A CURRENT METER USING A PHOTOTUBE

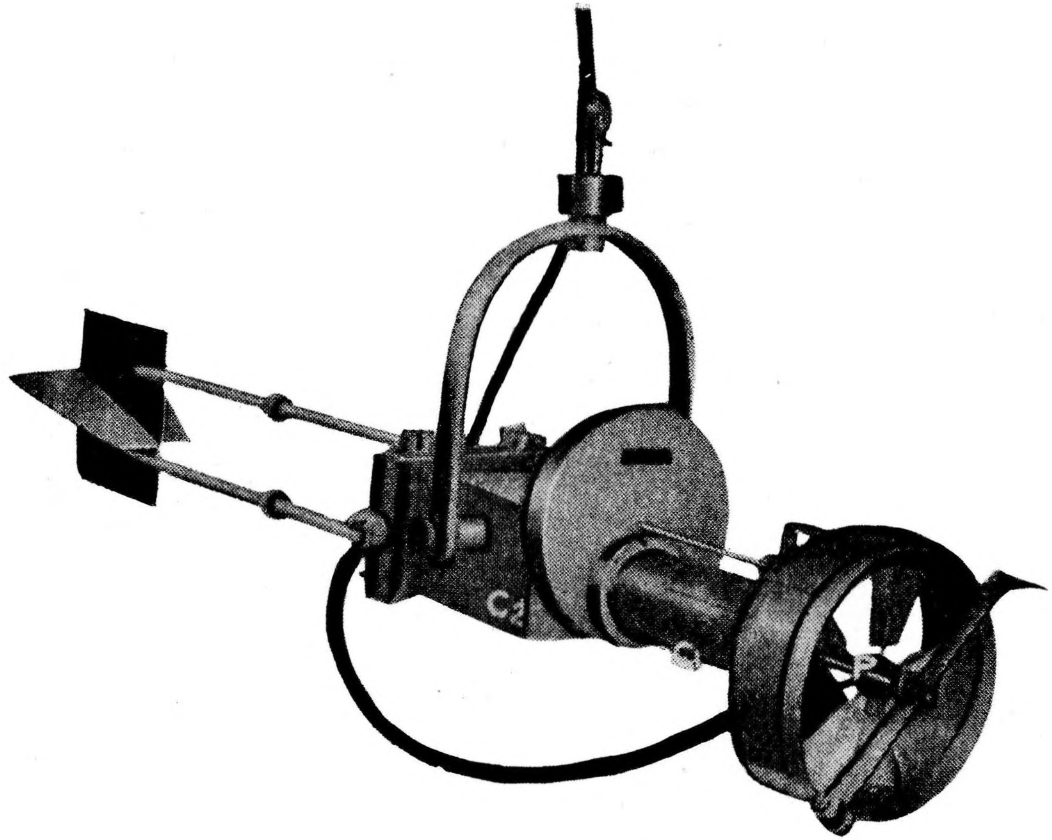


Fig. 1. — The under-water portion of the current meter, which sends photoelectric signals.

A CURRENT METER USING A PHOTOTUBE

Test Manufacture of a New Current Meter and Some Experiments on the Sea

by T. NAN'NITI
Meteorological Research Institute

(Extract from *Papers in Meteorology and Geophysics*, Vol. III, No. 4, page 286, published by the Meteorological Research Institute, Tokyo, Japan, March 1953.)

Abstract.

To measure velocities of currents automatically, the author has made a recording current meter using a phototube, in which the intermittent photoelectric current is depicted on a chart of a recorder on deck. The speed and direction of water current can be measured respectively by the time intervals and by the intensity of photoelectric current. Experiments on the sea have shown that by using the current meter, the actual under-water conditions can be immediately observed, and fine, accurate and rapid observations of water current have been made possible.

1. INTRODUCTION

Most of the types of the recording current meter, hitherto devised, require a water-tight chamber equipped with a propeller which rotates in accordance with the velocity of current. Since the shaft of the propeller penetrates the wall of the chamber, it becomes very difficult to keep the chamber water-tight under a hydrostatic pressure. In the new current meter here described, this difficulty is eliminated by using a beam of light in place of the shaft of a propeller. Furthermore, by using a phototube and a cylindrical mirror specially designed with a magnet, minute variations in both speed and direction of current can be measured.

2. PRINCIPLE OF THE PHOTOELECTRIC METHOD

In the present current meter, a light of constant intensity is emitted from a light source, and is reflected by a cylindrical mirror into a phototube producing photoelectric current.

A disc with holes which rotates in accordance with the current by means of a propeller is placed in the path of the light between the light source and the mirror. Therefore, an intermittent flash of light is produced by a rotating disc, the frequency of flashes being proportional to the speed of the current. Thus, the latter can be measured from the frequency of flashes.

The shape of the mirror is an equilateral triangle, more exactly, a trapezoid, girt around a cylinder like a belt, the apex of the triangle slightly overlapping the base. The cylinder is attached with a magnet at the bottom, which keeps it in a constant direction to the geomagnetic co-ordinate.

Since the light source moves with the direction of current, a light with certain intensity is reflected by the triangular mirror in accordance with the current direction. In other words, a certain value in the intensity of the reflected light corresponds to a certain value in the direction of current. Therefore, the latter can also be found from the measurement of the intensity of the reflected light.

3. THE DETAILS OF THE DESIGN

The current meter is shown in Figs. 1. C_1 and C_2 are brass cases, each with a glass window. GW_1 or GW_2, and their interiors are kept water tight, but water freely passes through between the two glass windows, GW_1 and GW_2. The light source, LS, is an electric lamp which is lit by a battery on deck; from the light source, a parallel ray is thrown through the window GW_1 into C_2. A disc, D, with holes, is rotated with a speed proportional to that of current by means of a propeller P. So intermittent beams of light are thrown on the window of the case C_2 by the rotation of the disc. As the light penetrates into the case C_2 through the window GW_2, it is restricted by a slit S, and a narrow linear beam of light is obtained, then it is reflected toward a phototube PT by a cylindrical mirror CM. The mirror is a ways kept in the constant geomagnetic direction by an attached magnet

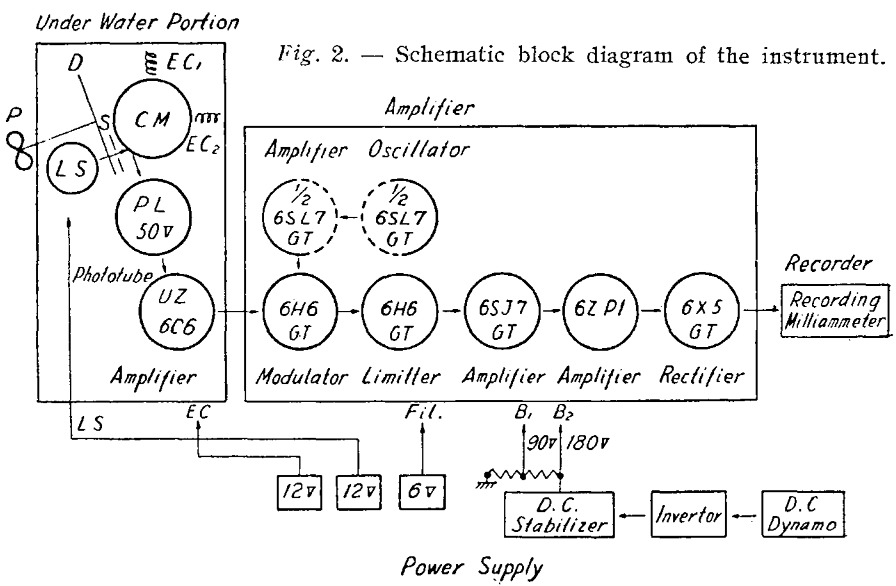
Now, since the current meter with the lamp and the slit is kept in the direction of current by its rudder, while the cylindrical mirror remains in a constant direction, the relative position of the slit to the mirror will be changed according to the direction of current. Consequently, the intensity of the light reflected by the mirror will be varied in accordance with the current direction, when the intensity of an incident light thrown into the case O_2 is kept constant. Hence the intermittent photoelectric current, with different intensities corresponding to the current direction, is produced by a phototube PT. In order to keep constant the intensity of the incident light, a variable resistance is inserted in the electric circuit, with which the voltage applying to the lamp is kept constant. However, if the extinction coefficient of water between the cases C_1 and C_2 varies during an observation the intensity of light upon the mirror will be changed, and it will cause an error in the observed values of the direction of current. In order to eliminate this error, two electric coils, EC_1 and EC_2, are set respectively in parallel and normal to the principal line of the instrument. By these coils, four kinds of electromagnetic fields, each differing by 90° in the direction, can be formed, when necessary. Therefore, the relation between the intensity of photoelectric current and the direction of water current can be readily recorded on the chart. Since the direction of the electromagnetic fields produced by the coils are either parallel or normal to the principal axis of the instrument, that is, the direction of the current, and a linear relationship exists between the photoelectric intensity and the direction of the cylindrical mirror (see Section 5), the direction of the water current can be determined, even when the intensity of incident light changes.

The photoelectric current is amplified by a vacuum-tube UZ-6C6 and then led to a micro-ammeter on deck by a cable. The speed of water current can be measured by reading the time intervals of intermittent photoelectric current, its direction being determined by measuring the electric current intensity.

Furthermore, automatic recording is also possible, by further amplifying the photoelectric current, for instance, by means of modulation. The amplifier and the recorder are included.

4. INSTRUMENTATION

Fig. 2. — Schematic block diagram of the instrument.



The schematic block and circuit diagram of the photoelectric measurement process are shown in Figs. 2 and 3. Each part of the instrument will be described in the following.

a) *Under-water portion.* This part is shown in Fig. 1. It is immersed into the water during observation. It sends the signal to the recorder on deck by way of a ten-fold rubber-covered cable 50 meters long. For detailed description, see the above section.

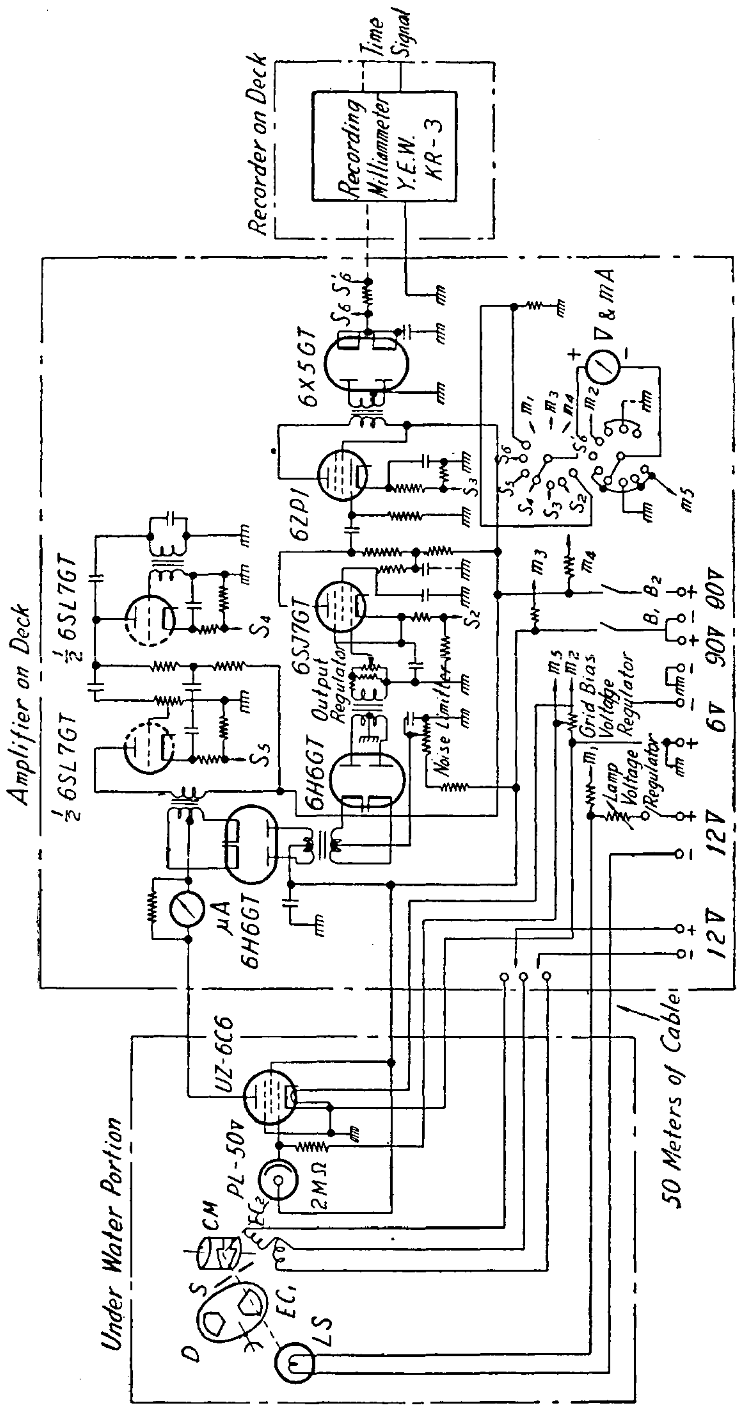


Fig. 3. — Schematic circuit diagram.

b) *Amplifier on deck.* This part is shown in Figs. 2 and 3. The upper part in Fig. 3 is an oscillator to generate a carrier wave. The direct photoelectric current is amplified by modulation method. The output current can be controlled by the grid bias voltage, noise limiter volume and output current regulator, all the voltages of the power supply being kept constant.

The characteristics of the instrument above mentioned are given in the following figures (Figs. 4 and 5). In Fig. 4, the relation between the grid bias voltage and the plate current of the vacuum-tube UZ-6C6 is presented. The relation between the plate current and the resultant recording current is shown in Fig. 5. These lines in the figure will be changed by the values of noise limiter volume and output current regulator. From the facts shown in Fig. 4 and 5, an adjustment of the instrument to obtain the linear relation between the photoelectric current and the recording current is found possible.

c. *Recorder and power supply.* Yokogawa's recording milliammeter, type KR-3, was used, in which the chart was rolled with a speed of 2 cm/min. At this rate of advance, a ten-meter chart roll will last 8 hours, and the batteries for the

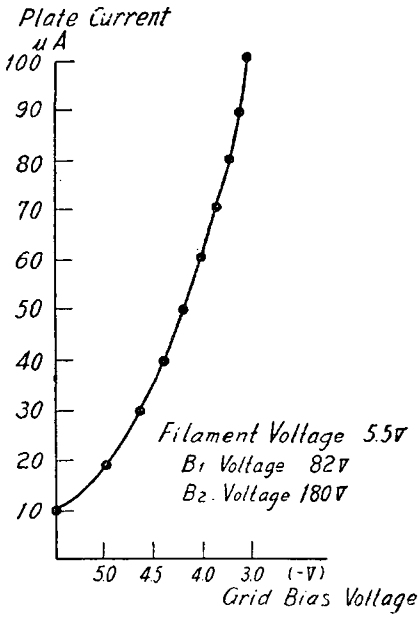


Fig. 4. — Relation between the plate current and the grid bias voltage.

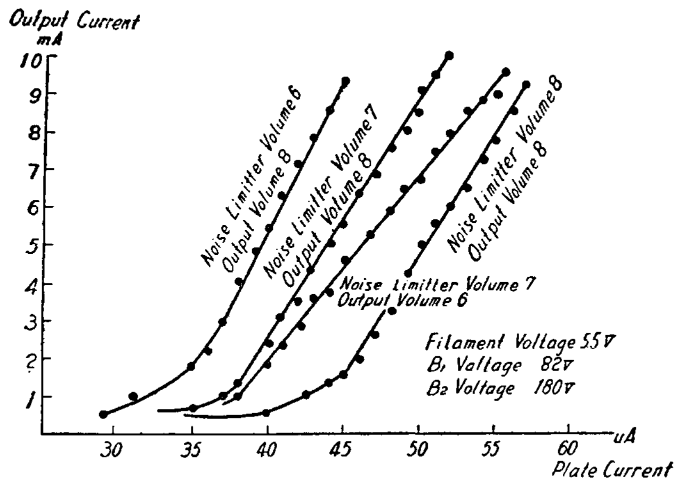


Fig. 5. — Relation between the output and the plate current.

electric lamp, the electric coils and the filaments of the vacuum-tubes will last more than 10 hours. Furthermore, the electric power required for the instrument is 90 volts and 180 volts direct current. Since direct current of 100 volts was available on board the ship, where the experiments were carried out, the direct current was first changed into alternating current by an invertor; then, it was changed into the direct current of 180 and 90 volts by a direct current stabilizer, the diagram of which is shown in Fig. 6.

5. THEORETICAL CONSIDERATION

Now let the current speed of water be v cm/sec. and the number of flashes of light be n times/sec., then we have

$$v = an^2 + bn + c,$$

where a, b and c are constants. Two holes are made in the disc, which turns once whenever water has run 20 meters. Therefore, the light path is opened once per 10 meter running of water. Assuming that it requires t seconds and l cm. of chart to record N times of the intermittent photoelectric current, we have,

$$n = N/t = N/30\ l,$$

then,

$$v = a\,(N/30\ l)^2 + b\,(N/30\ l) + c.$$

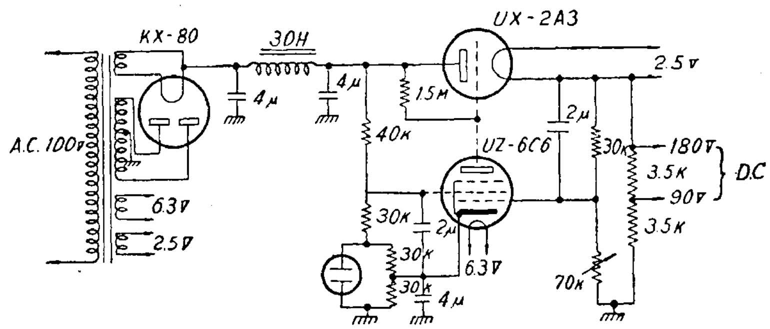
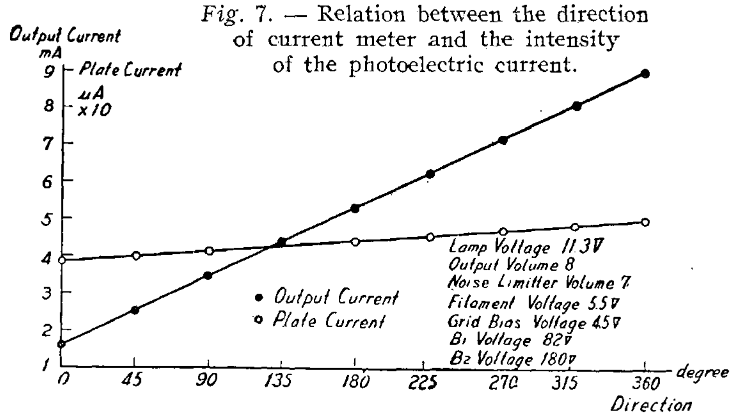


Fig. 6. — Schematic circuit diagram of D.C. stabilizer

Next, let the breadth of the slit S be B, and the vertical length of the mirror, CM, be $\alpha\theta + \beta$, $0° \leq \theta \leq 360°$ where both α and β are constants, and θ is the angle around the axis of the cylinder. The intensity of light reflected by the mirror is given by $I_0 e^{-kz\rho} \beta (\alpha + \beta)$ where I_0 is the intensity of the original light, k is the combined extinction coefficient of the glass windows and water, z is its optical length and ρ is the albedo of the mirror. So the photoelectric current i will be proportional to the angle θ that is $i = K\theta$, provided that the quantities above mentioned are kept constant. From Fig. 4 and 5, we can expect a linear relation between the recording electric current and direction of oceanic current. Such a relation in shown in Fig. 7.

Fig. 7. — Relation between the direction of current meter and the intensity of the photoelectric current.



6. EXPERIMENTAL RESULTS

The experiments were performed in Tokyo Bay on board the research ship *Asasiwo Maru*, on June 26th and September 17th, 1952. The hull of the ship is made of wood. The results are compared with those obtained by an Ekman-Merz current meter. Comparative measurements sometimes revealed angular disagreements as high as 82°; since the measurements were done in shallow waters of only three meters' depth, the instruments could be seen through the sea surface, The disagreements were recognized always to be due to the errors caused by the Ekman-Merz current meter although the sea was very calm.

The observation which was performed at Lat. 35°27.5' N. Long. 139°44.3' E. in Tokyo Bay on September 17th will be considered in the following. In the record which was obtained at the depth of 1.75 m., the current direction fluctuated with an amplitude of 40° and a period of 8 minutes, its main direction being S 30° W (210°) and speed 27.5 cm./sec. Though the speed calibration was not done, the values for the speed would almost be correct. The measurements were often interrupted by disturbances in the propeller caused by jelly fish. The minute fluctuation on the record, with the period of 2 or 3 seconds and the amplitude 2° and 3° (the maximum being 10°) might be caused by Kàrmàn vortex in the water.

In another record (*) in the same experimental run, the current direction

(*) Records are not reproduced here.

fluctuated with the amplitude of 30°, the period was from 3.5 min. to 5 min., its main direction was S 60° W (240°), and the speed 29.1 cm./sec.

A simultaneous observation with an Ekman-Merz and the new current meter was performed, the two instruments being set as near as possible to each other (Fig. 8). At 21 h. 58 min., according to the Ekman-Merz current meter, the direction of the current was 169°, the speed 31.7 cm./sec. while the record obtained by the new current meter showed that the current direction was 250°, the speed 30.0 cm./sec. Further, the old instrument measured a current of 178° in direction, and the speed 16.2 cm./sec, at 22 h. 38 min., while at 22 h. 39 min. a current of 260° and 14.4 cm./sec. was recorded by the present current meter.

Since the current meter under water could be seen from above the water surface, the direction of current in situ was clearly determined by visual observation from the situation of the meter. The current direction visually observed (SW or WSW) as shown in Fig. 8 agreed well with the record of the new instrument ; whereas the directions observed by the current meter of the Ekman-Merz type frequently showed disagreements with visual observation.

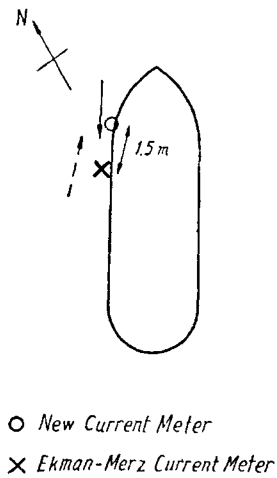


Fig. 8. — Position of the new and Ekman-Merz current meter in the comparative experiment.
The arrows show the direction of the current as observed by vision.
Heavy arrow : 1.75 m layer - Broken arrow : 3 m layer.
Records obtained at 1.75 m and 3 m. layer are not reproduced here.

Observation at a layer of 3 m. depth was commenced at 23 h. 15 min. The direction of current, as seen from the deck, was found, at first, equal with that at the 1.75 m. layer, that is, it was S or SW at about 23 h. 50 min. and turned to NE or E thereafter. At 00 h. 23 min., 18th, values of 58° and 13.6 cm./sec. were obtained by the Ekman-Merz, while, the record by the new instrument showed that the current was of 80° and 11.9 cm./sec. at 00 h. 20 min.

The fluctuation in the current direction, of the order of several minutes, which was observed in the upper layer, could not be detected in the record obtained at the layer 3 meters deep, although the measurements were performed successively. Therefore, it seems highly probable that the fluctuation in the pattern of current as recorded in the observation at the 1.75 m. layer really occurs, although it is also possible that the fluctuation arose from the turbulence which might be caused by the side of the ship, since the draft of the ship was 2 — 3 meters.

ACKNOWLEDGEMENT

The author wishes to express his hearty thanks to Dr. Y. Miyake and Dr. Y. Takenouti for their encouragement, to Mr. K. Kawamura for his kind advice, and to the members of the Oceanographical Division of the Central Meteorological Observatory for their help during the observations. His thanks are also due to the members of Turumi Seiki Co. and of Toho Denki Co., for the construction of the instrument.

This work was made possible by a grant in aid for research of test manufacture in 1951 from the Ministry of Transportation.

REFERENCE

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