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INSTRUCTIONS FOR TIDAL CURRENT SURVEYS

By

L. M. ZESKIND

Lieut. (j. g.) U. S. Coast and Geodetic Survey

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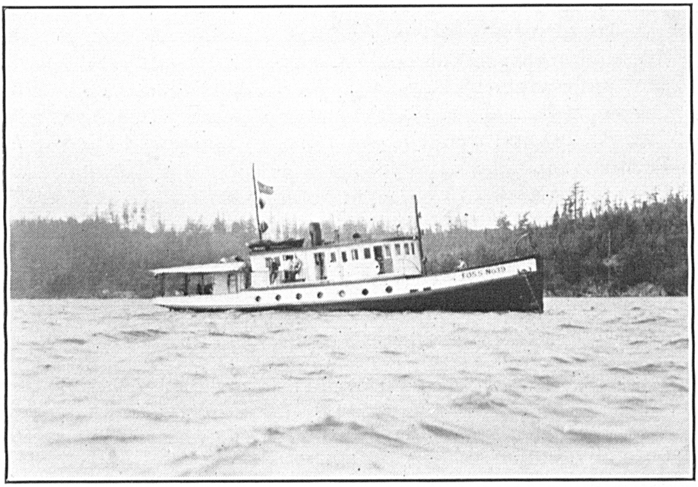
PREFACE

In the past the purpose of the tide and current work of the United States Coast and Geodetic Survey has been primarily to furnish data for the tide and current tables for the mariner. Recently the needs of the engineer have been given consideration, and comprehensive tide and current surveys of the important harbors of the country are now being made. The primary object of these surveys is to obtain information of value to shipping, to the engineer in harbor maintenance and improvement and sewage disposal, and in the study of current phenomena in general.

In executing current surveys in the past various methods and equipment have been tested and gradually developed, so that at the present time the procedure and practice followed in carrying on these surveys are becoming standardized. It is the purpose of this publication to furnish the field engineer of the survey the details of the methods employed and of the equipment used to serve as a guide and reference for future current surveys conducted by this bureau. It may also prove useful to other Government organizations and private interests which may find it necessary to engage in this type of work.

CONTENTS



FRONTISPIECE

INSTRUCTIONS FOR TIDAL CURRENT SURVEYS

By L. M. Zeskind, *Lieutenant (junior grade), United States Coast and Geodetic Survey*

Part I. INSTRUMENTS AND EQUIPMENT

INTRODUCTION

1. Data required.—The current data required in a tidal waterway are those which permit the determination of (*a*) the time, velocity, and direction of the current at selected points; (*b*) the relation of the times of strength and slack of current throughout the waterway; (*c*) the prediction in advance of the time of turning of the current and the time and velocity of current at strength throughout the waterway; (*d*) the local peculiarities of the current in the vicinity of wharves and at mouths of tributary streams; (*e*) the tidal flow on the ebb and on the flood through the various sections of the waterway.

GENERAL PLAN OF CURRENT SURVEY

2. Division of waterway.—In carrying out current surveys the following general plan is pursued: The territory to be covered is divided into such sections as found convenient. Predetermined locations are occupied as current stations in these sections where current data is necessary for the above. These stations are usually occupied for 25 hours or more, although in some cases a period of 13 hours is found to be sufficient in locations of lesser importance. In each section one or more stations serve as control stations which are occupied for the full period of time during which current observations are made in that particular section. In order to study the relation between currents near shore and those in the channel, it is necessary to make observations simultaneously at several stations on each of several selected cross sections of the waterway. These observations are usually for a period of 25 hours.

3. Control stations.—On completion of each section and before beginning observations in the next section, at least 25 hours of simultaneous observations are required at the control stations of the two sections in order to tie in the contiguous sections.

4. Scheme of survey.—The general plan followed is to start at one extremity of the waterway and work up or down. Obviously this scheme can not be carried out in every case, and it may be found necessary to deviate for different waterways. An illustration of the manner in which the scheme for a current survey is carried out may be had from the work undertaken in the Delaware waterway in 1924.

5. General plan followed in Delaware waterway.—Charts with the locations of thirty-seven places in the waterway where it was desired to obtain current data were issued by the office to the field party. The officer in charge of the survey, by consultation with the Army engineers, local port authorities, and mariners, and from a study of local conditions, recommended to the office of the survey certain changes in the locations of proposed stations and the addition of numerous secondary stations. These changes were authorized, and more than sixty stations had been observed on completion of the work.

6. For convenience in carrying out the work it was found feasible to divide the waterway into four sections. The locations of the sections and distribution of stations is shown in Figure 1.

Section 1, from the capes to Bombay Hook, contains stations numbered 1 to 9. For this section it was found feasible to employ station 10, outside the section, as the control station.

Section 2, from Bombay Hook to Edgemoor, Del., contains stations numbered 10 to 21, with station 10 as the control station.

Section 3, from Edgemoor to Fishers Point, contains stations numbered 22 to 37, with station 25 as the control station.

Section 4, from Fishers Point to Trenton, contains stations numbered 37 to 43, with station 37 as the control station.

All primary stations (numbered without suffixes) are for a period of 25 hours while secondary stations (numbered with suffixes, a, b, c,) are generally for a period of 13 hours.

7. Simultaneous observations were made on several cross sections throughout the bay and lower river where there is considerable width to the waterway, and therefore a likelihood of differences in current flow in various places on the cross section. In the upper part, where the Delaware River is narrow, it was obviously not necessary to have cross sections, and consequently single

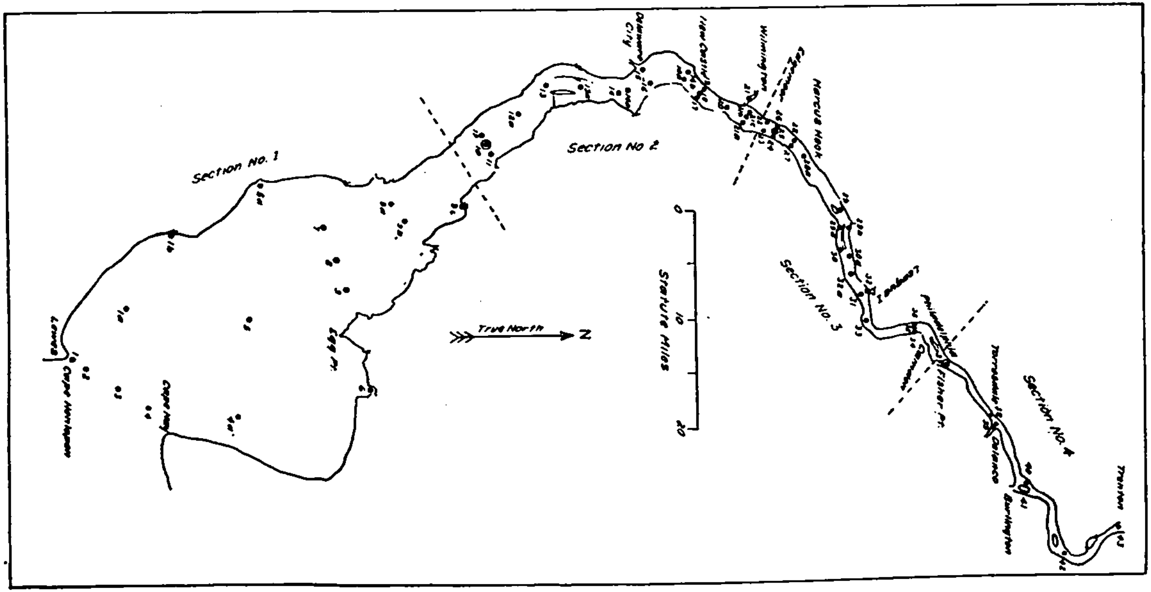


FIG. 1.—Distribution of current stations in Delaware Bay and River

stations were observed throughout. It will be noted that in addition to those in the main stream observations were made at the mouths of the various tributaries entering the waterway.

8. In this survey operations were begun in the upper section and carried downstream.

9. **General plan followed in New York Harbor.**—The general plan of survey outlined above was followed in New York Harbor in 1922. Since New York Harbor is composed of a number of intercommunicating tidal waterways, it was found convenient to treat each major waterway as a section, with control stations at each extremity, maintained during the period in which observations were made in the section. To link together the data for the entire harbor, simultaneous observations were made between the control stations of the contiguous sections.

FLOATING EQUIPMENT

10. **Selection of boats.**—The obtaining of current data requires the anchoring throughout the waterways of floating observation units. A tender which is used in the supervision of the various units and in the carrying of supplies is also required. The selection of floating equipment will depend upon availability of boats for hire and on the particular waterway in which the survey is to be made. Several factors must be considered before a final selection is made, among which are the strength of current likely to be encountered, liability to danger of collision, the protection afforded against weather conditions in the waterway, the ground tackle required, the sleeping accommodations necessary, and the clear deck space available for setting up gear. For harbor work the observing boats need have little power, but the tender should have a speed of 8 knots or more in order that the chief of party may keep in close touch with the operations, and that supplies may be distributed expeditiously to the various units.

11. It will sometimes be found that in the locality in which the survey is to be made no boats are available which fully meet the requirements or that the charter price of required launch is prohibitive. In such cases it is necessary to select that boat which is most suitable and economical.

12. In a waterway where the currents have considerable velocity and dense traffic brings in a factor of danger from collision it has been found necessary to employ flat-bottom barges or scows, which are towed from station to station by a tender, while in other water-

ways where the currents are moderate and the traffic light it will be found more economical to use a power launch 60 to 75 feet in length and capable of housing the complement of a unit. Again, in other waterways where the current is moderate, the harbor well protected against wind and weather, and danger of collision slight, it may be advisable to use smaller boats for surveying units, with one tender to house the observers. Generally, however, it will be found more satisfactory to have observers housed on the respective units to which they are attached.

INSTRUMENTAL EQUIPMENT

13. Arrangement of instrumental equipment.—In installing equipment on observation units all operating gear should be placed so as to reduce to a minimum lost motion in setting out gear after anchoring on station. Wherever possible gear should be under cover, so that it may be kept dry and at the same time so that the observations will not be interrupted in rainy weather.

CURRENT POLE

14. The current pole, which is used as a float in the determination of both velocity and direction of surface currents, consists of a pole about 3 inches in diameter, 15 feet in length, and weighted with sufficient lead at the lower end to float upright with about 1 foot out of water. In waters of considerable depth current poles 30 feet in length are used. Because of the varying density of the water in harbors it will be found that at times the pole will extend out of water more than 1 foot and will therefore offer a larger surface exposed to wind effect. To correct this enough sheet lead should be tacked on the bottom of the pole to cause not more than the specified 1 foot to project above the surface. It will therefore be advisable to have on hand several sheets of lead.

CURRENT LINE AND REEL

15. Marking of current line.—The line which is attached to the current pole and used in the measuring of the velocity of current consists of a log line three-sixteenth inch in diameter: This line is marked in principal divisions representing knots and secondary divisions for the tenths of knots. It is evident that the length of these divisions depends on the observation interval. As these intervals are usually in fractions or multiples of 60 seconds it is found convenient to mark the line for a 60-second run. Since a knot is a velocity of 6,080 feet in one hour or $\frac{6080}{60}=101.33$ feet in 60 seconds, if the line is to be marked for a 60-second run the distance between principal divisions should be 101.33 feet, and secondary divisions will be shown by lengths of 10.13 feet. If the current be weak, the log line may be let out for two minutes, and the velocity may then be obtained by dividing the number of divisions run out by two. If the current is strong, the line may be let out for 30 seconds and the number of divisions run out multiplied by two to get the velocity.

16. Formula for velocity of current.—The following general formula may be used in determining the velocity of current. If L=length of line in feet run out during an interval of T seconds, the velocity in knots is

$$v=\frac{L}{T}\times\frac{3600}{6080}=0.592\ \frac{L}{T}$$

17. Stray line.—Between the pole and the zero of log line there should be a length of approximately 100 feet of stray line, so that at the instant of marking time at the beginning of the observations the pole will be sufficiently astern to be beyond the effect of the disturbed waters in the wake of the vessel and it will also have attained the velocity of the current.

18. Current reel.—In order to facilitate the handling of the current log line, a wooden reel is used for paying it out.

PELORUS

19. Description and arrangement of pelorus.—The pelorus, which is used in obtaining the direction of the surface current when the observations are made with pole and line, consists of a brass disk about 8 inches in diameter graduated every 10°, from 0° to 360°, clockwise. It should be mounted in a position on the stern so as to allow the current line to swing through as large an unobstructed sector as possible. When the vessel from which the observations are being made is moored fore and aft, it will be necessary to mount a second pelorus forward. Peloruses should be fastened so that the 0° and 180° marks are on a line parallel to the keel of the ship, with the 0° forward. To establish uniformity in direction measurements, the current line should be stretched across the center of the pelorus and the inboard arc recorded.

PRICE METER GEAR

20. Price current meter.—In current surveys by this bureau in the past the Price (or Gurley) Current Meter[1] has been used for determining the velocity of the current. In adopting this meter for the work of the United States Coast and Geodetic Survey it was found necessary to use special equipment. Figure 2 illustrates the gear used and the method of installing.

21. Description and method of installing Price current meter gear.—In the harbor current surveys made by this bureau a plan has been followed which requires that observations be taken with the Gurley meter at several depths. It is therefore necessary that the meter be capable of being easily raised or lowered to the required depths. To accomplish this, it is found convenient to suspend the meter from a cable which is reeled on the drum of a hand-sounding machine. The cable is 0.133 inch in diameter and consists of three enameled wires, one of which is steel piano wire, 0.0335 inch in diameter, while the other two are copper wires, No. 20, B. and S. gauge. All wires are insulated from each other with a heavy braid covering all three. Considerable trouble has been experienced in the use of this cable due to wearing out of the braid and insulation by friction. For this reason it is planned for future use to cover this cable with a rust-resisting metal ribbon in the same manner as armored automobile wire. The function of this cable is not only to serve as a support for the meter but also, through the copper wires, as electrical conductors to form a circuit between the contact chamber of meter (*M*, fig. 3) and a set of earphones and dry cells, which are readily connected in circuit by a connecting plug at the inboard end of the cable. The end of the current cable passes through a hole drilled through the face of the sounding-machine drum to a connecting plug which is made fast in one of the holes in the web of the reel. The reel may be rotated to raise or lower the meter, and when it is desired to observe the batteries and earphones are plugged in, thus closing the electrical circuit.

22. Since in strong currents there is a tendency for the meter and current cable to tail out or depart from a vertical line, thereby vitiating the resulting velocities, it is found feasible to have the meter slide up and down on a second cable which is held vertically by a 200-pound globular iron weight attached to its extremity. The weight is raised or lowered by means of a small hand winch.

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[1] For detailed description of this meter see Manual of Gurley Hydraulic Instruments.

Obviously, when the weight is once lowered for any station the winch can be secured, since it need not be used to raise the weight until the observations at that station are completed. In order to hold the meter close to the steel cable, shackles should be attached at points indicated in Figure 2.

23. Method of suspending gear from boat.—To support the meter and weights a horizontal standard is rigged outboard in

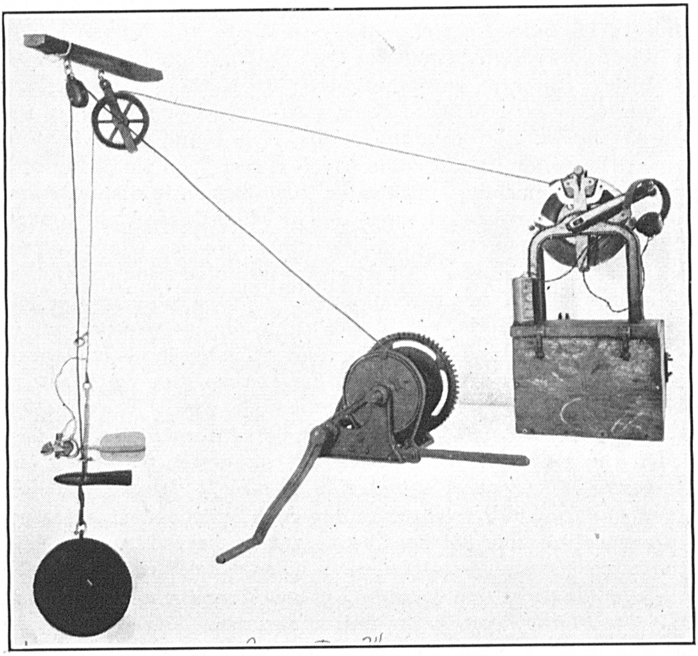

FIG. 2.—Method of installing Price current meter from standard of observing unit

most convenient manner, so that when the meter or the weight is raised or lowered they will at all times clear the side of boat. Attached to the standard by ringbolts and shackles is a sheave over which current cable passes, and also a snatch block over which the steel cable passes. Attached to the sheave is a registering dial, so that as the meter is lowered the depth will be shown on dial.

24. Electrical connections to Price meter.—Figure 3 gives a detailed view of Price current meter and the method of connecting it to the current cable. One copper terminal (D_1) is connected to plug in contact chamber while other terminal (D_2) is grounded on the frame of meter. The meter is supported from the current cable by means of a snap hook and a thimble.

CARE OF THE PRICE CURRENT METER

25. Contact point.—Difficulty has been experienced in using this meter in salt water due to the rapid corrosion of the contact point. To remedy this condition, the contact chamber is filled with medium cylinder oil which prevents the salt water from attacking the contact points. This does not appreciably affect the rating of the meter. It will be advisable, therefore, to always keep chamber filled with medium oil. Meters should be rated before and after current surveys.

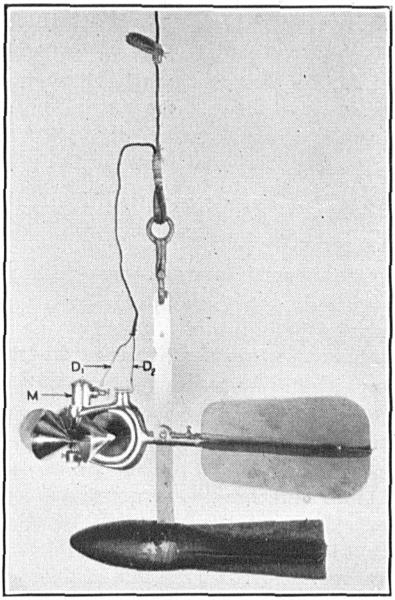

FIG. 3.—Detailed view of Price current meter

26. The following instructions on the care of the current meter are quoted from Manual of Gurley Hydraulic Engineering Instruments, pages 31–34:

"*To take the meter apart.*—When taking the meter apart, remove the tail vanes and the hanger stem; then loosen the set screw to the contact chamber and pull the chamber out by a slight twisting motion. Care must be taken to let the cups be free to turn, so that the worm gear on the upper end of the shaft can disengage from the teeth of the contact wheel. In handling the contact chamber it is well to take off the cap, so that the gear wheel can be seen during the operation. The pivot point can then be taken out and the cups released by loosening the upper part of the shaft with a spanner wrench. This wrench is so designed that it can be used for loosening all parts of the meter.

27. "In putting the meter together first attach the cups to the cup shaft. In doing this the upper part of the shaft should be inserted through the upper hole of the yoke before it is screwed to the lower part. Care must be taken to place the cups so that they will move counterclockwise. After the cups have been fastened to the shaft insert the pivot point and clamp it in place and then insert the contact chamber. In replacing the contact chamber the cups should be left free to move on the pivot point. Before inserting the frame nut the pivot point should be adjusted and firmly secured with the lock nut. The adjustment should allow a slight vertical motion of the cups."

28. To change contact chambers.—"(*a*) Loosen the set screw to the contact chamber in place; (*b*) carefully lift the contact chamber from the yoke; (*c*) carefully unscrew either the worm, or eccentric, from the shaft and screw in the other, which will be found in the small round tin box; (*d*) slide back in place the other chamber, which is in a block in one corner of the meter box, and tighten the set screw."

29. Special instructions.—Although the current meter is substantially made and will stand considerable hard usage, it needs careful handling and attention to insure its proper working. In this connection the following instructions (quoted from the manual) should be carefully observed:

"1. Be sure that the set screws are all tightened before putting the meter in the water, otherwise, some of the parts may be lost.

"2. Loosen the raising nut and see that the meter runs freely before beginning a measurement. Spin the meter cups occasionally during a measurement to see that they are running freely; that is, that they will continue to move for a considerable time at a slow velocity.

"3. See that the weights play freely on the stem, so as to take the direction of the current and thus avoid an unnecessary drag on the line.

"4. If any apparent inconsistency in the results of an observation throws doubt on its accuracy, investigate the cause at once. Grass may be wound around the cup shaft; the cups may be tilted by tension on the contact wire; the channel may be obstructed immediately above the meter; the meter may be in a hole; or the cup may be bent so as to come in contact with the yoke.

"5. After a measurement it is absolutely necessary to pour out any water that may have collected in the commutator box, to clean and oil the bearings (in order to prevent rust), and to inspect the pivot point.

"6. When the meter is not in use, the cups should never be permitted to ride on the pivot point. Lift off pivot point by means of knurled raising nut.

"7. Always see that the lock nut on the pivot point is screwed firmly against the frame nut, so that it will stay in place and carry the cups properly.

"8. Never use a dulled pivot. Always keep several extra pivots on hand.

"9. In measuring low velocities be sure that the meter is in a horizontal position. If it has a tendency to tip, the balance weight on the tail should be adjusted or the meter be held rigidly by inserting a plug in the slot against the stem.

"10. For velocities of less than 1 foot per second the pivot point should be the same as at the time of rating, sharp and smooth. As the velocity increases the condition of the point is less important, because the friction factor decreases.

"11. In taking measurements at high velocities sufficient weight and a stay line should be used to hold the meter in a vertical position.

"12. In very shallow streams the meter should be suspended from the lower hole on the stem, and the weight should be placed above.

"13. If the cups of the meter are bent, they may be easily put in shape by pressing them with a piece of wood or metal with a round, smooth end.

"14. The telephone receiver is very sensitive to electric currents and can be used to locate any break in the circuit. First try the telephone and battery together (figure 4 *a*) in a circuit having a make-and-break point, as at *a*. This may be done by using a knifeblade or a screw driver, making connection where the wires enter the plug. If there is no click in the telephone, then the battery or the telephone does not make a circuit. If there is a click, insert the meter in the line and test for a contact in the meter head (figure 4 *b*) by revolving the meter wheel. If the meter is all right, put the meter cord in the circuit and test both sides, either by inserting a fine needle that joins both conductors or by making double connection and touching alternate sides of the line *a* (figure 4 *c*).

"15. When the meter is not in use, disconnect the meter line from the battery, so that it will not become exhausted.

"16. Do not strike the telephone receiver, as a heavy jar will to a greater or less extent demagnetize the pole pieces, and to that extent will injure the receiver. If care is taken, it is very improbable that the telephone receiver will get out of order.

"17. Care must be taken not to short circuit the dry battery when the meter is not in use. To avoid this, the poles may be wound with adhesive tape."

BIFILAR SUSPENSION CURRENT INDICATOR

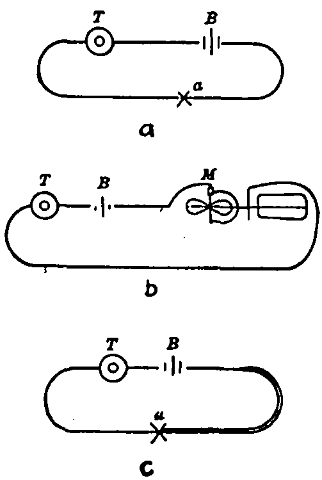

FIG. 4.—Testing Price meter circuit

For use in conjunction with the Gurley meter for observing velocity there has been developed by this bureau an instrument for obtaining direction of subsurface currents. This instrument, called the Bifilar current indicator, is shown in Figure 5.

30. Description.—Since it is required to obtain the direction of current simultaneously at three different depths, the Bifilar indicator is made up of three similar sections A, B, C, to each of which is attached horizontally by air craft wire a vane A^1, B^1, C^1, which can be lowered to the required depths by means of a reel L and crank K. The frame F F is made of light angle iron and is free to turn on a vertical shaft S by means of a ball-bearing joint. The vanes consist of 1½-inch pipe filled with lead to prevent lifting in a strong current. Attached to the end of the vane is a sheet-metal rudder which causes it to point in the direction of the current. As the vane is moved by the current, the motion is transmitted to frame F F, thereby causing a pointer I attached to the frame to move across the face of the pelorus P which is fixed to the shaft. By means of set screws the peloruses may be so fixed on the shaft that the 0 and 180° marks are on a line which is parallel to the keel of the boat. All 0° marks should be at the same end and directly under each other. The zero of the pelorus should be forward and 180° mark aft. In order to prevent the vanes from fouling each other, a cable with a 200-pound weight *M* attached to lower end is passed through holes drilled in the pipe of the vanes at the middle points.

31. Method of suspending.—The Bifilar current indicator is suspended from a wooden beam which extends outboard from the ship. In order to prevent strain on the gear when boat is rolling or pitching, the shaft is made fast to the beam by means of a universal joint *U*.

32. Depth indicator.—To measure the depth to which the vanes are to be set, pulley wheels *W* are attached to the frames over which the wire passes. These wheels are exactly 1 foot in circumference, and by means of a revolution counter *R* attached the vanes may be set at any required depth.

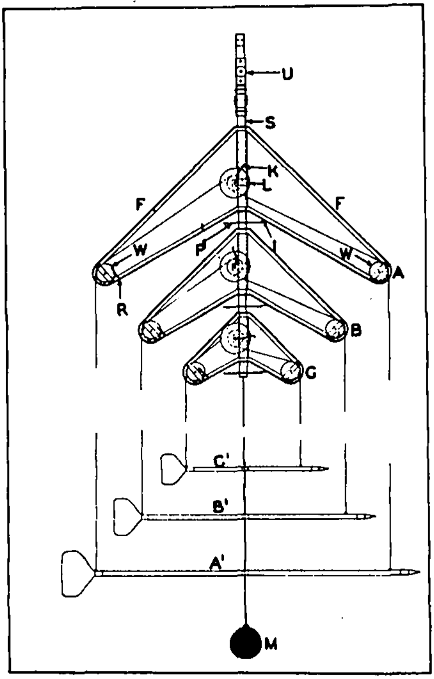

FIG. 5.—Bifilar suspension current direction indicator

PETTERSSON CURRENT METER

33. Advantages.—The instruments previously described require observers in each case. During the past year this bureau has tested with satisfactory results the self-recording Pettersson current meter. A few minor changes in the meter were made, correcting slight difficulties experienced. It is planned to make use of this meter more extensively in future surveys, since a self-recording meter of this type eliminates the necessity for employing a number of observers, representing a very considerable saving in the final

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cost of the current survey. In addition the self-recording meter quite likely furnishes a more accurate record, free from personal equations.

34. The use of the nonrecording current meters requires the anchoring of the vessel on station and employment of observers for the entire period of time for which current data are required. The holding of a vessel on station at times presents a difficult problem, due to the many factors involved—the depth of water, the kind of bottom, and the velocity of the current. In addition the pitching and rolling of the vessel may introduce considerable error into the observational data. The self-recording meter may be anchored on station from a buoy or float and for the purposes of this survey appears to be more satisfactory than the nonrecording type.

The following description of the Pettersson meter is taken from an article by Dr. Hans Pettersson appearing in the "Quarterly Journal of the Royal Meteorological Society," Vol. XLI, No. 173, January, 1915:

35. General description.—"In Figure 6 I have drawn a schematic vertical section through the current meter showing the more important parts of its construction. (The ratio between the horizontal and the vertical dimensions of the meter is exaggerated in the proportion of 2 to 1.) *C* is a cylinder of thick brass tested to withstand pressures equal to 800 fathoms of water. The internal dimensions of the cylinder are diameter = 10 cm.; height = 60 cm. When in use, the cylinder is kept hermetically closed by a lid which is pressed down by six strong screw nuts. The meter is suspended from a bronze ring *S*, attached to the lid by means of bronze ball bearings. Owing to this arrangement the meter is free to swing round almost without friction, two large and slightly diverging rudders of brass plate attached to the cylinder keeping parallel with the direction of the current.

36. "Below the cylinder there is an anemometer wheel *W*, which is set revolving even by very faint currents (down to about 4 cm. per second). After a considerable reduction in speed by means of a gear the rotation is transferred to the recording apparatus inside the cylinder. This is not effected by means of an axis or any other material transmission which would involve risk of leakage, but instead two parallel magnets are used, one rotating outside the bottom of the cylinder and the other one following it on the inside, M_1 and M_2. After a further reduction in speed the rotation is transmitted from the inner magnet to a vertical axis, which carries attached to its upper end a horizontal glass disk D_1. The disk has an opaque border with transparent numbers from 1 to 48 round its circumference.

37. "Once every thirtieth minute a flash of light is sent upwards through the edge of the disk from a small electric lamp L_1, which is fed with the current from two dry cells B_1 and B_2. The light then enters a tiny camera, where an image of the number on the disk which happens to be before the camera is photographed on a long film. The clockwork which moves the film also makes the contact which sends the electric current through the lamp at the moment of the exposure. By subtracting the number visible on one photograph from that on the next we find by how much the current has turned round the glass disk during the corresponding interval of 30 minutes. By means of an empirical table or a curve (which is practically rectilinear) the average velocity of the current referred to the same interval is then found in centimeters per second. With the present instruments a velocity of nearly 100 cm. per second is required in order to carry the velocity disk round by a complete turn between two exposures, so that the same number is visible on two succeeding photographs.

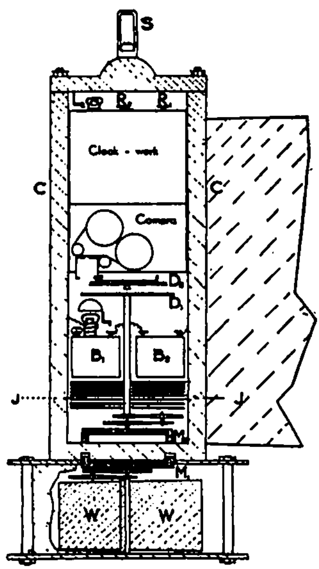

FIG. 6.—Section showing the principal parts of the Pettersson current meter

38. "Immediately above the velocity disk there is a similar disk D_2 of a slightly smaller diameter which carries two compass needles and has numbers round its edge for every 10° of arc. On each photograph there is therefore also a number from the second disk, giving the direction from which the current was flowing at the moment of the exposure.

39. "The clockwork will run for a fortnight, giving an uninterrupted record of nearly 700 observations of the velocity and the direction of the current. (Fig. 7.)

40. Details of construction.—"Among the details of construction the following may be mentioned. Across the orifice through which the light passes before entering the camera a fiber is stretched, an image of which is visible on each photograph dividing the field of vision in two.

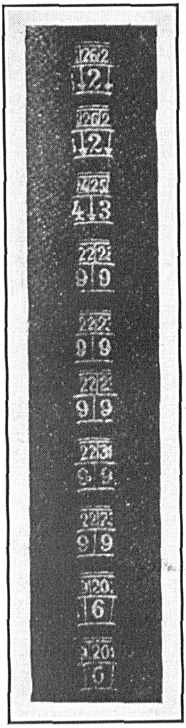

Fig. 7.—Film record of Pettersson meter

"Thanks to that arrangement it is possible to determine from the photographs the exact position of each disk at the moment of the exposure to within 0.1 of the distance between two of its numbers. This gives an accuracy of about 0.2 cm. per second to the recorded values of the velocity and of 1° to the direction.

"L_2 in the figure is an index lamp attached to the top of the case which holds the clockwork and the camera. It is set in series with the other lamp so that when it is seen to burn one may be certain that the lamp L_1 is also in working order.

"R_1 is a handle by which the clockwork is released or arrested. By turning round a second handle R_2 the moment for the occurrence of the next exposure may be advanced or retarded.

"Between the glass disks and the magnetic transmission are interposed a number of soft-iron disks (J, in figure 6) which protect the compass disk from the magnetic field generated by the transmission."

41. Detailed description.—The foregoing is a description of the meter from a schematic plan. A thorough knowledge of the various parts and of the construction of the meter is necessary to its proper operation. The Pettersson Meter is *composed of three parts*—*the outer brass casting* (C, figure 8) which contains in addition to the cylindrical water-tight compartment a turbine (W, figs. 6 and 8), connected by a gear train to a permanent magnet free to rotate, and two cylinders (O_1 and O_3, figure 8), which together contain the recording mechanism. The lower of these cylinders is shown in Figure 9. In this cylinder is contained the magnet M_2, which works in synchronism with the one attached to the turbine, the revolution and compass dials, and the batteries B_1 and B_2, and the electric lamp which produces the flash for exposing the readings on dials each half hour. These batteries are fitted in the cylinder on the two sides of the velocity shaft *Sh* so as to form a series circuit. To prevent the compass dial from slipping off its pivot, an adjustable pin *P* is screwed down barely to touch the top of the dial. The upper and lower cylinders when fitted together

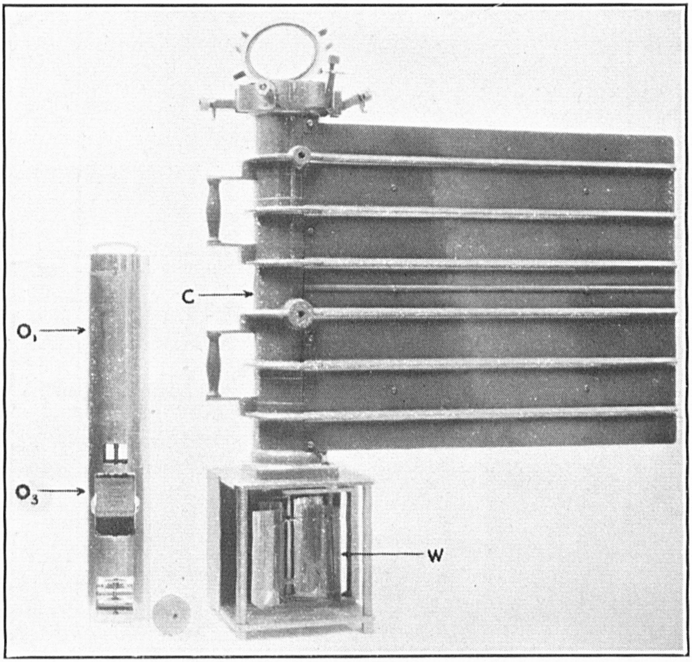

FIG. 8.—Exterior view of Pettersson meter

form a positive and light-tight joint. When so fitted, a shutter on a hinge joint is kept open by a finger *F* to permit the light from electric lamp in lower cylinder to enter camera in the upper cylinder. The two cylinders are connected electrically by a brass connector *E*, which fits into a socket in upper cylinder so that the flash of light may be controlled by clockwork in the upper cylinder. By this connection the index lamp or pilot light L_2 (fig. 12) is supplied with its energy.

42. Batteries.—In Figure 10 is shown a top view of the two battery boxes in position. Each box contains two single cells which are so arranged that the top of cell, or positive pole *T*, of one box is opposite the bottom of cell, or negative pole *B*, of

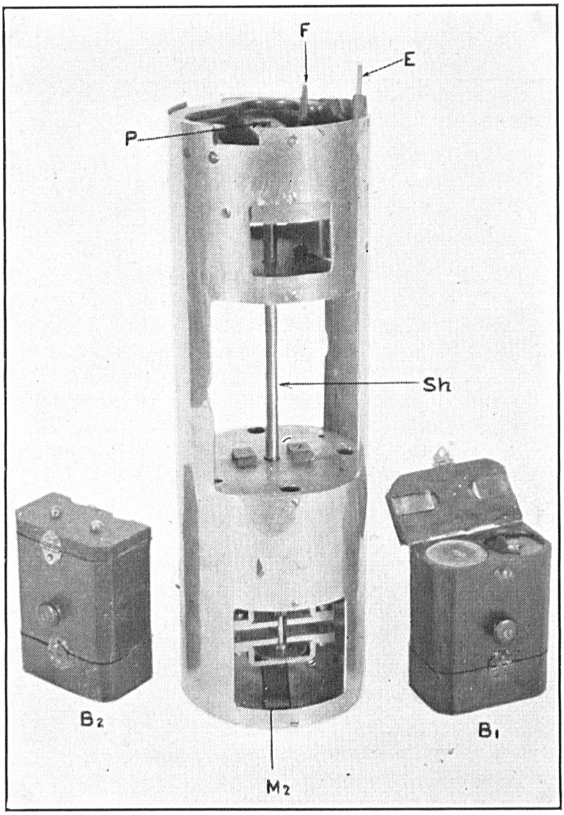

FIG. 9.—Lower cylinder of recording mechanism, Pettersson meter

the other box. All cells are therefore connected to form a series circuit.

43. Upper cylinder.—The upper cylinder of recording mechanism is shown in Figure 11. In order to protect the film the upper cylinder is inclosed tightly in a shell O_1, which is secured by means of a thumbscrew at the bottom. It is necessary to remove this shell only when taking out the film for developing or when putting in a new roll. By simply loosening the thumbscrew and twisting the handle H on top of cylinder so as to rotate it slightly the shell may be easily drawn off.

44. Clock mechanism.—The clock mechanism is inclosed in a second cylinder O_2 over which the shell fits snugly. The clockwork performs two functions. Through a set of gears G it rotates a reel R_t, which draws the film with a uniform motion across the camera C_m from a second or magazine reel R_m loaded with film at the rate of approximately 1 inch an hour; by means of a governor or inertia tripper an electrical contact is made at every half turn of a commutator, and hence a flash of light is sent up through the camera once every half hour. By removing four screws S_0 the top of the cylinder may be disengaged and the clockwork exposed. A movable arm attached to a hairspring may be so regulated that the flashes of light succeed each other by precisely 30-minute intervals. Clock may be wound by turning key in slot W.

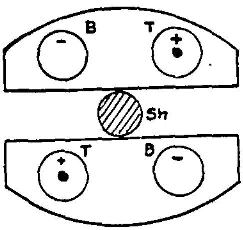

FIG. 10.—Battery boxes in position, Pettersson meter

In using the Pettersson meter it must be borne in mind that the mechanism is necessarily delicate because of the nature of the work it is designed to perform, and accordingly it should be handled with more than ordinary care.

CARE OF THE PETTERSSON CURRENT METER

45. Precautions.—Following is a list of instructions which should be observed in its use:

1. *Turbine.*—Make sure that movement of turbine on outside of cylinder (W, figs. 6 and 8) is not hindered by clogging due to grass, seaweed, or other obstructions. Turbine should revolve with faintest currents. Gear train should be perfectly clean and well oiled.

2. *Magnets.*—(*a*) Make sure that the magnet in lower case of recording mechanism (M_2, fig. 9) spins easily and without touching anywhere. (*b*) Make sure that the magnet on outside of cylinder (M_1, fig. 6) rotates freely and without touching anywhere.

3. *Batteries.*—(*a*) Make sure that batteries are strong by testing with bulb frequently. (*b*) Batteries should be connected in series. (See fig. 10.)

4. *Electrical connections.*—All electrical connections should be sharp and clean and following tests should be made. (*a*) Test for flash of light from lower lamp (L_1, fig. 6) by placing a conductor between the electrical connector (E, fig. 9) and the outside of the lower case. A bright flash of light should be seen through the edge of the revolution and compass dials. (*b*) Before putting film in meter test for flash of pilot light by placing two

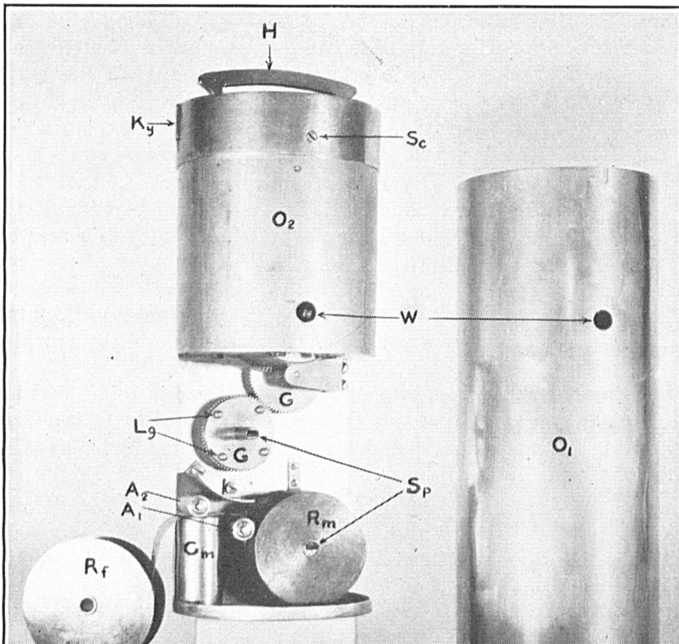

FIG. 11.—Interior view of upper cylinder, Pettersson meter

cases together and turning handle (R_2, fig. 12) through several complete revolutions. Two flashes of light should result for each revolution.

5. *Pivots.*—(*a*) Pin (P, fig. 9) over compass dial should be screwed down so as just barely to touch the dial.

6. *Film.*—(*a*) Care should be taken to see that film reel (R_f, fig. 11) is properly engaged to the lugs (Lg, fig. 11) on clockwork

mechanism. (*b*) Film should pass from underside of magazine reel (reel containing fresh film) over a roller (A_1, fig. 11), then across the camera (C_m, fig. 11), and under a second roller (A_2, fig. 11) to a slot in the film reel. In this manner the film will be flat in passing over camera. In order that the film should further be centered over camera, the reel retaining springs (*Sp*, fig. 11) at the ends of the shafts on which reels rotate should be so fixed that there is no transverse motion of reels.

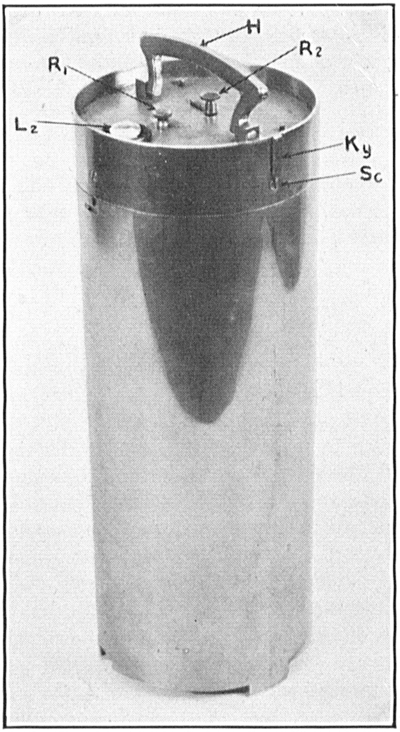

FIG. 12.—Exterior view of upper cylinder, Pettersson meter

7. *Gasket.*—Make sure that the gasket on outside lid of meter is in good condition, and that when lid is screwed down tightly that there can be no water entering the chamber which contains the recording apparatus. This is of extreme importance to the safety of the meter and record.

8. *Clockwork.*—Make sure that clockwork is so regulated that the flash of light for camera, as indicated by dial on top of cylinder, occurs at 30-minute intervals. This may be tested by letting clockwork run and timing several flashes. See that clock is fully wound by placing key in slot (*W*, fig. 11).

By observing the above precautions difficulties in the use of the meter will be largely avoided and delays usually incident to handling of new equipment reduced to a minimum. It will be advisable to give the meter a trial in the water for several hours to make sure that all mechanism is functioning properly.

92547—26——4

46. Removal of record.—After the record has been made at the station observed the lid of compartment is removed and the clock-work cylinder is taken to a dark room. Here the outer shell is removed, the film reel disengaged, and the exposed portion of film cut off and immediately put in developing tank. The end of the remaining section of the film is then inserted in the slot of the film reel, the shell put on, and the apparatus is again ready for use.

47. Film.—The film used is 16½ mm. Cine-Kodak film, and the time required for developing will depend on the kind and strength of developing solution used.

Part II.—METHODS AND PROCEDURE

In Part I detailed description was given of the instrumental equipment used in tidal current surveys. This section will be confined to the methods and procedure in conducting these surveys.

48. Methods employed.—There are three general methods employed by this bureau requiring the use of (1) the Price meter, pole, and bifilar current indicator; (2) the Pettersson meter; and (3) floats.

NONRECORDING METER

The first of the methods above enumerated requires the anchoring of a vessel or scow over the location in the waterway where the current data is required. The procedure in making a survey by this method is described below.

ORGANIZATION OF PARTY

49. In organizing a party for a current survey it will first be necessary to decide on the number of observation units it will be most economical to operate and the type of boat which will be most suitable for the work contemplated. Generally, however, the instructions issued to the chief of party from the office suggest the number of units that are to be used. Having chartered the floating equipment, it will next be necessary to purchase all supplies and equipment, organize the party, and install operating equipment on all units. Since continuous observations are required at all stations, it is of considerable importance that operations shall not be interrupted, and it is to this end that preparedness against emergencies should be made. It will be advisable as far as possible for each boat to be an independent observing unit, and it should therefore carry sufficient supplies and reserve equipment to meet any emergency likely to arise. A tender should visit units frequently to inspect work and carry necessary supplies.

50. Each observing unit is usually organized with six observers and one cook. Since observations are in progress day and night, it will be found convenient to have four-hour watches with two men on each watch, one of whom will be responsible for the watch. Of the six observers at least one should be a junior officer, who in addition to standing a regular observing watch will be responsible for the work of the entire unit.

LOCATION OF STATIONS

51. As mentioned in the first part of this publication, the field party is usually supplied with charts showing the exact locations of the stations at which the current information is desired. The boat should be anchored as near as possible to the given location. However, at times local conditions will be such that a deviation from this procedure will be found necessary. Oftentimes at stations located in channels where the traffic is heavy there is considerable danger of collision. Again, it may be found that the station planned is located in a place where the depth and bottom are such as to make anchoring impossible. In such cases the station observed should be as close as possible to the one indicated on the chart and which at the same time will be so located as to furnish the required data. It will sometimes be found that currents at given locations are not representative of the area in which they are located, and for this reason a shifting of position is highly desirable. For example, the given location may be in tide rips, swirls, or eddies, or where an unusual current exists, change of location therefore being advisable. It is at all times desirable where possible that the observing unit be anchored in the main thread of the current in the vicinity of the station, and if on anchoring it is found that data obtained are inconsistent or irregular, the boat should be moved to a better location.

52. Mooring of vessel.—It is also desirable that the boat or scow be moored in such a way that its position will at all times remain fixed and so that it will not swing on the flood and ebb. The importance of this is obvious for narrow channels or for waterways with rapidly varying cross sections, where a small variation in position may mean a considerable difference in the resulting data. Wherever possible, boats should be anchored fore and aft so that they will not swing with the tide. It will be found, however, that in many places conditions will be such as to make this procedure impractical, and in such cases boats should be moored with one anchor and with the least amount of chain that will keep the vessel or float from dragging anchor.

53. Determining position.—The location of each station is determined by the usual method of sextant angles between three or more charted objects or by tangents or compass bearings on three or more charted objects or tangents. Positions should be plotted and the angles or bearings entered in the record. A section of chart showing the location of each station should be pasted in the front of the record book.

54. Since it is desired to include as many slacks or strengths of current as possible at each station, if at the end of the required time for observing station it is found that the current is near the time of slack or strength it is advisable that observations be continued long enough to include the strength or slack.

DETERMINATION OF VELOCITY AND DIRECTION

55. Method of determining velocity.—The general scheme followed in obtaining current data by the nonrecording meter method is to determine velocity and direction data half hourly at three depths; that is, at 0.2, 0.5, and 0.8 of the depth in which the observation unit is moored, except that the maximum depth for lowest observation generally need not be greater than 80 feet. Observations near the surface should be below all noticeable wave motion and also below the keel of the boat or scow. It is obvious that this scheme can not be carried out for stations in shoal water, and in such places it is often sufficient to take observations at but two depths.

56. Immediately on anchoring on station the 200-pound weight attached to the steel cable is lowered until it is considerably below the lowest depth to be observed, and the winch secured. The cups of the meter are then lowered onto the pivot and the observations begun.

57. First the meter is lowered until it touches the surface of water and the current cable marked at a point where it leaves the drum of sounding machine. Then the depths to which the meter is to be lowered are measured off successively, by means of tape, and the cable marked. The meter can then be set at the required depth by stopping and clamping the reel of the sounding machine as the marks appear. Marks should frequently be checked by dial on registering sheave.

58. Procedure in determining velocity.—The procedure followed in making observations with the meter is as follows: Start with the one near the surface and follow by the mid-depth and near-the-bottom observations. Then reverse the order, but before the meter is raised repeat the lowest observation; then the mid-depth observation and finally the one near the surface. By this method a duplicate is obtained for each half-hourly set of observations with but little additional expenditure of time. In every case the exact time of the beginning of the observations at each depth is recorded to the nearest minute.

Whenever possible it is advantageous to make observations on the hour or half hour. If, therefore, the upper is made as much before the hour or half hour as the lowest observation is made after the hour or half hour, the mean will be exactly on the hour or half hour.

59. Correct time.—Correct time is of extreme importance in these observations, and arrangements should be made to check observers' watches or clocks frequently with a standard chronometer or timepiece which in turn is to be regularly compared with standard time. All discrepancies should be noted in the record book. In order to avoid all confusion, standard time should always be used and a statement to that effect entered in the record.

In connection with the use of the meter it is important always to keep contact chamber filled with medium cylinder oil, and when meter is not being used to lift it off the pivot point by means of knurled raising nut.

60. Method and procedure in determining direction.—Directions for the current at the three depths (0.2, 0.5, and 0.8 of the depth at station) are to be obtained simultaneously with the velocity observations by means of the Bifilar direction indicator. On arriving at each station vanes should be lowered to required depths. The vanes need not be disturbed again until station is completed. Observations are to be taken on Bifilar coincidently with those of meter and entered in record book. The heading of ship by ship's compass should be taken at the beginning of each half hourly set of observations. Care should be taken to see that the peloruses are always in perfect alignment, otherwise results obtained will be misleading.

61. Determination of velocity and direction with pole.—As a check on the results obtained by meter and Bifilar the current pole is used. As before described, the current pole gives only the velocity and direction of the surface current. Consequently, it usually serves as a check only on the 0.2 depth reading of meter. It is advisable, therefore, to make the pole observation at the time of the first meter reading. Should there be considerable discrepancy between the results of pole observations and the results of 0.2 depth reading of meter and Bifilar, investigation should be made to ascertain and correct the cause of this discrepancy.

62. When both observers are ready, the stray log line is paid out, and when the first knot passes a fixed point on taffrail both observers start stop watches, and while one counts clicks in the telephone receiver the other begins counting number of knots that pass out. At the end of 60 seconds time is marked again and the number of divisions, together with the estimated portion of last division run out, is entered in the record book. The line is then stretched across the center of the pelorus and the arc farthest away from the pole is read. This will be the forward semicircle of the pelorus, unless the pole is forward of abeam when the after semicircle is read. The heading of the boat by the compass at the same time is noted, which, with the pelorus reading, gives the direction of the current. Whenever possible, an angle is then taken between the pole and the reference object on shore, the exact location of which is shown on chart. When the pole is to the right of the reference object, the angle should be marked "R," and when to the left it should be recorded "L." In using fixed objects on shore for azimuth it is of advantage to choose those which are at some distance.

RECORDS

63. Data to be furnished.—Form 270 is used to record all data. In the front part of record all information called for should be completely filled in. Under "Description of current apparatus used," the following should be stated: (1) The kind of meter used and its number; (2) whether or not bifilar is used. If used, state the manner in which pelorus plates are set; (3) state how peloruses used in obtaining the direction of current by pole are set—whether 0° mark is forward or aft; (4) state how boat is anchored or moored—whether it is anchored with one anchor and therefore free to swing or whether it is anchored with two anchors or more and therefore held exactly on station; (5) any other information that will assist the office in correctly interpreting the results.

In the body of the record all headings and columns should be completely filled in and all data reduced. Below is shown a sample page of record book completely filled in.

All stations are to be numbered and the number inserted at the head of each page of record.

64. When the boat is anchored so that it is free to swing, positions should be taken at least once every two hours and recorded at top of page under "Position angles at station occupied." The time of taking the position should also be included.

65. Under "True bearings of reference objects" at top of page the reference object is some object on shore, the location of which is shown on chart and which is used as a reference point in obtaining the sextant angle to the pole. The true bearing of reference object is obtained from chart by laying parallel rulers on line between position of the boat and the position of reference object.

COAST AND GEODETIC SURVEY
Form 270

Current station No.: 13 Date: 8|15|24
General locality: Delaware River
Location of station: Mid-channel off So. End Artificial I Depth: 36 ft.
Latitude: 39° 27.3' Longitude: 75° 33.6'

Time 14.45
Position angles at station occupied: Reedy Is. Jetty Lt. 33 - 07; Liston Front Range; Reedy Is. Front Range 82 - 34
True bearings of reference objects: Reedy I. Front Range 235°
Time meridian: 75° W Tide gauge at

Time	Depth of Meter	Number of Revs.	Time in Seconds	Velocity by Meter		Velocity by Pole		Dir. of pole by Pelorus	Ship's head by Compass	Compass var.	Compass dev.	Dir. of current		Wind		Remarks	Observers
												From Angles	From Pelorus or Compass	Dir.	Vel.		
h. m.	ft.			Knots	Tenths	Knots	Tenths					True	Mag. True	Mag.	Miles		
13: 55	7.2	53	60	1	11			10	328	8° W	2° W		148			Meter repaired	
57	18.0	63	60	1	39			10	328		"		148			(break in circuit)	
59	28.8	52	60	1	15			10	328		"		148				
14: 00						1	5	5	328		"	142	143	calm		Reedy Is. Front Range to pole ∠ 93°	
02	28.8	53	60	1	17												
04	18.0	64	60	1	41												
06	7.2	61	60	1	35												J.M.N.
14: 25	7.2	86	60	1	88			10	332		2° W		152			large freighter passing	
27	18.0	80	60	1	74			15	332		"		157			close by.	
29	28.8	70	60	1	54			10	332		"		152	calm		weather: hazy	
31	28.8	67	60	1	48												
33	18.0	83	60	1	81												
35	7.2	84	60	1	84												W. F. M.
14: 54	7.2	106	60	2	33			0	341		2° E		155				
56	18.0	87	60	1	91			0	341		"		155				
58	28.8	76	60	1	66			345	341		"		140				
15: 00						2	4	5	340		"	160	159	5	2	Reedy Is. Front Range to pole ∠ 75°	
02	28.8	77	60	1	68											current running S.	
04	18.0	90	60	1	98												
06	7.2	102	60	2	23												W. F. M.

FIG. 13.—Sample page of current record book

66. Notes should be entered in the remarks column stating the estimated direction in which the current is setting, the condition of sea and weather, occurrences which may have some effect on results, or any other information which may be of assistance to the office in correctly interpreting the results. The remarks column for current observations is very important, for if correctly filled out it will assist in deciding questions arising in connection with a true interpretation of the data.

67. It will be found that each set of observations generally requires about 10 minutes. There will, therefore, generally be sufficient time between half-hourly observations for the reduction of records in the field. This will consist of filling in the columns: "Velocity by meter," "Compass variation," "Compass deviation," and "True direction of current, from angles and from pelorus."

68. Rating table.—Velocity of the current by means of the Price meter is measured by means of the number of revolutions the cups make in 60 seconds of time. To obtain the velocity of the current in knots corresponding to the revolution of the cups, a rating table is provided. This table is based on standardization tests made by the United States Bureau of Standards just prior to shipping the meter to the field. An example is shown on following page.

Enter left-hand column of rating table at the figure corresponding to the time in seconds of the interval of observations (usually 60 seconds) and follow line across until a column is reached, the heading of which is number of revolutions nearest the number of observed revolutions of cups. By interpolation between the value given in this column and that of the value in the preceding or following column, as the case may be, the exact velocity of the current in knots may be obtained.

69. Direction of current.—The compass variation may be taken from chart, while the compass deviation is taken from deviation table in front of record. The true direction of the current in degrees (the direction in which the current is setting) may be obtained from pelorus and compass by use of the following formula:

$$DC = P + SH + V + D - 180°$$

in which $D\ C$ = direction of current, P = direction of pole by pelorus, $S\ H$ = ships heading, V = magnetic variation, and D = compass deviation. Easterly variation or deviation is taken as positive and westerly variation or deviation is taken as negative.

70. From angles the true direction of current may be obtained by use of the following formula:

$$DC = TB + PA$$

in which TB = true bearing of reference object and PA = pole angle. A pole right angle is taken as positive and a pole left angle. is taken as negative.

The true direction as obtained separately by the above two methods should agree closely, and where a large discrepancy occurs the cause should be determined and rectified.

Rating Table for Current Meters.
Nos. 83, 84, 86, 96, 97, 99, 100, 1001,
Nos. 82, 85, 87, 88, 89, 90, 91, 98, 102, Rated February 11, 1925.

Time in Seconds	Velocity in Knots per Hour.													Time in Seconds
	5 Revs.	10 Revs.	20 Revs.	30 Revs.	40 Revs.	50 Revs.	60 Revs.	70 Revs.	80 Revs.	90 Revs.	100 Revs.	150 Revs.	200 Revs.	
40	0.20	0.36	0.67	0.99	1.33	1.66	1.98	2.31	2.64	2.98	3.30	4.96	6.60	40
41	.20	.36	.66	.97	1.30	1.63	1.94	2.26	2.59	2.92	3.23	4.86	6.47	41
42	.19	.35	.65	.95	1.28	1.59	1.90	2.22	2.53	2.86	3.17	4.76	6.34	42
43	.19	.34	.63	.93	1.25	1.56	1.86	2.18	2.48	2.80	3.10	4.66	6.20	43
44	.19	.33	.62	.91	1.22	1.53	1.82	2.13	2.43	2.74	3.04	4.56	6.07	44
45	.18	.33	.61	.90	1.20	1.50	1.78	2.08	2.38	2.68	2.97	4.46	5.94	45
46	.18	.32	.60	.88	1.17	1.46	1.75	2.04	2.32	2.62	2.90	4.37	5.81	46
47	.18	.31	.59	.86	1.14	1.43	1.71	2.00	2.27	2.56	2.84	4.27	5.68	47
48	.18	.30	.57	.84	1.11	1.40	1.67	1.95	2.22	2.50	2.77	4.17	5.54	48
49	.17	.30	.56	.82	1.09	1.36	1.63	1.90	2.16	2.44	2.71	4.07	5.41	49
50	.17	.29	.56	.80	1.06	1.33	1.59	1.86	2.11	2.38	2.64	3.97	5.28	50
51	.17	.29	.54	.79	1.04	1.31	1.56	1.83	2.07	2.34	2.60	3.90	5.19	51
52	.17	.28	.53	.77	1.03	1.28	1.54	1.80	2.04	2.30	2.55	3.84	5.10	52
53	.16	.28	.52	.76	1.01	1.26	1.51	1.76	2.00	2.26	2.50	3.77	5.01	53
54	.16	.27	.51	.75	0.99	1.24	1.49	1.73	1.96	2.22	2.46	3.70	4.92	54
55	.16	.27	.50	.74	.98	1.22	1.46	1.70	1.92	2.18	2.42	3.64	4.83	55
56	.16	.27	.50	.72	.96	1.19	1.43	1.67	1.89	2.14	2.37	3.57	4.74	56
57	.16	.26	.49	.71	.94	1.17	1.41	1.64	1.85	2.10	2.32	3.50	4.65	57
58	.15	.26	.48	.70	.92	1.15	1.38	1.60	1.81	2.06	2.28	3.43	4.56	58
59	.15	.25	.47	.68	.91	1.12	1.36	1.57	1.78	2.02	2.24	3.37	4.47	59
60	.15	.25	.46	.67	.89	1.10	1.33	1.54	1.74	1.98	2.19	3.30	4.38	60
61	.15	.25	.46	.66	.88	1.08	1.31	1.52	1.72	1.95	2.16	3.25	4.32	61
62	.15	.24	.45	.65	.86	1.07	1.29	1.50	1.69	1.92	2.13	3.21	4.26	62
63	.15	.24	.44	.64	.85	1.06	1.27	1.48	1.67	1.89	2.10	3.16	4.20	63
64	.15	.24	.44	.63	.84	1.04	1.25	1.46	1.65	1.86	2.07	3.12	4.14	64
65	.14	.24	.43	.62	.82	1.02	1.24	1.44	1.62	1.84	2.04	3.07	4.08	65
66	.14	.23	.42	.62	.81	1.01	1.22	1.41	1.60	1.81	2.01	3.02	4.02	66
67	.14	.23	.42	.61	.80	1.00	1.20	1.39	1.58	1.78	1.98	2.98	3.96	67
68	.14	.23	.41	.60	.79	0.98	1.18	1.37	1.56	1.75	1.96	2.93	3.90	68
69	.14	.22	.41	.59	.77	.96	1.16	1.35	1.53	1.72	1.92	2.89	3.84	69
70	.14	.22	.40	.58	.76	.95	1.14	1.33	1.51	1.69	1.89	2.84	3.78	70

FIG. 14.—Rating table for current meters

71. Compass deviation table.—An accurate deviation table is necessary to obtain the compass correction. This may be accomplished by the following methods.

72. Deviation obtained with vessel at anchor.—Where the boat is free to swing, deviations may be obtained by taking simultaneously the position of the boat and the compass bearing on some charted object on shore for numerous headings of the boat as it swings on change of current directions. By laying a parallel ruler between the position of the boat as plotted on the chart and the position of reference object, the true bearing of the reference object from boat is obtained. Subsituting values in the following formula, the deviation may be derived:

$$D = TB - CB - V$$

in which D=deviation, TB=true bearing, CB=compass bearing, and V=magnetic variation in the locality in which the swing is made.

73. In carrying out the above method of obtaining a deviation card it will be necessary to employ two observers, one of whom will take the two sextant angles for a position while the other will note the ship's heading by compass and take compass bearings to the reference object. Deviations for every 15° of arc will usually be sufficient. Accordingly, as the ship's heading reaches successive 15° marks on compass the observers will simultaneously take position of boat and the bearing of the reference object. This is to be continued until the swing is completed. Since in places where there are strong currents the boat will swing in a short period of time, it will be necessary for observers to make the observations more hurriedly than when ordinarily swinging ship.

74. **Plotting deviation results.**—Data having been obtained for each 15° of heading of the boat the deviations will be computed by the above formula. The resulting deviations for the various headings should be plotted with deviations as ordinates and ship's headings as abscissa and a curve drawn through these points. If observations have been correctly taken, a smooth curve should result, and if, therefore, it is found that the resulting curve is irregular in places, additional data should be obtained so that the final curve shall represent the true deviation of the compass.

75. The method described above, while not so accurate as a ship's swing by sun's azimuth or by ranges on shore, is sufficiently so for use in connection with the determination of direction of current. The advantage of using this method lies in the fact that the deviation table may be obtained simultaneously with current observations and therefore without any loss of time of the party.

76. **Obtaining deviation by swinging on ranges.**—Where boat is moored fore and aft it will obviously be impossible to use the above method. In this case the "range method" has been successfully employed in previous years. This method consists in selecting two objects on shore which are definitely located on the chart and which are so situated as to be clearly visible from the boat. To form a sensitive range, the front object should be as near as possible while the back object should be at a distance. The selected

range should be located at a place where it will be convenient to carry out the ship swing without being in the way of traffic. As in the preceding case deviations, should be obtained with the boat's head on every alternate 15° rhumb.

77. The procedure is to place the boat on the various headings and come up on range slowly. When the two objects on shore are in line, the boat is on range and a compass bearing is taken at this instant on the shore objects. This bearing, together with the true bearing of the range as obtained from the chart by parallel ruler, and the magnetic variation, when applied in the preceding formula will give the deviation for the various headings. As heretofore stated, the plotted deviation curve should be fairly smooth, and if considerable irregularity results further data should be obtained.

78. If at any time during the current observations there is reason to believe that the compass has been disturbed, another deviation table should be made out as soon as possible. At the end of the season a second ship's swing should be made.

79. Compass should be so installed on boat as to always be in a fixed position and therefore free of any movement.

RECORDING METER

METHOD OF ESTABLISHING STATION

80. **Suspending meter from vessel.**—The Pettersson current meter as heretofore described is an automatic self-recording current meter which is suspended either from a vessel or from a hydrographic station. In suspending from a vessel it will be necessary only to attach meter to the end of a rope or cable with sufficient weight to hold the meter in a vertical line. Since there is a compass needle in this meter, it will be necessary to have a weight so situated as not to produce a magnetic field which will interfere with the compass. For this reason it will be found convenient to use a 200-pound globular iron weight suspended at a distance of 3 feet or more from the top of meter.

81. **Suspending meter from hydrographic station.**—To use the Pettersson current meter to its best advantage it should be suspended from a hydrographic station. One such station reported to have been employed successfully in connection with Swedish current surveys is known as the Gustaf Ekman Submarine Hydrographic Station. This station is described in the Quarterly Journal of the Royal Meteorological Society, Volume XLI, No. 173, January, 1915.

For comprehensive current surveys the following general method, as shown in the figure below, is suggested:

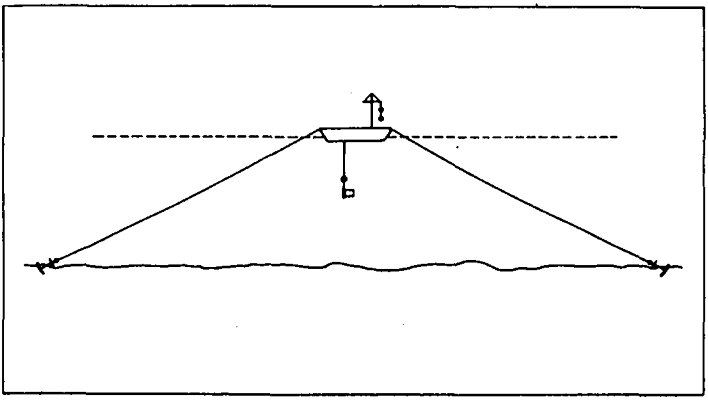

FIG. 15.—Method of establishing unwatched recording current meter station

82. Suggested method of suspending from scow or float.—Anchor a small scow or log float with two anchors, one upstream and the other downstream, so that the scow or float will not move with a change in direction of current. Suspend from the scow or float in such a way that it can be readily raised or lowered, the Pettersson meter with a 200-pound globular iron weight about 3 feet above the top of the meter. In order to avoid risk of having station destroyed by collision, day and night signals should be displayed on an upright so as to be clearly visible at a distance. Since the clockwork in the meter will run continuously for approximately 11 days, it should not be necessary to visit station any oftener than this period of time. Where the scow is used, on completion of observations, the gear can be hauled in and the scow towed to the next station. If a log float be used, it may be towed to next station if the distance be inconsiderable; when distances between stations are great, as in a general survey of large areas, it may be found more economical to remove anchor and meter gear, discard float, and build a new float at the next station. Comprehensive surveys are made usually in harbors where the stations are in close proximity, and it will therefore generally be feasible to tow barges or floats from one station to another.

PROCEDURE IN OBSERVING

Previous to beginning observations the tests suggested under instructions for use of meter should be carried out and meter should not be put in water unless it is working in every detail.

83. Preliminary operation.—To start observations, first put the lower case containing batteries, dials, etc., into the brass cylinder and rotate until hole in bottom of the case engages the pin located in the bottom of the cylinder. Press down case to make sure it rests snugly on the bottom of the chamber. Then lower the upper or clockwork case into the chamber and rotate until the key on the outside of the case and near the top, fits into the slot in the inside of the chamber, and press down until the case will go no farther. By this means a contact will be made—through the electrical connection extending up from the edge of the lower case—between the clockwork in the upper case and the battery and lamp circuit in the lower case.

84. Starting the recording mechanism.—Having properly placed the recording mechanism into the brass cylinder, next start the clockwork by turning handle R_1 (fig. 12) on top of case until it points to letter *R*. This will release clockwork, as indicated by the beginning of the ticking of the clock. Then slowly turn the handle R_2 (fig. 12) in a clockwise direction until a flash is made by the pilot light L_2. Record exact time of flash and with pencil make one mark on case opposite pointer arm and another mark diametrically opposite and near the circumference of the circle described by the pointer. Pointer arm is in continuous motion as long as the clockwork runs, and the pilot light will always flash as the pointer reaches one or the other of the diametrically opposite points.

85. Beginning observations.—Having noted the time of the first flash, immediately put the lid on top of cylinder and press down tight by means of the six screw nuts, so that the cylinder will be hermetically sealed. Then lower the meter to the proper depth and secure.

86. Ending observations.—At the close of the observations haul the meter out of water and immediately take off the lid. Allow the clockwork to continue running until a final flash is made by the pilot light. (The time of this flash can be predicted by noting the distance the pointer of the contact handle R_2 is from the nearest pencil mark.) The exact time of the flash should be recorded and the clockwork stopped by moving handle R_1 to point opposite letter *S*. The upper case containing film is then removed and taken to a dark room. Here the exposed portion of film, which is wound on upper or film roll, is cut off and immediately developed. The end of the remaining film is cut at the corners and inserted in the slot of the upper film roll. The film having been adjusted, the outer shell of the case is put on and the mechanism is ready for further observations.

87. Developing of film.—In order to insure satisfactory results with the Pettersson meter, a dark room should be installed on the boat which serves as the. tender. This room should be absolutely light-tight and equipped with a safe light. For developing, a standard developer should be used, together with a hypofixing solution. Film should be left in developer long enough to bring figures out clearly. This will generally require about three mintues. It should then be rinsed with water and put in hypobath until clear. After this wash with clean water for about 20 minutes.

REDUCTION OF RECORD

88. Time of record.—Having developed the film, the next procedure will be to reduce and tabulate the record. Figure 16 shows a sample page of the Pettersson current meter record.

As heretofore explained, there will be two sets of figures on the film for each half-hourly record, separated by a horizontal line. The first current record will be the bottom set of figures on the film. Consequently, in reducing the record it will always be necessary to start at the bottom of film. The upper figure of each record represents the reading of the velocity dial, while the lower figure represents the reading of the compass dial. The first step in the reduction of the record will be to count the number of half-hourly records on the film. Next, the elapsed time in hours and minutes between the time of first and last flashes should be computed. Since exposures of film may not follow each other by exactly 30 minute intervals, it will be necessary to divide the elapsed time between first and last flashes by the number of records, minus one, to get the true interval between records. The times of these records can then be tabulated by starting with the time of the first flash and adding progressively the time intervals to successive records. These times should be entered in column 2 of the record.

89. Direction of current.—The direction of current is obtained from the lower part of half-hourly record which is photographed on film from the compass dial. The arrangement of this dial is shown in Figure 17 below.

It will be noted that each quadrant has a distinctive marking and is divided into 9 parts with numbers 1 to 9. Each number, therefore, represents 10° of arc. For the northeast and northwest

Record of Current Observations
(Pettersson Meter)

Current Station No. 10	*Depth of Water at Station.* 24 feet
General Locality: S.E. Alaska, Wrangell Narr.	*Depth of Meter:* 12 feet
Location of Station: Rock Point	*Time Meridian:* 135° W
Latitude: 56° 40.3′	*Longitude:* 132° 58.3′
Position angles at station occupied: N. Green Rocks. Bn. / Rock Point / Finger Point Bn.	75° 45′ / 95° 17′

Date	Time of Record	Direction of meter from dial	Comp Var.	Direction of Current	Rev. dial reading	Dial diff.	Velocity of Current K.	Velocity of Current Tenths	Mean time of Intervals	Remarks
1925	h. m.	Degrees	Deg.	True. Deg.			K.	Tenths	h. m.	
8/19	5 36				1					
	6 06	290	31 E	141	25	24	0	86	5 51	
	6 36	290		141	46	21	0	76	6 21	
	7 06	290		141	8	10	0	36	6 51	
	7 37	290		141	9	1	0	04	7 22	
	8 07	140		351	33	24	0	86	7 52	
	8 37	130		341	10	25	0	90	8 22	
	9 07	135		346	39	29	1	04	8 52	
	9 37	150		01	21	30	1	08	9 22	
	10 08	135		346	4	31	1	12	9 53	
	10 38	140		351	36	32	1	15	10 23	
	11 08	140		351	18	30	1	08	10 53	
	11 38	120		331	47	29	1	04	11 23	
	12 08	140		351	24	25	0	90	11 53	
	12 39	140		351	44	20	0	72	12 24	
	13 09	135		346	10	14	0	50	12 54	
	13 39	130		341	13	3	0	11	13 24	
	14 09	160		11	20	7	0	25	13 54	
	14 39	140		351	36	16	0	58	14 24	
	15 10	280		131	8	20	0	72	14 55	
	15 40	285		136	31	23	0	83	15 25	
	16 10	285		136	10	27	0	97	15 55	
	16 40	285		136	40	30	1	08	16 25	
	17 10	285		136	23	31	1	12	16 55	
	17 41	285		136	3	28	1	01	17 26	
	18 11	285		136	28	25	0	90	17 56	
	18 41	290		141	48	20	0	72	18 26	
	19 11	290		141	10	10	0	36	18 56	
	19 41	275		126	11	1	0	04	19 26	
	20 12	125		336	32	21	0	76	19 57	
	20 42	135		346	14	30	1	08	20 27	
	21 12	140		351	5	39	1	40	20 57	
	21 42	140		351	43	38	1	37	21 27	
	22 12	125		336	33	38	1	37	21 57	

FIG. 16.—Sample page of Pettersson current meter record

quadrants numerals begin at the north and increase toward the east and west, while in the southeast and southwest quadrants numbers begin at the south and increase toward the east and west. By noting the number and distinctive quadrant mark the compass direction which the vanes of the meter assume due to the flow of water is obtained. This direction is entered in column 3 of record. By adding variation (column 4 of record) the true direction assumed by the vanes or the direction from which the current comes may be calculated. Since by direction of current is implied the direction toward which the current is setting, 180° must be added to the recorded direction to obtain the direction of set of the current. This should be recorded in a fifth column of reduction table.

90. Rating table, Pettersson meter.—In order to have at hand a table which will give the velocity of current corresponding to distance moved by dial in 30 minutes of time, it will be necessary to calibrate the instrument. The method of calibration consists of determining the number of revolutions made by outside turbine for a known velocity at which the meter is towed. As before explained the motion of the outside turbine is reduced considerably before being transmitted to the shaft which carries glass dial. This reduction is accomplished by two gear trains as shown in Figure 18.

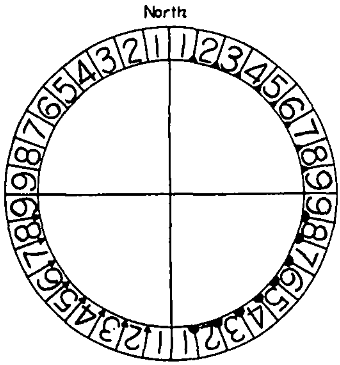

FIG. 17.—Arrangement of compass dial, Pettersson meter

91. Relation between turbine and dial velocities.—The numbers opposite the gears give the number of teeth in each gear, and the ratio of reduction is given opposite each set of gears. The total reduction is $10 \times 9 \times 5 \times 4 = 1,800$, and therefore for each 1,800 revolutions of outside turbine there is but one revolution of the velocity dial. Obviously, then, if the outside turbine is rotating at the rate of one revolution in one second it will make 1,800 revolutions in 30 minutes, while the velocity dial will have passed through but one complete revolution during this time.

92. Calibration of meter.—The calibration made by the Bureau of Standards gives the velocity of current in feet per second corresponding to a given number of revolutions per second of outside turbine. The calibration curve for Pettersson meter No. 93, based on tests made in March, 1925, is given by the following straight line equation, in which

V = water velocity in feet per second, and

N = the number of revolutions of outside turbine per second

For $N < 0.37$; $V = 2.725\ N + 0.072$

For $N > 0.37$; $V = 2.920\ N$

93. Since it is desirable to determine the velocity in knots corresponding to a difference in dial numbers for 30 minutes of time, it will be convenient to have a rating table which will give this information directly.

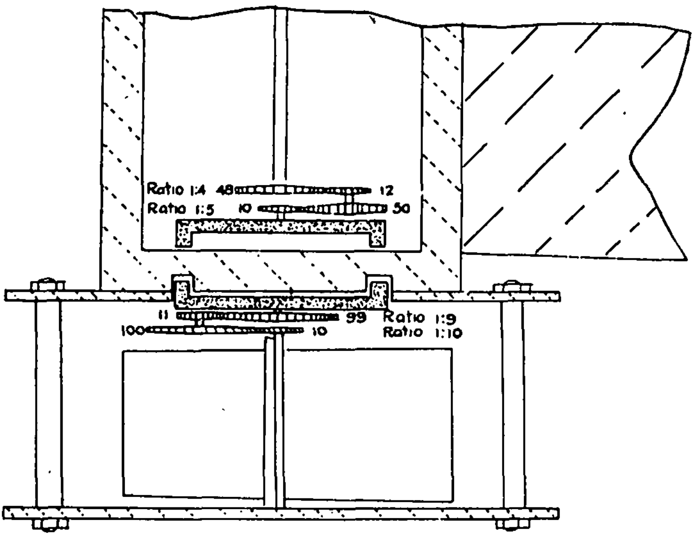

FIG. 18.—Arrangement of velocity reduction gears, Pettersson meter

94. It has been pointed out that, with the outside turbine moving at the rate of one revolution in one second of time, the dial will make one complete revolution in 30 minutes of time or the full 48 numbers in which the dial is divided will have passed a given point. It is evident, therefore, that for N in the above formula it will be necessary to divide by 48 the difference in dial readings for successive half-hourly records. To change velocity in feet per second to knots multiply by $\frac{3,600}{6,080}$. The above formula may therefore be rewritten as follows:

For $N^1 < 18$

$$V^1 = (2.725 \times \frac{N'}{48} + 0.072) \times \frac{3{,}600}{6{,}080}$$

For $N^1 > 18$

$$V^1 = 2.920 \frac{N'}{48} \times \frac{3{,}600}{6{,}080}$$

in which N' = dial numbers passed through in 30 minutes and V' = water velocity in knots.

95. It is therefore possible by the above formula to compute the velocity in knots corresponding to half-hourly dial differences. Below is shown a rating table based on the calibration referred to above which gives velocity to the nearest hundredth of a knot for dial differences from 1 to 210.

96. Use of rating table.—In the table following the velocities corresponding to successive dial differences of 10 are shown in the second vertical column, while the velocities corresponding to the intermediate unit differences are shown in vertical columns headed 1–9. For example, to obtain the velocity for a dial difference of 128 enter the first left-hand column at 120. Horizontally across in the column with heading 8 will be found the velocity; that is, 4.61 knots.

97. Velocity of current.—Having tabulated the time and direction of each record, it will next be convenient to tabulate in a sixth column (fig. 16) the corresponding reading of the velocity dial record. In a seventh column actual dial differences made during successive intervals are recorded. In this connection it will be remembered that the last number on dial is 48, and consequently if a later reading of dial is less than the preceding one multiples of 48 must be added to the later reading before subtracting the earlier reading in order to determine the actual distance the dial has moved in the 30-minute interval. This difference in dial readings is the means for obtaining the number of revolutions that have been made by the outside turbine in the approximately 30 minutes.

98. It will be observed from the rating table for the Pettersson meter that, corresponding to one rotation of dial in 30 minutes or a dial difference of 48, the velocity is given as 1.73 knots. In many places where it is desired to obtain current data velocities of 6 knots or more may be encountered. In registering a velocity of 6 knots approximately 170 dial numbers must pass a given point; or, expressed in another way, the dial must pass through almost four complete revolutions. Since according to the present arrangement there is no way of determining from film record the number of revolutions made by dial for a velocity greater than 1.73 knots, it will be necessary to interpret the record for these greater velocities. While for some places it will be somewhat difficult to interpret the record, generally it will be possible to obtain the

RATING TABLE.

Pettersson Meter Number 93, Rated March 12, 1926.

Velocity in knots corresponding to difference in Dial numbers: one-half hourly intervals.

Dial Difference	0	1	2	3	4	5	6	7	8	9
0	0	0.04	0.07	0.11	0.14	0.18	0.22	0.25	0.29	0.32
10	0.36	0.40	0.43	0.47	0.50	0.54	0.58	0.61	0.65	0.68
20	0.72	0.76	0.79	0.83	0.86	0.90	0.94	0.97	1.01	1.04
30	1.08	1.12	1.16	1.19	1.22	1.26	1.30	1.33	1.37	1.40
40	1.44	1.48	1.51	1.55	1.58,	1.62	1.66	1.69	1.73	1.76
50	1.80	1.84	1.87	1.91	1.94	1.98	2.02	2.05	2.09	2.12
60	2.16	2.20	2.23	2.27	2.30	2.34	2.38	2.41	2.45	2.48
70	2.52	2.56	2.59	2.63	2.66	2.70	2.74	2.77	2.81	2.84
80	2.88	2.92	2.95	2.99	3.02	3.06	3.10	3.13	3.17	3.20
90	3.24	3.28	3.31	3.35	3.38	3.42	3.46	3.49	3.53	3.56
100	3.60	3.64	3.67	3.71	3.74	3.78	3.82	3.85	3.89	3.92
110	3.96	4.00	4.03	4.07	4.10	4.14	4.18	4.21	4.25	4.28
120	4.32	4.36	4.39	4.43	4.46	4.50	4.55	4.57	4.61	4.64
130	4.68	4.72	4.75	4.79	4.82	4.86	4.90	4.93	4.97	5.00
140	5.04	5.08	5.11	5.15	5.18	5.22	5.26	5.29	5.33	5.36
150	5.40	5.44	5.47	5.51	5.54	5.58	5.62	5.65	5.69	5.72
160	5.76	5.80	5.83	5.87	5.90	5.94	5.98	6.01	6.05	6.08
170	6.12	6.16	6.19	6.23	6.26	6.30	6.34	6.37	6.41	6.44
180	6.48	6.52	6.55	6.59	6.62	6.66	6.70	6.73	6.77	6.80
190	6.84	6.88	6.91	6.95	6.98	7.02	7.06	7.09	7.13	7.16
200	7.20	7.24	7.27	7.31	7.34	7.38	7.42	7.45	7.49	7.52
210	7.56	7.60	7.63	7.67	7.70	7.74	7.78	7.81	7.85	7.88

FIG. 19.—Rating table, Pettersson current meter

true current data without error. The following suggestions will assist in the correct interpretation of the data as obtained from the film record.

99. The relation between the time and velocity of current generally takes the form of a cosine curve, where velocity is the ordinate and time the abscissa. The strength of the current is represented by the amplitude of the curve and slack water the point of zero velocity. The curve will alternately vary from slack, or period of no current, to strength, or period of strongest current.

100. In Figure 20 are representative current velocity curves for maximum strengths varying from 1 to 7 knots. These curves

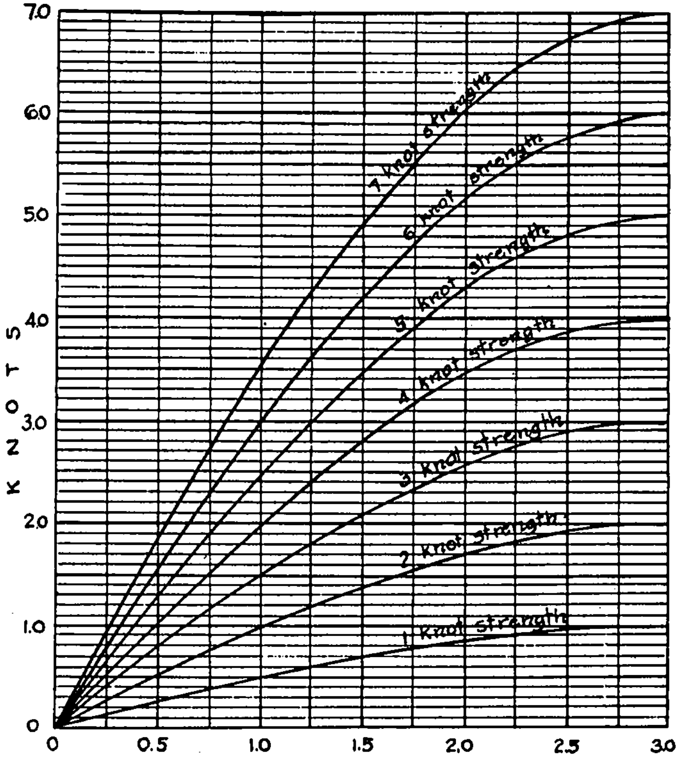

FIG. 20.—Representative current velocity curves

illustrate the velocity variations between slack and strength. Where there are two tides in a day, the time between a slack and following strength will be approximately three hours. The velocity curves as obtained from actual observations will closely resemble the curves shown, and these graphs are therefore of assistance in interpreting the velocity record of the Pettersson meter.

101. The approximate time from the record of the first slack current will assist greatly in correctly reducing the record. This data can be determined form the current direction record of film, for where the current direction changes abruptly, and reverses, a slack water has been passed through.

102. If we start reducing the velocity record from this point, the difference between dial readings for two successive records near slack water will give the mean velocity during this half hour. If we plot this velocity together with the slack, we have the beginning of the velocity curve. If again for the following half hour interval we get a dial difference equal to or less than the preceding one, we know that the dial must have made more than one revolution, and from a study of preceding graphs it is evident that for a current of a maximum strength up to 7 knots the dial would not make more than two revolutions during second half hour, and hence 48 should be added to recorded dial difference to get the actual dial difference, and the velocity will be that in the table corresponding to this difference.

103. For example, suppose that for the first half hour the dial difference is 25. The corresponding velocity obtained from table will be 0.90 knot. For the second half hour suppose that the dial difference is 16. The corresponding velocity according to table is 0.58, which represents a decrease in current when it should have been increasing. We are therefore led to the conclusion that the dial must have made a complete revolution in the half hour, and therefore the actual dial difference should probably have been 48 + 16 or 64, with a corresponding velocity of 2.30 knots. If we plot these two points together with the slack on cross section paper, there will result a portion of a cosine curve of amplitude corresponding to a maximum velocity of 6 knots. The remaining half-hourly velocities should, therefore, fall on such a curve, and it will therefore be an easy matter to determine the correct dial differences and therefore the correct velocity for the various records on film.

104. Having completely filled in the actual dial differences in the seventh column of reduction table, the corresponding velocities as determined from the rating table should be entered in an eighth column. Since the difference in dial numbers gives a measure of the rotation during the half hour, the velocity obtained will be an average velocity, and the corresponding time will therefore be the mean time of the dial readings.

In a ninth column the mean time of interval should be entered opposite the corresponding velocity.

FLOATS

105. In places where the current is swift and the channel very narrow it has been found to be impracticable to take current observations by any of the methods described. In places such as these detailed current data are often of very considerable importance, and it will therefore be of advantage to describe a method successfully employed by Coast Survey parties in the past.

This is known as the "float method" and consists of measuring the time required for a wooden float to pass between two sets of ranges on shore, the distance between which has been previously determined.

106. Description and methods.—Two types of floats have been used, depending upon whether they are thrown into the stream from an auxiliary boat or from shore. In the first case the floats are made of 2 by 2-inch lumber, consisting of two horizontal crosspieces about 3 feet in length with an upright about 4 feet long in the middle, all nailed together. Where the float passes the range at a distance from the observers on shore it may be found necessary to put white or black cloth flags on the floats. These flags should be small, so that wind will not affect speed of float. In narrow passages where the current is of such velocity that floats can not be set out from a boat it will be necessary to cast them from the shore, and in this case small 2 by 2-inch strips about 18 inches long and wrapped in cloth can be used advantageously.

107. Observing at night with floats.—In most places it will be found impracticable to make float observations at night. In narrow passages, however, where the floats are cast from shore, night observations may be made by following the float in the current with the aid of focusing flashlights and automobile spotlights.

108. Determination of direction.—It will be noted that the above method is for determining the velocity of the current. Since this method is used in narrow channels, the direction can be closely approximated by observing the general path of the floats.

LIST OF REQUIRED INSTRUMENTS AND EQUIPMENT

109. In connection with current surveys various instruments and special equipment are required. Below is furnished a standard list of the more important of these instruments and equipment which will be required in a comprehensive current survey employing as many as four observing units. Sufficient spare items have been included to take care of normal replacement. If a lesser number of units are to be used, the number of instruments can be reduced proportionately.

110. To obtain the current data by means of the Price meter, pole, and Bifilar method the following will be necessary:

10 meters, Price current.
1 package parts, spare for current meters.
10 weights, large, for current meters.
5 weights, small, for current meters.
1,500 feet cable, current, 3 strand double braid.
500 feet cable, current, armored.
8 peloruses.
4 reels, current.
8 lines, current log.
8 poles, current, 15-foot.
4 sheaves, registering.
4 winches, small hand.
4 machines, hand sounding.
8 watches, mean time.
12 watches, stop.
6 clocks, hydrographic.
4 indicators, Bifilar current direction.

111. While anchored for current observations, this bureau has found it possible, without additional expenditure of time or money, to obtain temperature and density of sea-water data. For this purpose the following instruments are required:

6 cups, water specimen.
6 cups, hydrometer.
5 frames, reversing.
6 hydrometers, density 1.000–1.011.
6 hydrometers, density 1.011–1.021.
6 hydrometers, density 1.021–1.031.
4 thermometers, deep sea.
4 thermometers, for hydrometers.

112. Since tidal currents are a result of the tide, data in regard to tidal currents are very often referred to the tide. For this reason it will often be necessary to obtain tidal data simultaneously with current data, and the following instruments will be required:

1 level, Wye, with tripod.
1 rod, levelling.
2 gauges, tide, portable automatic.
4 staffs, tide.
Marks, tidal bench.

113. In addition to the above the following miscellaneous items will be required in the work:

4 compasses, boat.
3 dividers, hairspring.
3 dividers, pocket.
4 lines, lead.
1 pen, drop bow.
4 protractors, Courts.
4 rulers, parallel.
2 scales, metric; 1–1 meter, 1–¼ meter.
6 sextants, hydrographic, with spare mirrors.
1 set stamps, steel.
4 tapes, steel.
2 triangles, 60°–10 inch.
2 triangles, 45°–10 inch.
2 typewriters, portable.
1 barometer.

114. In the use of the Pettersson meter for obtaining current data the following instruments and equipment will be required. The quantities will depend upon the particular survey contemplated

Pettersson meters.
Safelight, Red series II.
Sidelight, Series III, for above.
10-watt bulbs for above.
Developing powders.
Acid fixing powders, kodak.
Kodak developing boxes No. 1.

115. Besides the articles above listed various miscellaneous supplies and equipment will be required, such as hardware for installing gear, ship chandlery supplies for equipping boats, equipment for feeding and housing party, etc. The kind and amount of this equipment will vary for different parties and it will therefore be necessary for the chief of party to decide on these items.

INDEX

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