DESIGN OF AN IMPROVED TURBIDITY METER

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Several methods have been used in measuring the turbidity under the sea surface. Young (1942) and Jerlov (1953) sampled sea water and measured its light transparency and light scattering by the use of a Tyndall-meter. Powell (1936), Atkins (1938) and Utterback (1938) measured the decay of daylight under the sea surface with the undersea photo-cell and calculated the extinction coefficient of the sea water. Pettersson (1936) and Joseph (1949) measured the extinction coefficient of the sea water *in situ*, using the transparency-meter (or the turbidity-meter). In 1953 a new type of turbidity-meter was designed by the author (Fukuda, *et al.* 1954). In this instrument, the flux of the source light is cut about 400 times a second by the rotating sector, and this modified light produces an alternating current in the photo-cell circuit. Next in the amplifier circuit, only this alternating current is picked out leaving the other current produced by the daylight, and so with this instrument the turbidity can be measured *in situ*, without any disturbance by the daylight. This iustrument, however, was so complicated that it became bulky and often went wrong. So the author designed another type of turbidity-meter in 1955 the details of which are reported here.

Details of the instrument

Fig. 1 and Fig. 2 respectively show the schematic diagram and the outer view of the instrument. The instrument consists of the electric source (a), the measuring part (b), the leading wire system (c) and the submarine part (d). The submarine part is a brass cylinder 12 cm in diameter and 123 cm in length. This cylinder is divided into three chambers; on the left-hand is the watertight box of the light source, the middle part is the water passage and on the right-hand is situated the light-receiving box. The submarine part is hung down to 200 m depth from the deck with a cabtyer cable (the leading system c in Fig. 1) which consists of two copper wires and two steel ones. The cable is wound on an iron reel, the rotating drum of which has a mercury connector on its rotating axis. This connector was specially designed by the author, as shown in Figs. 3 and 4 so that the connection between the measuring part and the leading wire might never be cut even when the drum was rotated.

Fig. 1 also shows an electric circuit diagram of the instrument. The electric source consists of three batteries of 6 V; two of them are for the light source in the submarine part and the other is for the A-cell of the amplifier in the measuring part. B-cell of the amplifier is a 67.5 V dry cell and packed in the amplifier box. As the light source, a small tungsten lamp is used and the lamp current is adjusted to be just 1.25 A using

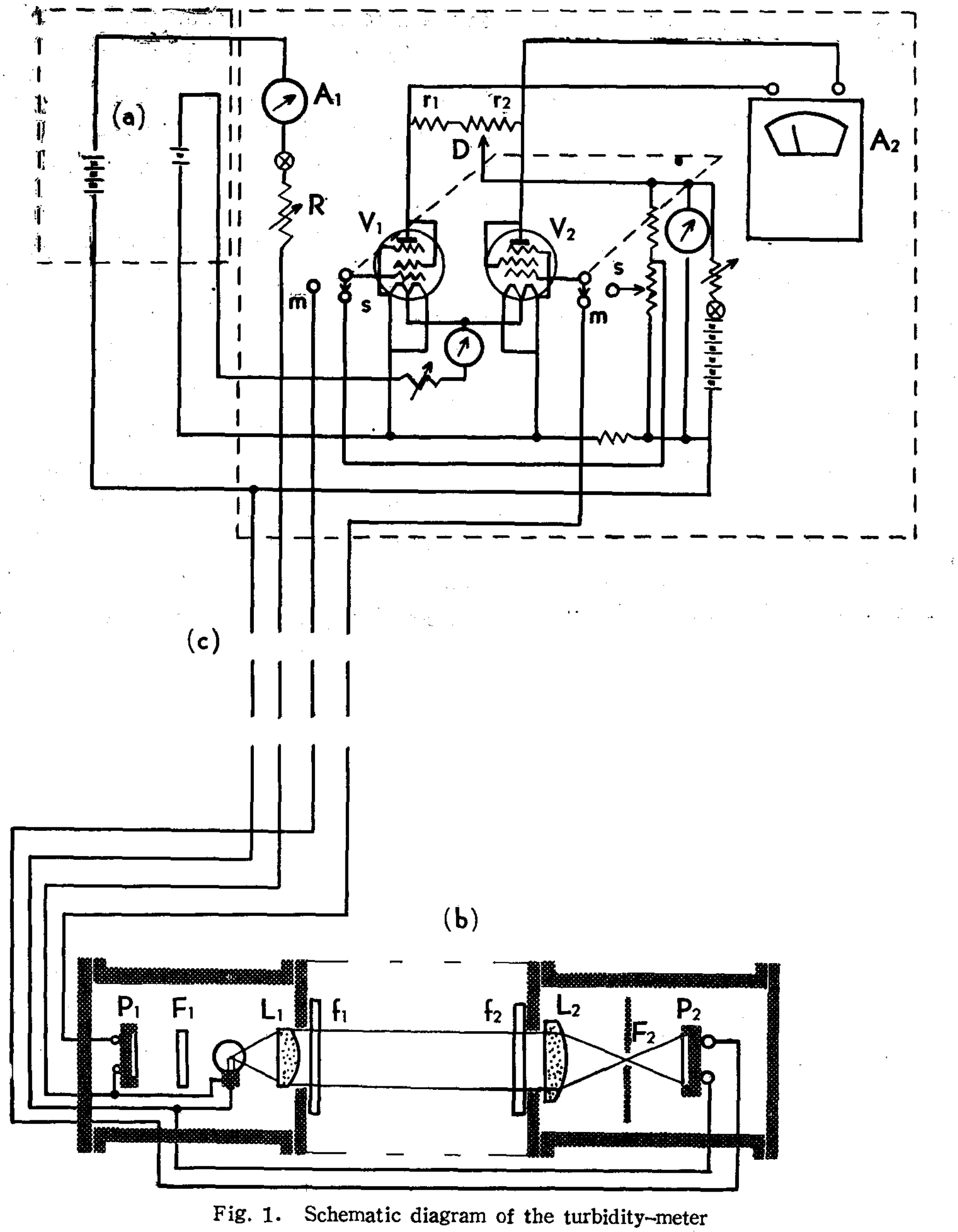

Fig. 1. Schematic diagram of the turbidity-meter

an ammeter A_1 and resistor R. Under this condition the candle power of the lamp is 1.4 and the colour temperature of its filament is about 2800° K. A part of light flux which diverges from the source lamp is made into a parallel beam through the lens L_1 and goes out through the window glass f_1 into the water. The beam, having passed through the water for a distance of 70 cm and being decayed by the suspended matter

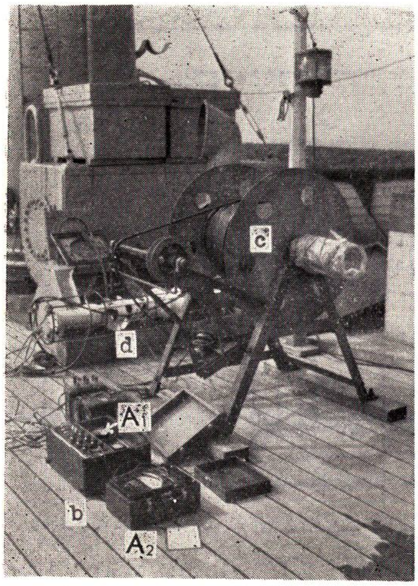

Fig. 2. Outer view of the turbidity-meter

in the water and also by water molecules itself, comes into the photo-cell chamber through the window glass f_2. Through the lens L_2 the parallel beams is converged at a pinhole F_2 through which the beam passes to reach the photo-cell P_2. However often beams of the submarine daylight enter by the window glass, the most of them are cut off by the lens L_2 and the pinhole F_2 because those beams are not parallel to the optical axis of the lens and pinhole system. This was ascertained by several preliminary experiments.

Another part of the flux of the source lamp goes in the opposite direction through the filter F_1, its heat ray being eliminated; it reaches the compensation photo-cell P_1. This photo-cell together with photo-cell P_2, two similar vacuum tubes and two resistors r_1, r_2

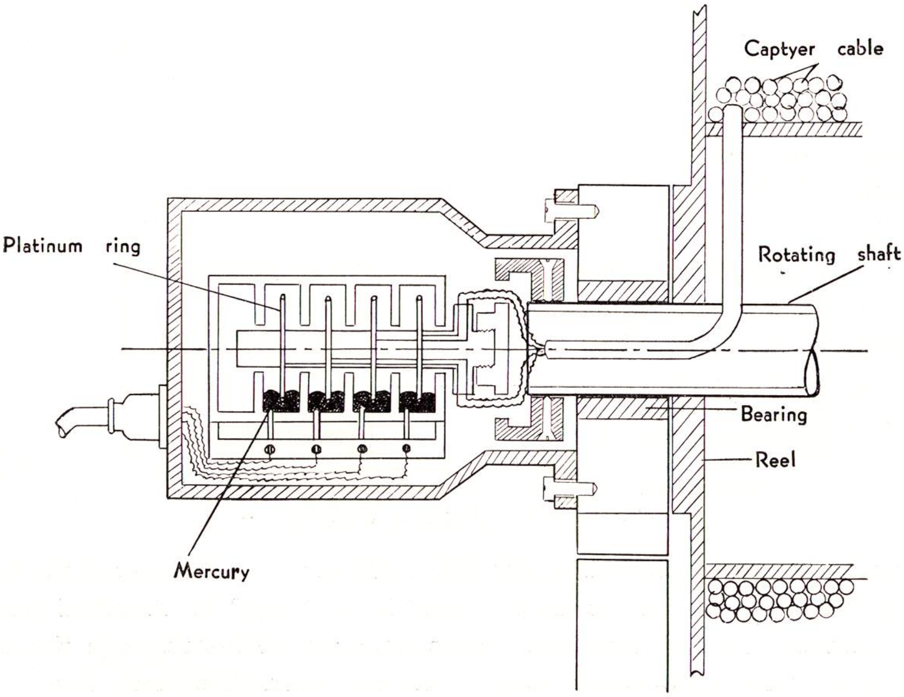

Fig. 3. Schematic diagram of the rotating mercury connector

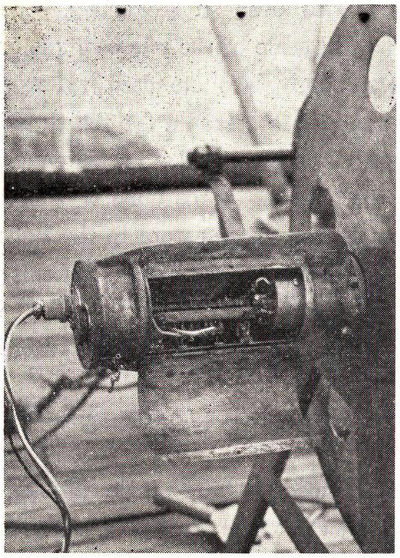

Fig. 4. Outer view of the rotating mercury connector

constitutes a bridge circuit. Before the submarine part is hung down into the sea, the switch is on to the terminal s (i. e, standard) and two standard voltages are inserted respectively to the grid of each tube in place of the electromotive force of the two photo-cells. Then, the divider D of the two resistors r_1, r_2 being set at the fixed point, the filament current and the B-voltage of the tubes are adjusted so that the indication of a micro-ammeter A_2, which is inserted between plate terminals of the two tubes, shows a definite value. These procedures being finished, the switch is changed to the terminal m (i. e. measurement) and the divider D is adjusted at the fixed indication of the micro-ammeter. This adjustment can be carried on with high accuracy, but the adjustment of the light intensity of the lamp is very difficult, because the fluctuation of the electric current responds to far greater fluctuation of the light intensity. Therefore the compensation circuit is significant. The effect of the preceding P_1 circuit was examined in the laboratory. After the adjustment of the bridge circuit was finished in the air, the submarine part was lowered into the tank water. The reading of the micro-ammeter was 5.4, when the lamp current was adjusted to 1.25 A. Here the reading of the micro-ammeter means the difference of the meter indication in the measurement and in the bridge adjustment. Then the lamp current was changed over from 1.21 to 1.30 A and the reading of the micro-ammeter changed from 4.23 to 6.00, as shown in Fig. 5. This result shows that the adjustment of the lamp current in the accuracy of 10 mmA corresponds to the accuracy of 3 % of the reading of this instrument. In fact on the ship the lamp current adjustment of the instrument could hardly be made more

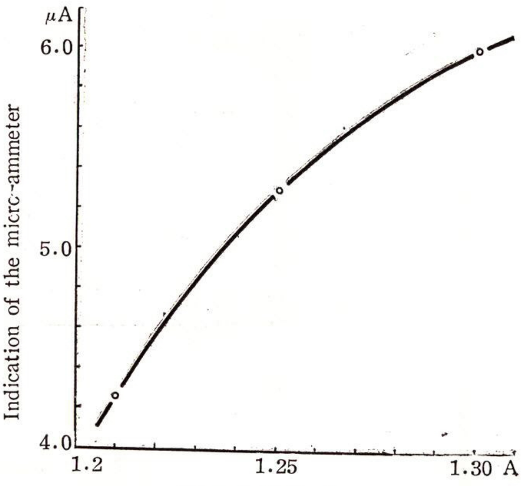

Fig. 5. Relation between the indication of the micro-ammeter and the lamp current

accurate in practice. The turbidity of the sea water varies over an extremely wide range from the coastal area to the open sea, so that the full scale of the micro-ammeter can not cover this wide indication of the turbidity; accordingly two standard voltages which are to be sent through in the grid circuit of the tubes are prepared for the turbid water and the transparent one. A further difficulty which happens in the measurement when hanging the submarine part down to the deep is the blurring of the window glass. It is considered that such blurring is caused by condensation of the moisture in the light receiving chamber coming from the cooling by the cold sea water. This difficulty however, could be removed by packing some desiccating agent in the chamber. In the laboratory the chamber was put in the tank water of 0° C; the blurring was no more seen on the window glass.

The method of calibration

The turbidity of the sea water has not yet been defined to be a single physical quantity, and so the indication of the measuring instrumant is often used in a relative expression of the turbidity so far as measured with the same instrument. Three types of ideas, however, are considered to be important for the definition of the physical

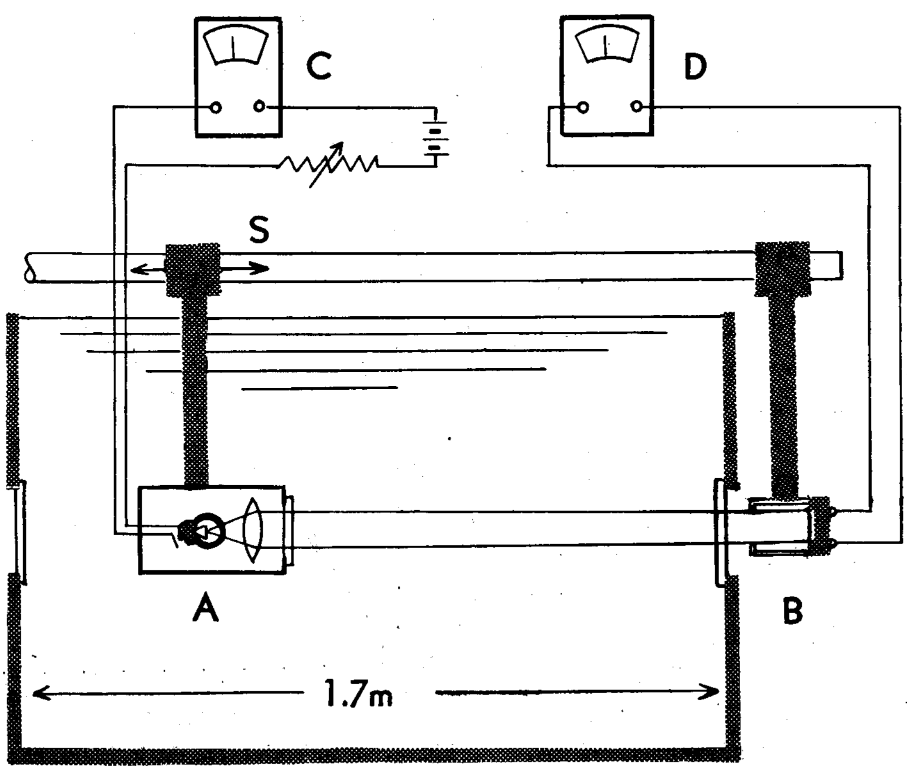

Fig. 6. Schematic diagram of the apparatus for calibration

quantity of turbidity. In the first idea, the behavior of the daylight under the sea surface is noticed and the extinction coefficient is defined as the measure of the turbidity of the sea water which affects the decrease of the submarine daylight. In the second one, a parallel light beam from an artificial light source is used instead of the daylight and again the extinction coefficient is defined. The third idea is that the quantity of the suspended matter and its size distribution in the sea water are considered also to be the measure of the turbidity of the sea water. The principle of every method of measuring turbidity developed to date has originated from some one of these ideas. The herein descrided instrument is designed on the basis of the second idea and the indication of the meter is naturally to be calibrated to the extinction coefficient in the turbid water. The calibration was made in the tank of the laboratory. For that pursose an apparatus measuring the extinction cceefficient of the tank water was specially designed, the schematic diagram of which is shown in Fig. 6. In Fig. 6, A is a watertight box including a light source lamp and condenser lens, B is a photo-cell fixed on the outer side of the tank window, C is a light source circuit and D is a precision micro-ammeter indicating the photo-current of B. A is dipped in the tank water and brought nearer to the photo-meter B guided by tne sliding system S. Indications of the micro-ammeter are read at several values of the distance between A and B. Using these data and the Lambert,s law the extinction coefficient can be calculated. In Fig. 7 is shown the relation between the readings of the turbidity meter obtained in waters of several degrees of turbidity and the extinction coefficients of the same water obtained by the preceding method. The result shows that by the use of this turbidity-meter the extinction coefficient can be measured within the error of $\pm$ 0.015 per meter. The calibration was made only within the range of 0.40–1.50 in the values of the extinction, because any more transparent water could not be prepared for the experiment of calibration. The calibration in a more transparent range is expected to be performed in the near future.

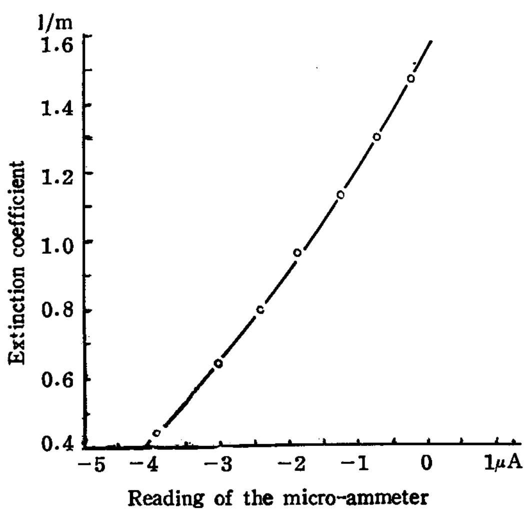

Fig. 7. Calibration curve of the turbidity-meter

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References

Atkins, W. R. G., Clarke, G. L., Pettersson, H., Poole, H. H., Utterback, C. L. & Angström, A. (1938). *Conseil Perm. Internat. P. l' Explor. de la Mer, Journal du Conseil*, 13.

Fukuda, M., Inoue, N. & Nishizawa, S. (1954). *Bull. Fac. Fish., Hokkaido Univ.* 5. (in Japanese with English abstract).

Jerlov, N. G. (1953). *Rep. Swed. Deep-Sea Exp.* 3 (Phys. & Chem. 3).

Joseph, J. (1949). *Dtsch. Hydrogr. Z.* 2.

Pettersson, H. (1936). *Rapp. et Proc.-Verb.* 101.

Powell, W. M. & Clark, G. L. (1936). *J. Opt. Soc. Amer.* 26.

Utterback, C. L. & Higgs, P. M. (1938). *J. Opt. Soc. Amer.* 28.

Young, R. T. (1942). *J. Mar. Res.* 5.