown here.

The mean density of each complete float and transmitter is adjusted to an accurately known value by immersing it in a salt solution of known density and temperature

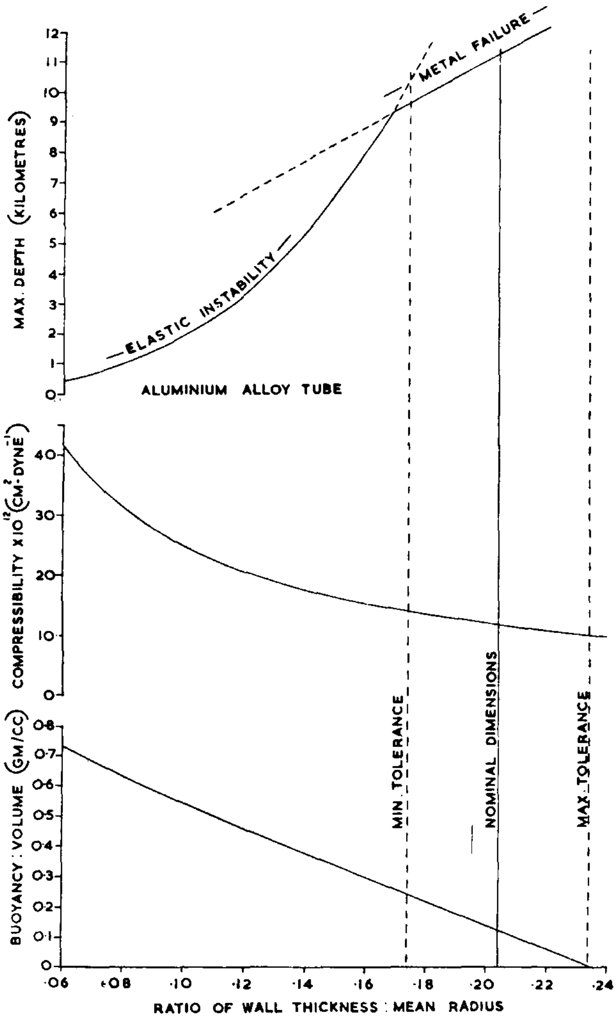

Fig. 1. Compressibility, buoyancy per unit volume, and maximum depth for aluminium alloy tubes.

(in the present case this was 1·0264 at 14·1°C) and adding weights until it is neutrally buoyant. This adjustment can be made to 1 gm. without difficulty, with a float weighing about 10 kg. in air. The density can be altered to any desired value by adding or subtracting weights, in proportion to the total weight of the float. All the extra weights are put inside the buoyancy tube, so that no change in volume has to be allowed for. Before launching any of the floats, temperature and salinity observations are made and the water densities *in situ* calculated from tables (ZUBOV and CZIHIRIN, 1940). The extra weight required to take the float down to any desired depth can then be determined, from the known density at that depth and the calculated compressibility of the float. Allowance has to be made for the tempera-

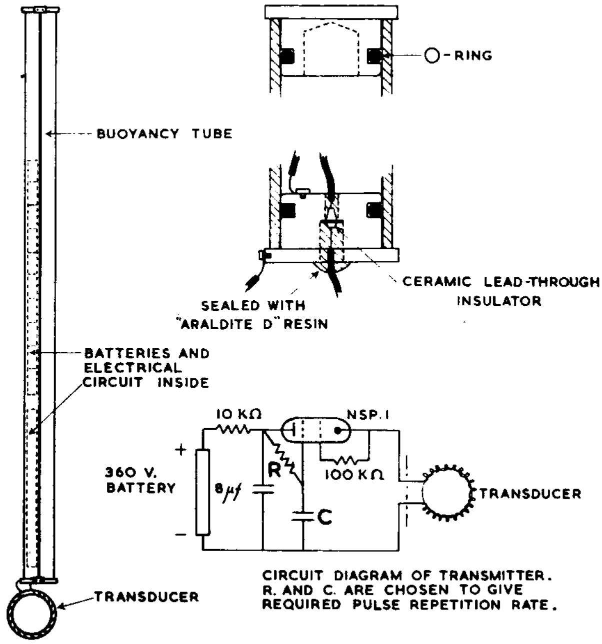

Fig. 2. Sketch of float and end plugs, and circuit diagram of acoustic transmitter.

ture change, but the effect of this is small. For an example of the order of magnitude of these extra weights, in the area where the present measurements were made, a float arranged to stabilize itself at 1,000 m depth had 38 gms. negative buoyancy at the surface.

METHOD OF TRACKING A DRIFTING FLOAT

The original plan was to follow the floats by means of the ship's echo-sounder, observing the responses of the floating transmitter when it was triggered by an outgoing echo-sounder pulse. This would have the advantage of indicating directly the depth of the float, but the narrowness of the beam of the echo-sounder made searching for the float very difficult and an alternative method had to be used. This scheme is illustrated in Fig. 3.

With the ship stopped head-to-wind, two hydrophones are lowered over the side, as far apart as can be conveniently arranged. The signals from them are fed via separate tuned amplifiers to a double-beam oscilloscope, the time-base of which can be triggered from signals applied to either beam. Pulses from the floating transmitter are received at different times at the two hydrophones, and the magnitude and sign of this time-difference can be measured on the oscilloscope.

As the ship's head falls away from the wind direction, the time-difference is observed as a function of the bearing of the line joining the hydrophones. It follows a " figure-eight " polar diagram, with sharp zero-values when the bearing is at right angles to the line from the ship's position to the float. Usually, observations over an arc of about 120° are enough to indicate the bearing from the ship to the float. The process is repeated with the ship in other positions, and the intersections of these bearings locate the float in a horizontal plane. The ship's position is determined by radar range and bearing from an anchored dan buoy, and the movement of the dan buoy itself is checked by sounding over small but recognizable nearby features on the sea bed.

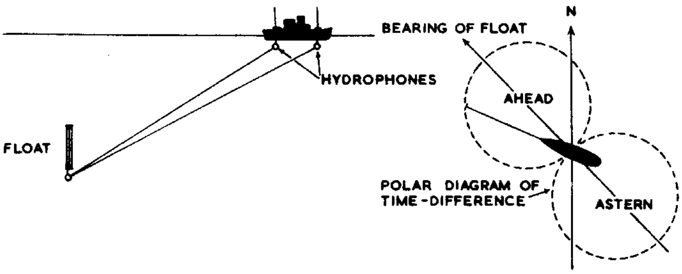

Fig. 3. Method of locating float.

The depth of the float can be estimated each time a bearing of it is taken, from the size of the " figure-eight " pattern obtained when the time-differences are plotted. The ratio of the maximum time-difference observed, (when the ship is heading directly towards the float) to the direct travel-time from one hydrophone to the other, is the cosine of the angle between the horizontal and the ray coming from the float to the ship. The depth of the float can then be found when the horizontal distance between it and the ship is known. The direct travel-time between hydrophones is measured by floating a transmitter on the surface and observing the maximum time-difference at the two hydrophones, as the ship is swung round.

To avoid errors in bearings and in the time-differences, the hydrophones are kept fairly shallow (about 7 m) and are weighted to prevent their cables from straying too far from the ship's side.

OBSERVATIONS

Of the six floats used during the May-June (1955) cruise of " Discovery II," one was lost in trying out the echo-sounder method of tracking, two others disappeared within a few hours of being released, one developed an electrical fault after 8 hours running, and the other two worked satisfactorily. No explanation can be offered for the loss of two of the floats, though it may possibly have been due to undetected flaws in the tubes causing the compressibility to be higher than the calculated value.

The track followed by one of the floats is shown in Fig. 4, together with the positions of the dan buoy used as a reference mark. These are plotted relative to the southern end of a submarine ridge, rising about 200 m above the surrounding plain. The sides of the ridge are quite steep, and the depth to the plain is 5,330 m. Trouble was experienced with the dan buoy dragging its sinker along the sea bed, and the interpolation between successive fixes is uncertain, so that only the average drift can be determined. This is 5·7 cm/sec, in the direction 250° (true). The float was loaded to sink to 900 m, and estimates of its depth ranged from 800 to 1,500 m.

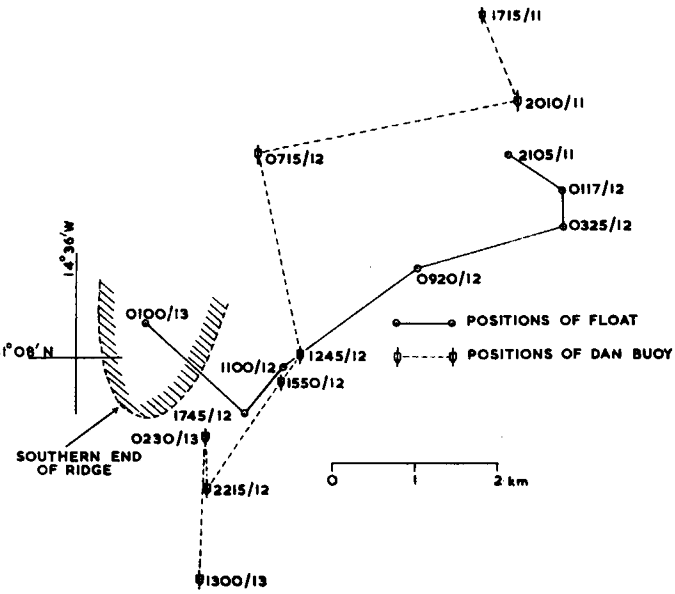

Fig. 4. Track of float, 11th-13th June, 1955.

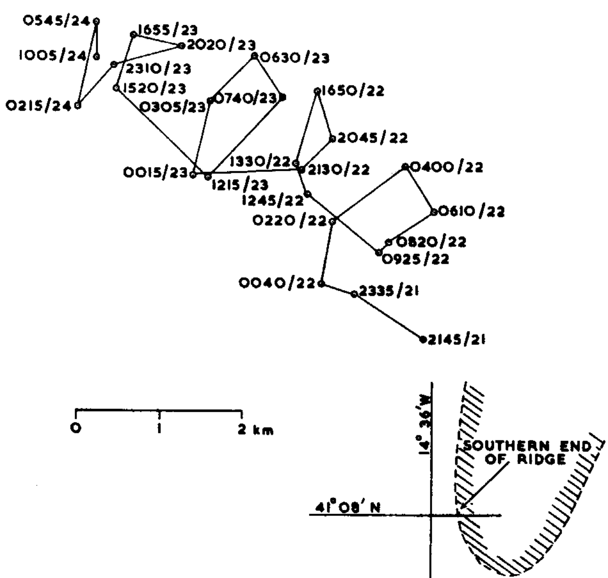

Fig. 5. Track of float, 21st-24th June, 1955.

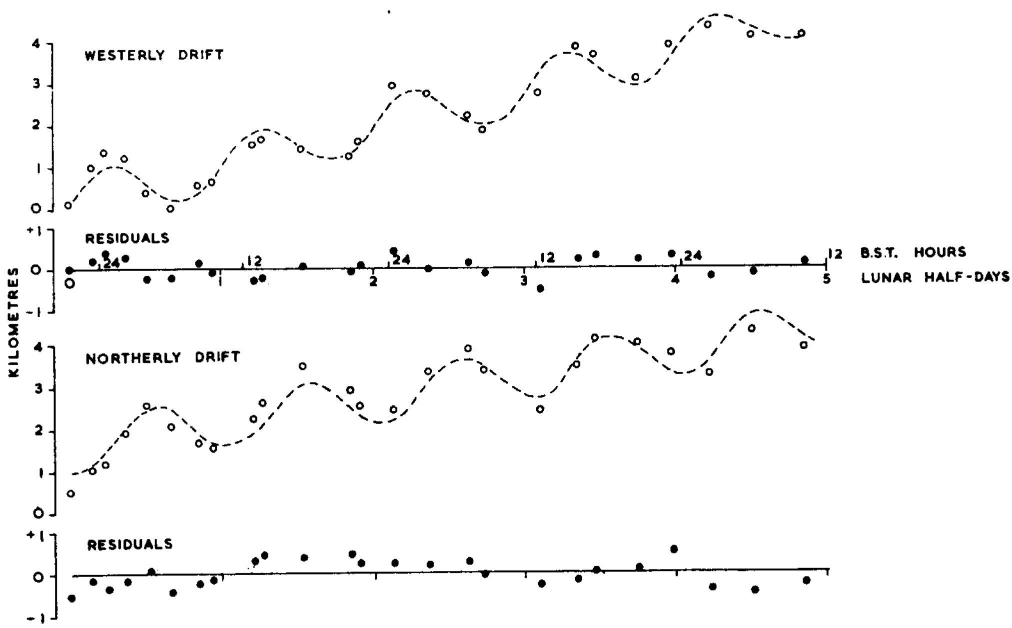

Fig. 6. Northward and westward movements of float plotted against time.

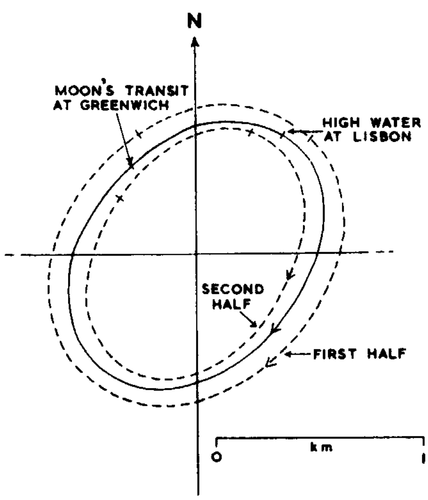

Fig. 7. Tidal components of displacement combined to form an ellipse.

Another float, loaded for 400 m depth, followed the track shown in Fig. 5. More frequent fixes were made, and the dan buoy was more securely anchored, so that tidal oscillations can be seen superimposed on the drift.

The northerly and westerly displacements of the float are plotted against time in Fig. 6. A steady drift plus a lunar semi-diurnal oscillation has been fitted by least squares to each of these, leaving the residuals shown. There is some tendency for the residuals to show an 18-hour fluctuation (approximately the period of inertial oscillations in this latitude) but it is not very significant, since the estimated uncertainty of each observation of the displacement of the float is about $\pm$ 0·2 km. Combining the drift components gives a resultant current of 2·4 cm/sec. in the direction 300° (true). The tidal components of displacement are plotted together as an ellipse in Fig. 7. The ratio of the lengths of the axes is 0·73, which agrees fairly well with the theoretical ratio (for an infinite ocean) of 0·68 in this latitude. The direction of the major axis, and the *cum sole* direction of rotation, are also in agreement with theoretical predictions (Bowden, 1954). The tidal current, varying from 7·3 to 10·0 cm/sec., is similar in magnitude to those measured by the " Meteor " and " Armauer Hansen " expeditions (Defant, 1932 : Ekman, 1953).

To estimate the uncertainty of fitting these tidal oscillations, the observed displacements have been divided into two groups and separate fittings made. The results are shown as the dotted ellipses in Fig. 7.

The depth measurements show considerable scatter (Fig. 8), with a mean value of

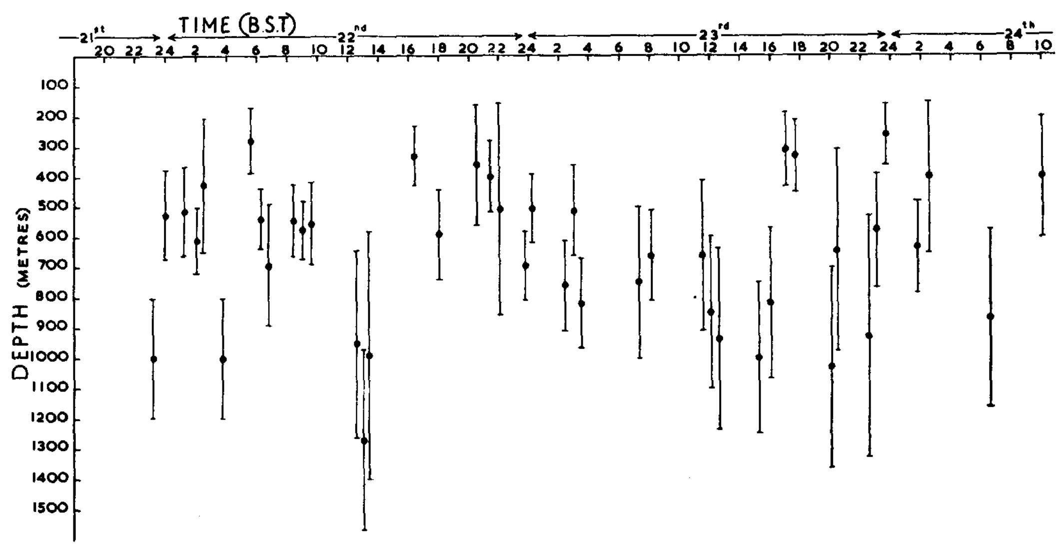

Fig. 8. Depth estimates.

about 600 ($\pm$ 200) m. The observations are too uncertain to show whether any genuine depth oscillations occurred, but they are sufficient to demonstrate that the sinking rate, after the first few hours, is very small.

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