ON THE INSTRUMENTAL MEASUREMENT OF LINE SHAPE UNDER WATER *

Concerning the Determination of the Vertical Distribution of Slope (Magnitude and Direction) down Oceanographic Wires, and the measurement of the Current-Caused Obliquity of a Rope strained between and Anchor and a Sub-surface Buoy.

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ABSTRACT

After a short review of the problems arising from wire-angle, and a consideration of some views expressed and results obtained by earlier writers, a description is given of two devices designed to measure the shape of terminally-weighted wires let down into the sea with water-bottles attached. Both devices can be used intermediately between water bottles and, whilst customarily operated by messengers, they can function via the solution of restraining tablets. One of them contains a compass which serves to reveal the directions of those curvatures in a loaded suspension wire which can be produced when deep currents cause a pronounced leading-away of a wire whose departure angle is kept negligible by manoeuvring the ship. Particular usefulness is seen for the devices when bottle lowerings have to be made well below the depth limit of unprotected reversing thermometers. This latter is usually about 5,500 metres but very exceptionally 7,000 metres.

Finally a description is given of a very simple device which records the slant of a rope buoyed from an anchor. The purpose in this case is to learn the heights above bottom at which an affixed current-meter has worked.

DISCUSSIONS OF THE PROBLEMS

Any considerable review of the existing literature which deals with the important subject of « Wire Angle of Oceanography », the title of Mosby's monograph which appeared two years ago (1952) would have to take account of a goodly series of papers dating back from the latest by Watson (1953) wherein he assails Mosby's work in some particulars, at least to the times when Ruppin first propounded the idea of thermometric sounding in 1906. Between those times would come quite a number of contributions by various authors to which we here need to make no more than passing reference without even listing them in full, since instrumental approach to the problem is thought to be novel. There seems to be

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* With an Appendix supplied later by Mr. A. J. Lee on page 200.

good grounds for assuming it to be so because no voice was raised to other effect when the first rough version of a submarine wire-angle gauge was demonstrated before a full gathering of the Hydrographical Committee of the International Council for the Exploration of the Sea a year ago. In so far as our present interest is concerned, oceanographical vessels fall into two categories: those which can manœuvre to keep the entry angle of their wire sensibly vertical, and those which cannot. With the latter type the oceanographer has to accept departure wire angle up to the limit to which he can work.

It may be recalled that aboard the « Carnegie » during her famed seventh cruise, large wire angles were experienced under adverse conditions of wind and current. The working limit was initially 45 degrees of slope because there was uncertainty of the messengers running down the wire at greater angles. By drilling the messengers and plugging them with lead, their weight was increased from 7 to 13 oz. and somewhat flatter wire courses could then be worked. It might be thought that a 50° slope would be considered a working limit, but correction tables do exist ranging up to 60°. In them experiences are implicit of 100 m. of wire sufficing to reach only half that depth, and of 3,000 m. of wire being necessary to attain the depth of 2,050 m.

During the « Snellius » Expedition (1929-1930) the ship was always manœuvered to keep the entry angle virtually zero, and yet, at a station south of Mindanao, repeated checks with unprotected thermometers attested that 800 and 1,200 m. of wire sufficed only to reach the depths of 544 and 814 m. respectively. These details imply an overall slope of 40°. At the time, bearings taken on islands showed that the ship was drifting fast. A still greater disparity between wire length veered and depth attained characterised the bottle lowerings made at Station 1766 occupied by R.R.S. « Discovery II » on 8th May 1936. She was then working off the coast of South Africa about midway between Durban and East London at a place where the echo depth was 2,538 m. The wind was from SSW and of force Bft. 3. A thermometer-checked depth of 950 metres had required the paying-out of 2,000 m. of wire.

Wüst in his classic paper on thermometric sounding published in the celebrated « Meteor » reports, tells us that in 66 % of all cases the wire angles encountered on « Meteor » stations were less than 15° with wire lengths not more than 1 % in excess of the depths actually reached. Averagely, the 33 % of cases characterised by wire angles greater than 15°, involved wire lengths not exceeding real depth by more than 1.5 %. The greatest difference between wire length and depth actually attained (as reported by Wüst) was 258 m. This was for an occasion of big angle and of wire length amounting to 6,000 m. It is interesting to recall Wüst's statement that the error made when estimating true depths is no nearly as considerable as one might expect from the angle of departure of the wire; that, in other words, the wire, inclined at the surface, follows a much more nearly vertical path as it goes deeper. E.C. Lafond in his valuable work « Processing Oceanographic Data » presents the data sheet for a station on which 1,090 m. depth was reached with 1,200 m. of wire out.

By kind permission of the United States Hydrographer, Captain J.B. Cochran U.S.N., the writer is allowed to refer to his participation in a cruise aboard the oceanographic survey vessel U.S.S. « Rehoboth ». It was largely as the result of new experience gained on that cruise that the device to be described below came to be made. On one station thirteen Nansen bottles were secured on the cable between outwindings of 500 and 3,200 m. The departure wire angle was 48° and the depth attained by the lowest bottle was later found by thermometer to have been 632 m. in defect of wire length. On the same station with the same thirteen bottles distributed on an outwinding of only 500 m. of wire, the latter entered the water at 30° slant and was later found to have reached a depth 65 m. in defect of its own length.

It chanced that during the cruise in question, opportunity presented itself to pay considerable attention to a seapeak rising from a large extent of flattish ocean bottom. An aim was to find whether there existed a lift of bottom water up the (presumed) weather slope of the seapeak, and there was consequently a compelling need to raise water samples and bring up temperature information from just (and only just) above the peak. Since the ship drifted so quickly over a feature of such small area and had to steam back to windward and locate it again by echo sounding from time to time, it was quite impracticable to make successive lowerings reaching progressively deeper each time until, having started with « safe depths », one could eventually put a bottle down almost to touch the peak. Such step-by-step progress downwards is possible enough where there is a large extent of virtually flat sea-bottom because, given an adequate supply of unprotected reversing thermometers, it can always be learnt how far down the lowest bottle has been.

Suppose that the seapeak carries 1,300 m. of water and that the ship is just in position above it with 1,000 m. of wire veered carrying 10 water bottles affixed at equal intervals along its lower 500 m., and suppose further that the wire angle is 45°. The problem is of course to know what extra length of wire can be quickly unwound to ensure that the lowest bottle samples at a level negligibly-little above the surface of the sea peak and yet runs no risk of being pulled off the wire. In such a case it is not enough (as it very often is) to learn the depth bottles have been down to; what matters is being able to send the lowest bottle down quickly and safely to a desired depth during the brief time that a ship can remain above a small-area feature which it may have been something of a problem to locate. It is no sufficient answer to use a propeller-operated bottle of the usual type which is deliberately allowed to lie on the ocean floor with the knowledge that it will not enclose a water sample until after having been raised some seven metres or so of the bottom. Such a bottle would not meet the need because, when drifting over a seapeak, it would be just as liable to be torn off the wire as would the usual type of messenger-operated bottle unless the precise depth of descent could be controlled, and in that case of course there would be no preference for the propeller variety. One could not count upon the great good fortune which attended Defant when his lowest bottle dragged along the bottom on the Altair Kuppe and brought up that precious sample of coral which was later treated so reverently as it made its tour between expert and expert.

There seems to be only one practical way of becoming able to send down « this that and the other » type of cast with the knowledge that such and such an observed wire angle calls for the veering of such and such an additional length of wire in order that the bottles can reach such and such a desired depth. That way is to build up an empirical table such as the one which had been prepared (and was continually being improved) by Mr. Al Brown who was working aboard U.S.S. « Reboboth » when the writer had the privilege to cruise in her. His table dealt with lowerings of 14 Nansen bottles on the wire at a time and, based upon past findings as to the thermometrically established depths reached at times of occurrence of various departure wire angles, it gave ever-improving information as to « Expected Depths » for various unwindings of wire in association with different entry angles.

To reach such and such desired depths with such wire angles, the echo depths had to be multiplied by tabulated factors to arrive at the lengths of wire which would have to be veered. Brown's multiplying factors ranged up to 1.3 in two cases: to attain the respective depths of 1,675 and 2,773 m. lengths of wire one-third in excess of those values had respectively to be veered with a departure wire angle of 55° in the deeper case and of 50° in the other. It was largely the value of Mr. Brown's table that moved the writer to approach the wire angle problem as set below, because it was clear that if instrumental measurement of submarine wire angle succeeded, it would not only have ad hoc value on a station. It would enable a table of the kind drawn up by Mr. Brown to be filled up in detail much more quickly to the end that the aim set out in some detail above could be achieved, namely, the ability to know in advance how much wire to veer to reach desired depths under varying conditions of wire angle and with different numbers and spacings of bottles.

It has now to be remarked that discussion so far has been limited to one particular set of circumstances. Up to now, all said has related to the situation when the only force on the wire is that arising from the drag through the water imposed by the drifting ship; in other words the ocean is at rest or in uniform motion from surface the bottom. Studies of wire angle and attained depths hitherto made based upon considerations of Mechanics, have, even when supported by ad hoc experimentation, been obliged to postulate either complete stillness or uniform conditions of motion on the part of the water column or have treated the problem of the assumption of a known distribution of water motion in the vertical. Mosby (1952) did both these things but, as he states: his was « an attempt to determine the shape and position of the wire in the sea, when the relative currents are known ». Of course quite often they neither are nor can be, and Mosby declares the need for specially-designed intruments to determine the true depth.

Towing a 100 m. long wire with a terminal loading of 11.3 kg. he arrived at very useful findings as to wire angles produced. These rose to 30° for an advance of one knot. He had also towed pendulum indicators in a tank to arrive at data on wire resistivity to water pressure. Perhaps of chief interest to us here is his findings that, with a long suspension wire, the presence of ordinary loadings of water bottles makes little difference to slope. For instance, he declares that the presence of five Nansen bottles spaced on a wire affected the obliquity only to the extent of half a degree — adding only 3 m. in 200 to the depth attained. He concludes that one can simply ignore the presence of Nansen bottles as an influence on wire slope. A further finding of Mosby's which is of present interest is that, when an unloaded kilometre-long oceanographical wire is lowered into the sea and towed at 1 knot it takes up an entry slope of 43°47' with its lower end reaching the depth of 780 metres. Mosby concludes his study by saying that, generally speaking, the old practical rule holds good that the smallest errors exist when the ship is manœuvred to achieve minimal departure angle of the wire.

He concludes also that it is essential to know the vertical distribution of velocity in order to correct the depths, and cites the case of a « Michael Sars » station occupied near the Grand Banks in 1910 when the existence of a 1-knot current was inferred hydrodynamically relative to assumed zero movement at the 1,000 decibar level. On that occasion no trustworthy depth corrections could be made from the use of the graph he had prepared. It was particularly in connection with lowerings into waters known to be the seat of strong stratified currents moving oppositely, and for investigations at places where strong deep movements of unknown direction may exist, that the devices to be described were thought necessary and were made. For instance, in the Straits of Gibraltar, where the separation level of the two oppositely-directed water movements migrates so markedly in the vertical with tidal stage and other factors, it would be most interesting and useful if the carry-away of the wire (kept virtually vertical at its entry into the water) could be learnt in respect of depth, speed and direction. The same applies to the Bosporus, the Dardanelles, the Strait of Bab-el-Mandeb and to a goodly number of other places as well.

In this connection thought turns to the very effective way in which the existence of a strong deep current running in a very different direction from that at the surface above it, was demonstrated by Townsend Cromwell and his associates when working in the equatorial waters of the Pacific Ocean (1954).

They used extensive surface drags of great water-holding power (like herring drift nets) to reveal the surface current and followed them by Radar up to ranges of 5 miles. For their deep drags they used light muslin cones (like sea anchors in shape) attached to aluminium alloy hoops weighted below and buoyed above. They lowered these on piano wire bent on below a manila line (furnished with accumulators) leading down from a surface pole buoy. By dint of measuring the velocity of the deep drag relative to that of the surface drag, they were able to establish the existence of a deep current running very differently from that in the surface waters above it.

Whilst they mention that the employment of long-line fishing gear had earlier given indications of the existence of an eastgoing current below the westgoing South Equatorial Current, Cromwell and his associates make no reference to the fact that workers on the « Capricorn » Expedition in common with investigators on the « Shellback » Expedition a year earlier, had also made observations to much the same effect. They has used a modification of the confined submerged biplane-shaped drag described by Pritchard and Burt in the November 1951 issue of the Sears Foundation Journal of Marine Research, and used so fruitfully in the course of estuarine observing by the Chesapeake Bay Institute. Evidence was obtained of the existence at places of the Equatorial Countercurrent under the South Equatorial Current, and Munk's use of the Chesapeake Bay drag had shown a tendency for the latter current to slow down and perhaps reverse in the depths. However, there is talk in the reports of the measuring of wire angles having been primitive, and it is suggested that the devices which are described in the present article, could give good service in that connection.

It would be quite a serious omission if we failed to take account of Pollak's very pertinent paper (1950) which deals with the determination of the actual depths reached by water-bottles let down in the customary manner.

He fully discusses the relative merits of the cosine curve method of estimating the depth attained by water-bottles spaced between such as carry pressure-responsive thermometers, and that in which veered wire length is plotted against the « wire length minus depth » values got in respect of the bottles furnished with reversing thermometers of the unprotected type (hereafter « U.P. thermometers »). He had worked under circumstances when only two or three U.P. thermometers were available with a deep water column to investigate and had, in consequence, had very good cause to appreciate the great difficulty of estimating the depths attained by the majority of his bottles.

He dwells upon the difficulty attaching to depth assessment when working well below the depth limit for U.P. thermometers. A point of interest is that he had apparently had experience of one U.P. thermometer « stiff enough » for use down to 7,000 m.

It is worth recalling in passing that the great depths worked by the Danish expedition ship « Galathea » in the Philippines Trench when she raised her precious deepest-ever samples of living matter, and by H.M.S. « Challenger » when she lowered a plummet down through 10,863 m. of water in the Marianas Trench were well beyond the competence of U.P. thermometers to throw light upon the slopes taken up by the lowest length of wire.

Pollak concludes his valuable paper with the information that the cosine curve method gives smaller errors in depth estimation down to about 2,500 m., whereas the other method excels beyond that depth. If, instead of being an instrumental attack upon the problem of wire-angle, this paper were devoted to the mechanics of a wire drawn slowly through the sea by a drifting ship or towed throught it at speed, a large measure of attention would have to be given to the detailed study carried out by Gougenheim (1938) nearly twenty years ago — and to earlier papers listed by him in the bibliography which accompanies his important paper. The point of mentioning Gougenheim's paper here in this article dealing with an instrumental approach to the wire angle problem, is that a slope gauge of the type described below for use on a rope could certainly serve to measure the shape of the wire when a submarine sentry (Gougenheim's « Plomb-Poisson ») is towed at ordinary speeds behind a ship. That figured here was actually towed at 8-knots in the tank at the National Physical Laboratory with success, although it is not in the ideal from to be so towed.

Most readers of this paper will be acquainted with the success and great practical value of B. Kullenberg's study of the shape and length of a wire cable used for deep sea bottom trawling (1951). He worked out what lengths of a cable 12 mm. in diameter would have to be veered to ensure that a slowly-towed bottom trawl would keep bottom at depths of as much as 5,000 m. and more.

The Swedish expedition ship « Albatross » was able, thanks to Kullenberg's expert computations, to carry out 14 trawlings all at depths greater than 4,000 m. From ten of them catches of bottom-animals were obtained. It was due to the reliability of Kullenberg's computations that the Danish expedition ship « Galathea » was able to use her big trawl successfully down at the astonishing depth of 7,130 m. in the Sunda Trench. We mention these things here because there is no reason whatsoever why wire angle gauges of the type to be described should not (if made to go on a thicker cable) be used in connection with such computations as Kullenberg so skillfully made. There seems no good reason to go any further in citing former papers since specialists on the subject of wire angle will be familiar with the work carried out by Jacobsen when he first designed his Libelle current-meter, with Kullenberg's study of the resistance of a cylinder towed through water, with Hishida's paper on the inclination of a wire lowered from a ship into the sea, and with Hirano's « attempt to correct errors of the sounding caused by wire inclination » (1952). A point of interest is that Hirano (like Mosby in the same year) brought the observation of messenger-descent speeds into his study. He (Hirano) gives some interesting particulars for a wire of length 500 m. entering the sea at a slope of 45°.

The excesses of wire length over depth attained were in m.):

146.5 per cosine argument
83.5 from Japanese Hydrographic Office correction tables
78.0 by applying a method due to Fukutomi and
93.0 from the study of messenger descent speeds

SOME DESIDERATA

It would be useful to know reliably up to what speeds ships lying-to can drift downwind under weather conditions approaching those at which oceanographical lowerings have to cease, i.e. at times when wire angles are maximal. Much questioning has been directed at seamen from whom it was hoped the information would be forthcoming for a good reason to appear later. Unfortunately, not many expert sailors have been willing to commit themselves. However, the harbour authorities at Le Havre are on record as having found that a ship as big as the « Liberté » drifts downwind at 1/3 knot on occasion, and that tankers have been blown across the harbour at a speed approaching 1/2 knot — but much depends upon whether they are loaded or light.

In what follows, where we had occasion to take account of towing speeds standing for ship drift, we have deliberately assumed the possibility of speeds which submit the instruments to over-exacting conditions.

Touching briefly upon the expected usefulness of instruments which can reliably measure the shape of a submerged loaded wire, it may be claimed that, in addition to serving ends sufficiently obvious from what has already been said, their employment could throw some useful light upon the direction and speed of deep currents. Also, if they could be sold cheaply enough, the use of them might well achieve some saving with U.P. thermometers. Then too, there are many connections in which it is necessary to know the slopes and directions taken up by towed wires and trawl warps to say no more.

As to piano wire soundings made down to the greatest ocean depths, wire angle gauges of the kind to be described would give no service since they are necessarily heavy to ensure that they remain lying plumb on the underside of a sloped wire, i.e. that they hang direct towards the ship whose drift it is which tows them through the water. To ensure that they do not swing round on the wire and trail in the current instead of stemming it (as they must) they have to be made much too weighty for use on a very long sloped piano wire stretching down into the ocean depths. Even if adapted for fixation on such wire their own weight would « put a bend » into wire as thin and light as piano wire.

The gauges described below require that the wire cable on which they are used shall be under tension adequate to prohibit their bending it by their own weight. Such tension always exists when deep-sea lowerings of reversing bottles are made, but the same need not be true in the case of the Knudsen insulating bottle. This latter instrument is extremely useful for sampling down to modest depths, but it is very often used under conditions which make estimates of the depths reached by it little better than guesswork.

This is serious when layerings are being studied. Admittedly, if the ship manœuvres to keep the departure angles virtually zero, the depths reached with such modest lengths of wire veered will not be seriously different from those lengths — but it has to be remembered that the insulating bottle is often used from ships which cannot so manœuvre and which have to use the bottle on occasion on a very-sloped wire. To estimate the depths of sampling acceptably it would be a great advantage to know the shape of the submerged wire, but the bottle in question would not usually be weighted enough to permit the use of heavy wire angle gauges without falsifying the depths inferred, since they might bend the the wire by their own weight. The cure would be to improve the attachment of the wire to the bottle enough to make safe the addition of considerable extra weight.

THE INSTRUMENTS

The present writer (J.N.C.) will do no more than describe the gauges in general terms leaving an adequate technical description to the pen of Mr. Woods whose responsibility it has been (within the firm of Kelvin and Hughes) to carry ideas into practical effect. In doing so he has contributed very much to their construction and functioning from his own ideas and engineering knowledge.

The first model of the wire angle gauge made which was (as earlier stated) demonstrated before the Hydrographical Committee of the International Council for the Exploration of the Sea, contained no compass and was little more in appearance than an empty wooden photograph frame more or less of foolscap size. On one side there were twisted hooks and a very simple screw clamp enabling it to be fixed on to an oceanographical wire. On the top was fixed a simple metal seasaw-bar which could rock on a fulcrum at about 1/3 distance from the side affixed to the wire. Hanging from the underside of the bar at its end remote from the wire was a little skewer of knitting-needle thickness and strength. This could swing freely in all directions like a conical pendulum when its end of the bar was raised but, when the latter was depressed, it could be seated in a small bushed hole in the top of the frame. The other end of the seesaw-bar has a pointed rod screwed down through it in such a manner that the length of projection beneath the bar could be varied. It was arranged very simply that, when the end of the rocking bar remote from the wire was down and the skewer held firm with its lower end in its restraining hole, the point of the rod screwed down through the bar at the end next the wire bore down upon a small square of glass seated in a bottomless hole gouged out from the top of the wooden frame. This square of glass was actually half a microscope slide.

In the situation so far described, a blow on the seesaw bar delivered at the end next the wire, would break the glass and would result in the end remote from the wire raising the little skewer out of its restraining hole. In use this blow would be delivered by a messenger, sent down the wire from the observing ship. Near the top of the frame inside its limb next the wire a screweye was fixed into the wood, and, internally along the bottom of the frame an inch or so above the lower end, a band of wire gauze was fixed horizontally. A pendulum bob of pear shape having a spike beneath it furnished with a hinged barb was hung from a thin line which passed up through the screw eye and ended attached to a small key ring. The length of this limp pendulum was such that, with its bob just free of the gauze, the line was tight when the key ring was « threaded » on to the little skewer. A second line with a key ring secured on one end and

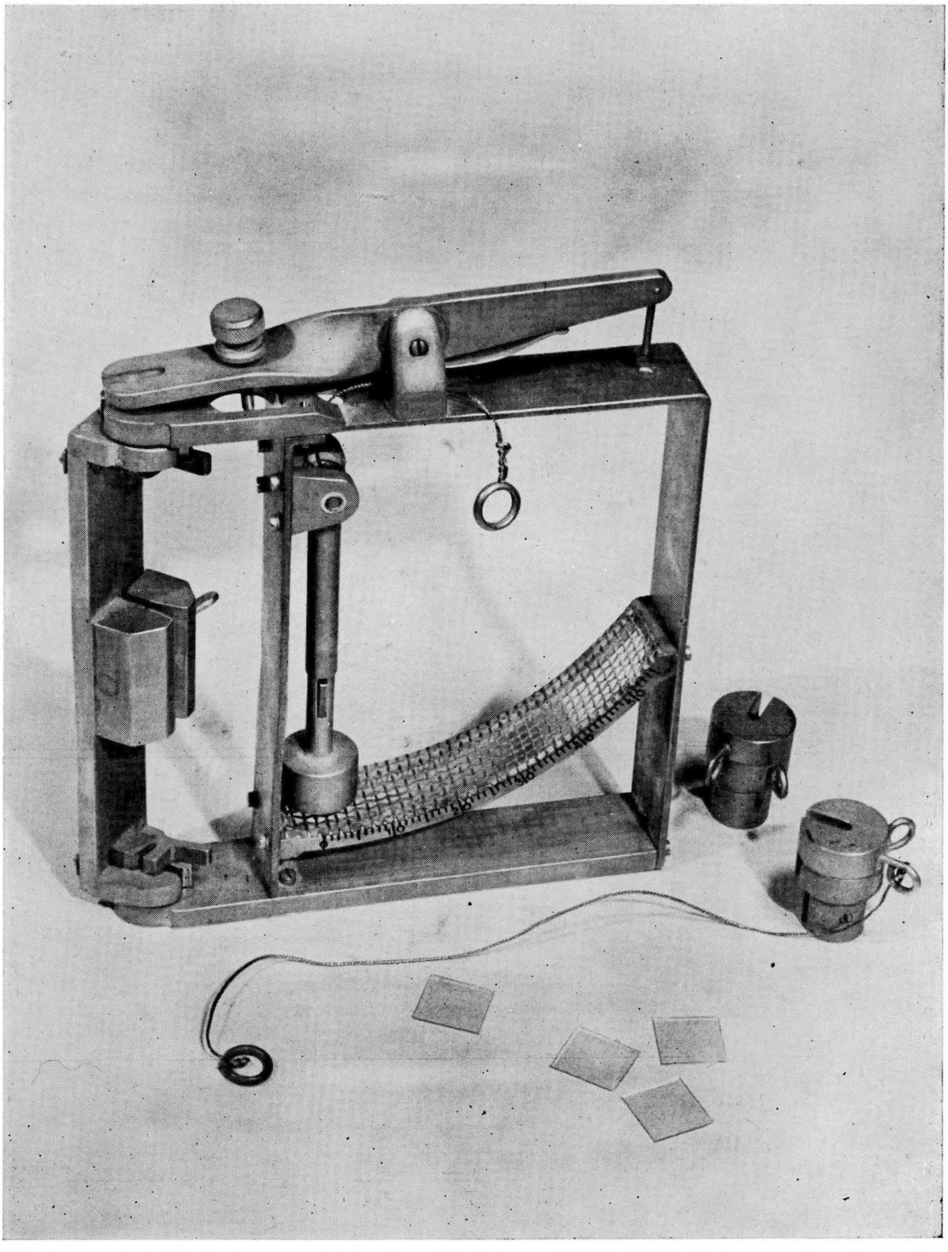

Fig. 1

The Wire-Angle Gauge without Compass Messengers and Glass Squares.

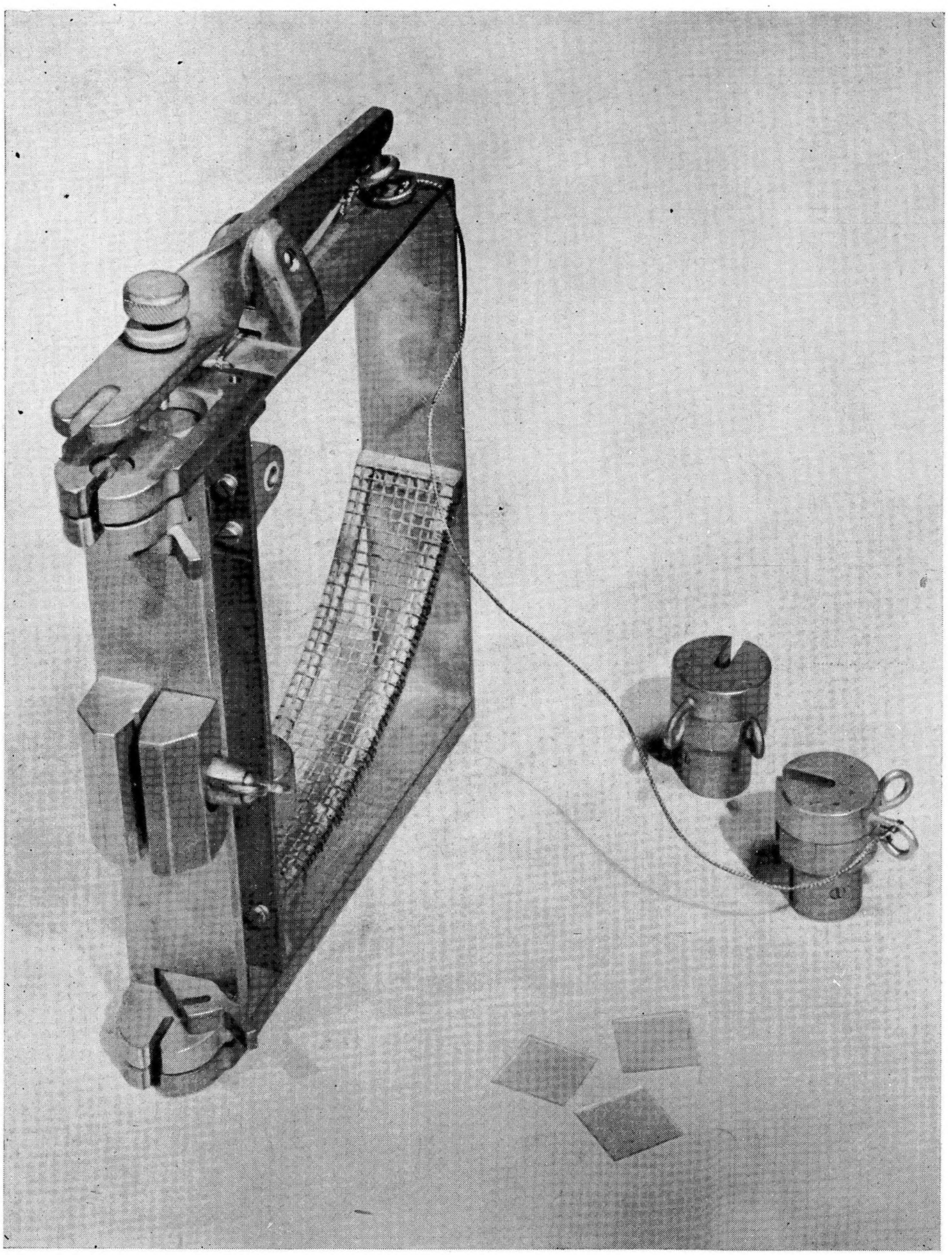

Fig. 2

As Fig. 1 but showing how the Pendulum is cocked and the lower Messenger (due to run on down the wire) is attached.

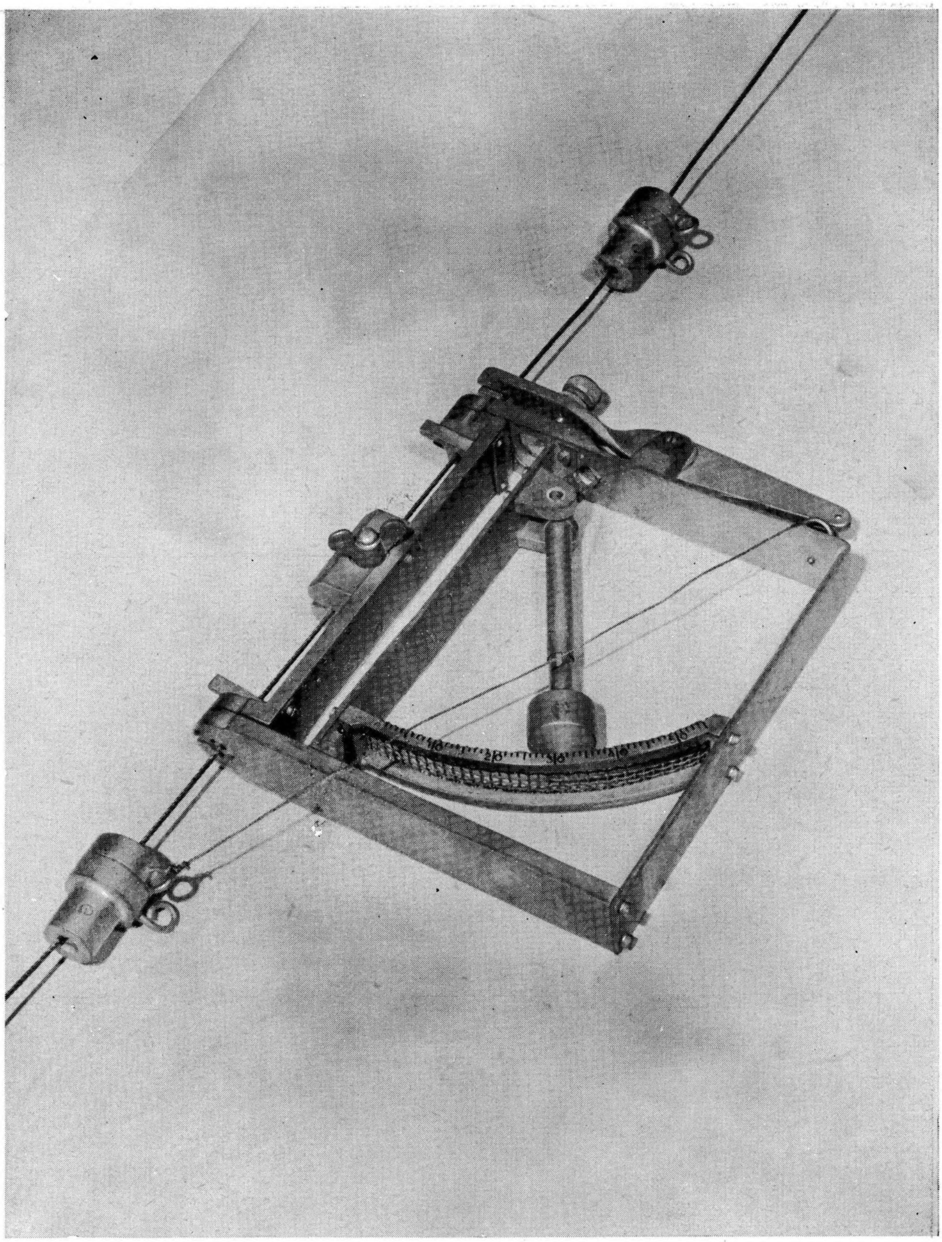

Fig. 3
Showing the Wire-Angle Gauge without Compass attached to a Wire sloped at 32°. This Laboratory Picture simulates the Situation when the Messenger is arriving from the Ship above.

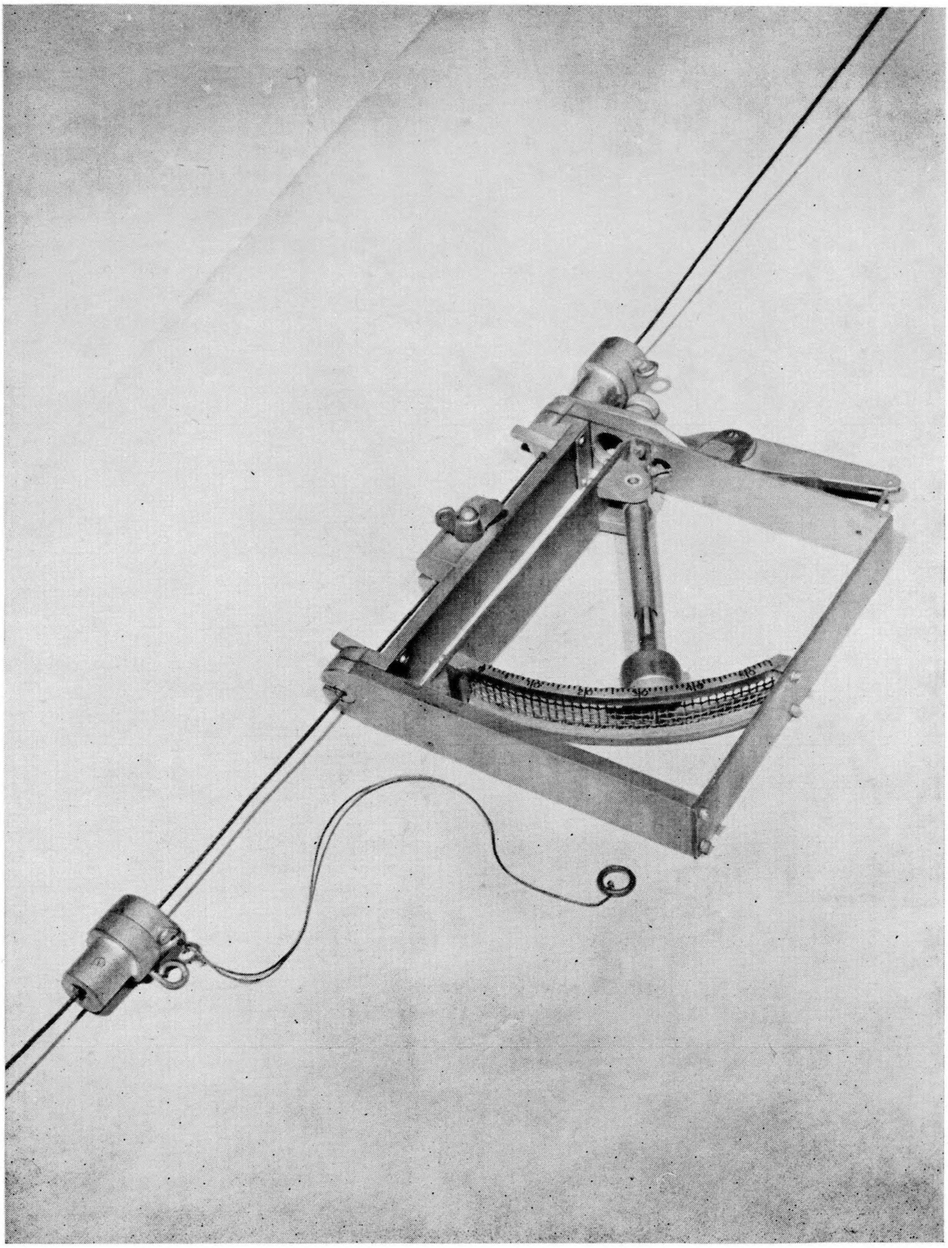

Fig. 4

As Fig. 3 but after the arriving Messenger has struck, has broken the Glass Square, has caused the Pendulum to drop to lock itself into the Gauge, and has let the lower Messenger run on down the Wire.

a messenger secured, on the other, was of such length that, when its key ring was « threaded » on the skewer as well, the messenger could be secured on the water-bottle wire at a point below the gauge. One side of the frame of the latter was filled in with perspex to hold the pendulum under some measure of restraint.

Enough has now been said to make it clear that the gauge could be « cocked » and affixed to the wire in such manner that, when a messenger was sent down the latter, the glass would break to let the lower messenger travel on to trip a bottle or another gauge further down. At the same time the pendulum would drop and its barb become fixed into the wire gauze. The position at which the pendulum spike entered the gauze would tell the slant of the wire at the time the messenger arrived.

When the demonstration was made the idea was accepted as novel but the criticism was made that the gauge might, when the wire was drawn through the water by the drifting ship, twist round the wire and not register the slope of the latter correctly. Clearly this criticism had to be met, and a first stage was to make the gauge heavy and to make it completely open with no side to catch water pressure unduly.

Mr. Woods had the idea to depart from the limp pendulum, and what the gauge finally became when made to his ideas will be adequately conveyed by his description and the accompanying photographs. Later, the present writer suggested the incorporation of a compass; that also was achieved by Mr. Woods who is left to describe it himself below with the aid of his photographs reproduced. Some oceanographical wires are completely non-magnetic, and none tested by the writer showed any effect which would put complete acceptance of the slope directions given by the compass-containing wire angle gauge in any doubt.

The other slope meter for use on a rope strained between an anchor and sub-surface buoy, was thought out to enable fishermen using a certain simple type of current-meter affixed to the rope in question, to know how far above bottom the current-meter would have worked. They would know the rope distance between anchor and current-meter, and would learn the slant of the rope from the gauge. On entering a simple table (of multiples of cosines) they would learn what vertical interval the rope distance amounted to.

In essence the device is like what one would have if a book with perspex covers had all its pages torn out and the spine made springy enough to remain always closed. At that stage a pendulum is pivoted centrally inside the front cover. The pendulum has small projecting spikes which face a rubber annulus stuck inside the other perspex cover. So long as the « book » is held open the pendulum can swing, but as soon as the « book » closes the pendulum is gripped securely. In use the « book » is kept open until two tablets of highly-compressed potassium iodide have dissolved away. The whole thing is mounted so that it can be fixed to a rope in such manner that it can swing freely all round the latter. This is achieved by means of a bracket which can rotate freely yet is fixed (for distance above the anchor) by being clawed round a special metal bobbin. This latter is in two halves each of which is furnished with small internal spikes. They can be gripped together round the rope and secured firmly by dint of inserting two pins. With this gauge it was essential to achieve lightness to ensure that its own weight would not « put a bend » into the rope. Actually it weighs only 1.3 kg. in water. The critical test to which it was submitted was staged in the motionless water of a 17-metre deep reservoir. With suitable anchor and the buoys which would be used in the sea, its attachment to the rope caused no departure from the vertical at all. It is foreseen that a small version of this simple rope inclinometer could serve very usefully to reveal whether near-bottom waters are or are not in motion. Such a miniature version could be used in the depths of the ocean buoyed up by means of a paraffin block and held down to a pseudo-anchor (such as a sack of gravel) from which it would achieve release after the solution of a bag of salt or soda or the like. Of course there would be the problem of recovery after ascent to the surface but, if cheap enough, quite a number could be used. Also, there would be the possibility of letting the ascended gauges become the analogues of drift bottles if a questionnaire card enclosed in plastic were carried by each gauge. Should such a use of the gauges be successful, it would doubtless be possible to fit a simple compass inside them which would be squeezed (and so clamped for current direction) when the leaves closed after the tablets had dissolved.

TESTS OF THE GAUGES

It will be some time before the opportunity presents itself to carry out really deep sea lowerings of water bottles with the wire angle gauges used intermediately, on the wire between reversing bottles furnished with U.P. thermometers (1). That would be an investigation of great usefulness but until such time as an adequate number of the wire gauges becomes available (they are not cheap), the writer must perforce rest content with the results of tests carried out at the National Physical Laboratory. In the course of these the gauges were more exactingly tested than they could be in the sea. The tests described briefly in what follows have since been amplified by one carried out at sea off Plymouth from the research vessel « Sarsia » of the Marine Biological Association. It is also referred to below but the purpose of it went little beyond making sure that the gauges work satisfactorily when down in the sea in that the messengers infallibly break the glass and so let everything function. The tests carried out in the long tank in the Ship Division of the National Physical Laboratory were done by affixing the wire angle gauges to a taut wire which could be towed in such manner that the instruments were kept about three feet below surface (fig. 7). There was a spring balance at one end of the wire and tension in the latter could be adjusted by winding on a small winch. Very effective arrangements existed whereby the taut wire (kept usually under a tension of from 230 to 270 lbs.) could be towed through the 9 ft-deep water at any speed desired and at easily-contrived slopes of different magnitude.

The following was the range of slopes of the towed taut wire during the trials of both instruments each of which was tested separately:

8°, 12,8°, 18°, 27 1/2°, 37° and 45°

Runs were made at varying speeds from 0.3 to 3·9 knots with a twofold purpose:

1) To determine the maximum speed at which the inclinometer continued to point in the direction of motion. This is referred to as the critical speed.

2) The relationship of the actual angle at which the wire lay (as measured accurately by clinometer) to the angle recorded by the submerged gauge.

Throughout the experiments the pendulum was free to swing, and so far as any results quoted below are concerned, the messenger hanging on the wire beneath the tested gauge was always present.

(1) But see the Appendix since added.

The tests were really too exacting because when working from ship board a fast drift would never be associated with a small wire angle. When the wire was but little out of the vertical, and the wire-angle gauge least able to point stably in the direction of motion, the speed of movement would be accommodatingly minimal. At the other end of the scale small speeds of drift and large slopes would never go together. The official report on the tests goes into considerable detail, some of which has to do with effects which would not be met with when working deep lowerings from shipboard. It was found that at the large angles, 20° and over, the instruments ran satisfactorily. Certain minor shortcomings reported at smaller angles would, the writer fully believes, disappear completely under the conditions of use from shipboard. The official report states that the flow of the water had an effect on the recorded angle when the towing speed was above 1.8 ft/sec. (1.08 knots).

Should it ever be found that a ship, from which the wire-angle gauges might be in use, does drift in excess of that speed, it would be an easy matter to decide what allowance had to be made to cancel out the under-reading due to pendulum drift. The final, easy, and convincing thing will be when the gauges have been proved on deep-sea lowerings. It does not seem at all likely that under working conditions the gauges will ever be drawn through the water at 1.2 knots whilst the suspension wire is only 8° out of the vertical, nor that, with angles of 12.8, 18, 27 1/2, 37 1/2 and 45° respectively, the speeds of drift will ever exceed the values 1.92, 2.16, 3.0, 3.3 and 3.6 to 3.9 knots which the compass-containing inclinometer can experience without « turning over » on the wire.

SEA TEST

The two wire-angle gauges and the very simple inclinometer for use on a rope were fully tested from the research vessel « Sarsia » in the vicinity of the Eddystone Rock on 2nd June 1954. The vessel was generously placed at the writer's disposal by Mr. F.S. Russell, Director of the Marine Biological Association of the United Kingdom, and Dr. Cooper kindly attended the tests and worked the reversing water-bottles. Mechanically, the inclinometers all functioned perfectly and there was not the slightest hitch in working the wire-angle gauges intermediately with water-bottles. Since, in the neighbourhood concerned, the tidal streams may well change direction with depth at times, a final check on the acceptability of the directions recorded by the wire-angle gauge is intended. It will be taken to a deep reservoir near Staines and towed near bottom on all headings from a motor-boat. In such motionless water, of course, the slope directions recorded will have to be in keeping with the boat's travels.

TECHNICAL DESCRIPTIONS (BY A.J.W.)
THE WIRE-ANGLE GAUGE WITHOUT COMPASS

The development of the present gauges began soon after the demonstration of the original wooden model before the Hydrographical Committee of the International Council for the Exploration of the Sea. It was at once seen that it was necessary to make the gauges free to rotate about the water-bottle wire in order that they would hang true beneath the latter when it was sloped, and would face the direction of movement through the water without fail even if the wire to which they were attached should twist somewhat on account of changing tension.

This was done by constructing the gauges in two parts, one of which is clamped tightly on the wire. The other part swings about it and contains all the mechanism. In order that the gauges may be affixed to an already-taut wire, the bearings are slotted to admit the latter and retaining hooks are sprung into place to keep the wire central in the bearings (A, Fig. 1) (A, Fig. 2). Once the freedom to rotate about the wire had been obtained, it was no longer necessary to have the pendulum weight suspended on a cord. It could now be mounted in trunnions to swing only in the plane of the gauges. This achieved the further advantage that it was no longer necessary to cover in the sides of the gauges to restrain the pendulum; consequently the framework could be made quite open.

This done, the water could flow through the gauges with very much reduced power to prevent them hanging true under the sloped wire.

The pendulum trunnions were mounted in bushes of a new plastic - polytetrafluorethylene (« PTFE ») known also as « Teflon » and « Fluon ». This has an extremely-low coefficient of friction and is entirely unaffected by sea water (B. Fig. 1).

The pendulum is cocked prior to lowering a gauge into the sea, by squeezing the spring umbrella-type catch on the lower part of the pendulum rod, pushing the latter up into the tubular upper part, and catching the ring attached to the end of its braided copper supporting cord under the pin of the trigger bar. At the same time the ring attached to the lanyard of the fall-away messenger is put round the same pin.

In order that the free swinging of the pendulum shall not be constrained by the copper cord which holds up its bob, the cord is brought out through a loose brass spindle so that its point of bending is at the centre of rotation of the pendulum. The pull of the cord makes no difference to the reading of inclination up to the full scale range of 50° from the vertical.

It is not at all necessary to have two hanging pins beneath the top trigger bar as did the original wooden model. The gauge is more easily operated with only one pin. In Fig. 3 the gauge is shown cocked ready for lowering. In Fig. 4 it is seen as it is after the glass has been broken and the pendulum has dropped; the prong of the latter has pierced the gauze, the spring catch has locked the pendulum down, and the fall-away messenger has been released to run down the wire to operate a water-bottle or another gauge below.

The gauge is made entirely of brass tin-plated all over to avoid corrosion troubles. The overall dimensions are 26 cms. by 22 cms. by 4 cms. and the weights in air and water are respectively 3.65 and 3.2 kg. The gauge is made for use on standard water-bottle wire 4 mm. thick but could be made for other sizes if required.

THE WIRE ANGLE GAUGE WITH COMPASS

As soon as the simple gauge just described had been constructed, it was realised that the possibility had been opened up of not only measuring the inclination of a submerged wire but, if a compass could be fitted, of registering also the direction in azimuth of submarine wire slope.

To this end another wire-angle gauge was made exactly the same as the former one except for the design of its pendulum. The upper part of the com-

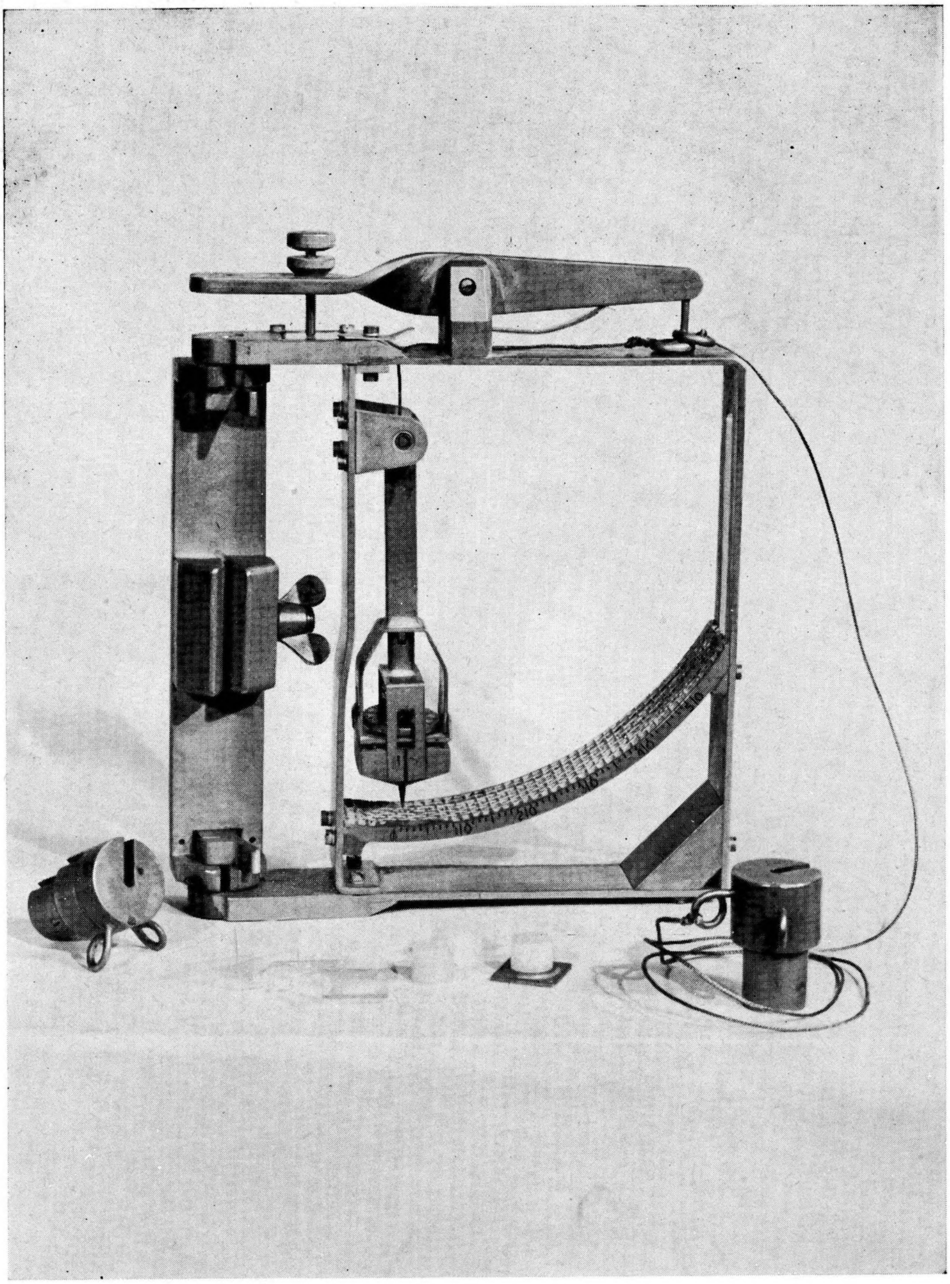

Fig. 5

Showing the directional Wire-Angle Gauge which incorporates a Compass. The small cylindrical Objects are highly-compressed Tablets of Potassium Iodide for use when the Instrument is not operated by Messenger.

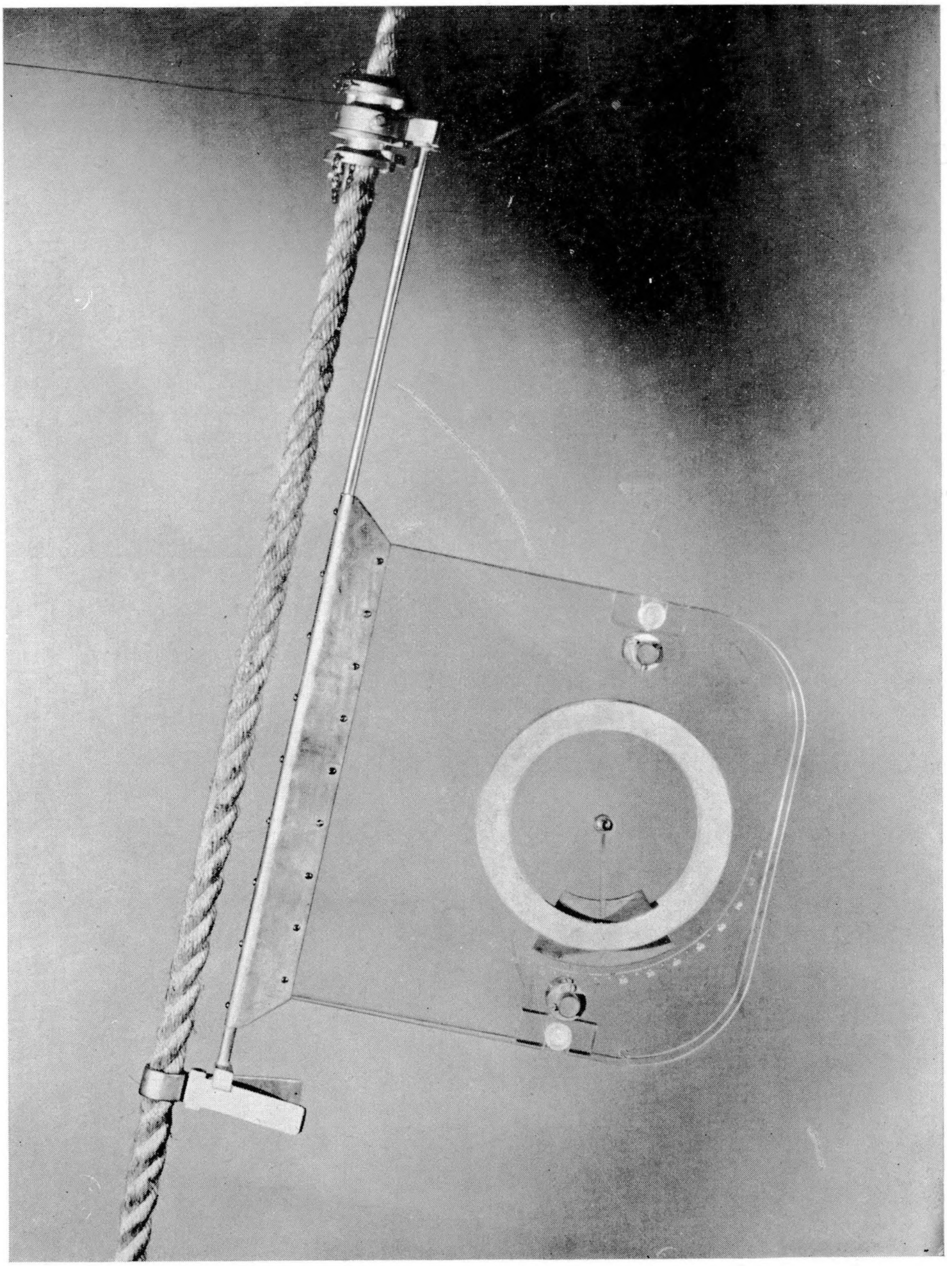

Fig. 6
Showing the simple Inclinometer used to reveal the Slope of a rope strained between an Anchor and a Sub-Surface Buoy. The « Perspex-Book » is shown held agape by two of the Tablets which dissolve to let the Pendulum become firmly gripped. The Means adopted to ensure that the Inclinometer can swing freely round the Rope is shown.

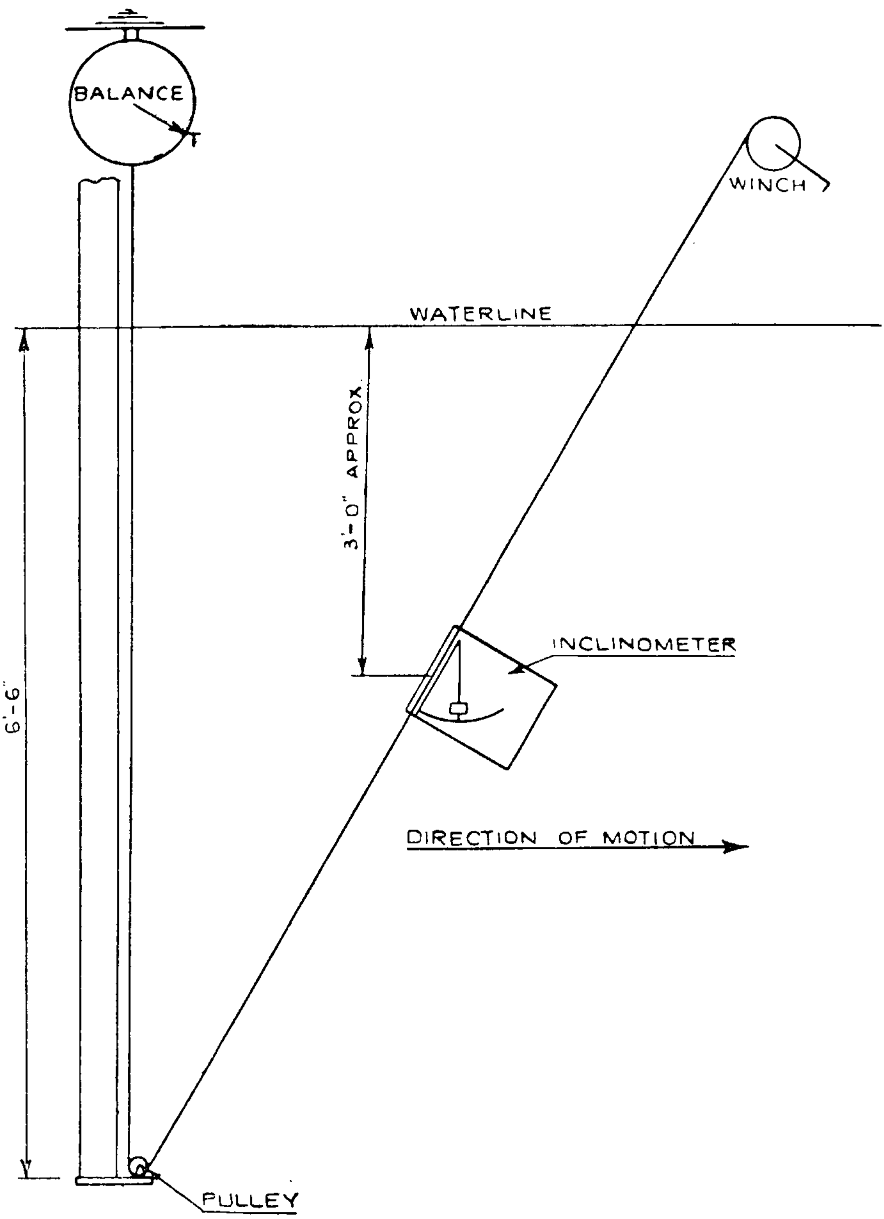

Fig. 7

Showing the Towing Arrangements provided in the National Physical Laboratory and used in the Tests described.

posite pendulum rod in this second gauge was made of square brass tube up into which the round brass rod of the lower part was slipped with a spring catch fitted as before.

The round rod is not at all likely to lose its easy sliding fit in the square tube due to sand getting in between them.

Reference to Fig. 5 will show the square tube of the pendulum supporting a stirrup which holds a horizontal plate under the compass. The round rod carries the heavy square pendulum bob with its terminal prong for piercing the gauze arc. Standing up in the centre of the pendulum bob is a short pillar, at the top of which is the jewelled cup on which the compass pivot tipped with platinum iridium rests. On the horizontal plate under the compass is a rubber ring which is free of it when the gauge is cocked for lowering.

When the glass is broken by the messenger, the braided copper cord running up through the pendulum is released and the square pendulum bob drops down to engage its prong in the gauze arc. It becomes locked down by the umbrella-type spring catch whose end can just be seen in Fig. 5. Because the compass jewel is fixed to the square pendulum bob, it is drawn away from the compass pivot at the instant the compass is clamped between the rubber ring and a light spring which comes down for that purpose when the pendulum bob descends. This is a necessary safety provision to avoid damaging the compass pivot or jewel and to preserve their delicate and frictionless working.

The gauge with the compass has the same dimensions as the simpler one but is somewhat heavier. It weighs 3.9 kg. in air and 3.4 kg. in water. Fig. 5 shows some squares of the thin glass (2.5×2.5 cms) used in the gauges. Seen also are some of the potassium iodide tablets which are usable in a little holder to take the place of the glass slips if it be desired to operate the gauge under certain conditions which do not permit employment of a messenger. In such case, the horizontal trigger bar being spring-loaded, the gauge functions when a restraining tablet has dissolved away.

THE ROPE-OBLIQUITY GAUGE

Nothing needs adding to what has already been said above about this device beyond the bald facts that its dimensions are 68 cm. by 36 cm. and that it weighs 2.1 kg. in air and 1.3 kg. in water. Customarily used on a 2 1/2-inch rope, it is illustrated in Fig. 6.

ADDITIONAL ACKNOWLEDGEMENTS

The writers desire to place on record their indebtedness to the Metropolitan Water Board (in the person of Dr. F. Greenshields) for generous help and facilities in connection with trials made in one of the great reservoirs near Staines.

Critical tests could not possibly have been made without the use of the towing channel in the Ship Division of the National Physical Laboratory, and a particular debt is accordingly acknowledged to the Director of the N.P.L. for the services rendered by Mr. A. Silverleaf of his staff, and for permission to reproduce fig. 7.

Thanks are tendered also to Professor G. Wüst for kindly supplying a very useful resume of wire-angle experiences during the course of the « Meteor » expedition (1925-1927) 'though it was unfortunately not received in time for citation.

ADDENDUM

Since the above paper was written information has been obtained on speed of ship drift and associated entry angle of the bottle wire in connection with wind speed. In the case of the oceanographical survey vessel U.S.S. « Rehoboth » mentioned above, Mr John Lyman has informed the writer that routine oceanographical work ceases at wind force 7, and that deep casts are cancelled whenever the preceding shallow casts have involved an entry wire angle of 35 degrees or more. From curves kindly supplied, it is learnt that ship drift to leeward amounts to very nearly 6% of the wind speed responsible in the case of USS « Rehoboth ». From this it would follow that routine oceanographical work would have ceased before the ship could be drifting at 2 knots down wind. Still concerning the same ship, the information supplied shows further that an entry wire angle of 35 degrees would exist when the wind was about Beaufort force 5, i.e. at a time when the ship could be drifting at 1 1/4 knots to leeward.

Further information gleaned from reports emanating from the 18th Navigation Congress held in Rome in 1954 is to the effect that, with a ship whose projected underwater area amounts to half that above water, the rate of ship drift would be only 1/50 of the wind speed, a value seen to be only one-third of that cited above as applicable to USS « Rehoboth ».

This information can be taken as showing that the wire angle gauges can always be used quite reliably from research vessels lying on station with engines stopped, so far as possible errors due to horizontal tow through the water are concerned.

Naturally however, it remains desirable to do further work on deep stations to make sure that the gauge-recorded slope is not falsified by vertical ship movements due to rolling and to lifting and falling on waves.

Whilst there seems no good reason to suppose that it would be, the desirable evidence will be sought by Mr. A. Lee who has very kindly contributed the Appendix which follows. In addition to trials against the showings of adequate numbers of deep-sea reversing thermometers of both types used in the customary way, at least two other lines of attack on the problem have suggested themselves and will, it is expected, also be followed during Mr. Lee's future work in the Barents Sea.

Of course, when measurements are being made of the slope of a line which is anchored to the sea-bed and not attached at its upper end to a ship or other large object afloat on the surface, the same concern for possible falsifications due to that amount of the rise and fall of the line which is not accommodated by the accumulator, does not arise. A case in point is provided when using our simple rope inclinometer already describd and illustrated.

Did a published account of it exist, one could make more than passing reference here to the instrument devised in Canada by Professor E.E. Watson to reveal the distribution of current speed in the vertical in shallow seas. In that instrument, a float attached to a spooled wire, rises gradually from the bottom and, as it pulls the wire off the spool, a pendulum device serves to make a scratch on a smoked slide to the end that the slope of the wire (telling the current speed) is learnt for all heights above bottom as far as the surface.

In that case too, there is freedom from concern with up-and-down movements imparted from the surface but the problem is not (as with us) to measure the obliquity of a line of fixed length, and so far as is known, Professor Watson's device does not register the directions of slope. In an estuary where strong currents oppositely-directed can occur in close superposition, to record direction does seem of great importance.

APPENDIX

NOTE ON THE USE OF THE CARRUTHERS-WOODS WIRE ANGLE GAUGE

By A.J. LEE

Two Carruthers-Woods wire angle gauges were used during Cruise 4/1954 of the Ministry of Agriculture and Fisheries' Research Vessel « Ernest Holt ». This took place in the Barents Sea between Norway and Spitsbergen in June. Only one of the gauges was of the type fitted with a compass.

The « Ernest Holt » cannot be steamed up to the hydrowire in order to reduce the wire angle. It is therefore necessary for hydrographical work to be done with the ship lying beam on to the wind and sea. In bad weather the wire angle becomes large, and the work is done from a platform on the stern so as to make it easier and safer to handle the gear.

At six stations the gauges were used in conjunction with a series of Nansen water bottles, so they were always operated by means of messengers. They worked satisfactorily at all depths down to 1000 metres, the greatest depth sampled on this particular cruise. They were easy to handle even in bad weather conditions. For instance, at one station they were used in a Force 7 wind, with a sea 12 feet high accompanied by a long moderate swell. The ship had a lively roll, but no difficulty was experienced in attaching the gauges to the wire or removing them from it.

An unprotected thermometer was used on three water bottles in each series: one was placed on the lowest bottle, one near the top of the cast and one at an intermediate depth. A terminal weight of 1. cwt. was always used on the bottom of the wire. One of the wire-angle gauges was usually placed near the bottom of the cast and the other near the top.

The depths of reversal of the bottles fitted with unprotected thermometers were obtained by means of the standard technique, and the interpolated depths for the remaining bottles and the wire-angle gauges were calculated from the thermometric depths by means of Pollak's method. (Reference 6 of the foregoing paper). This necessitates plotting the depth difference between wire length and thermometric depth against wire length, and, as the slope of the resultant curve is equal to (1-cosine wire angle), the wire angle at any depth can easily be obtained. Thus it was possible to obtain the difference between the wire angles as given by the thermometric depths and those given by the wire-angle gauges. In all cases but one this difference was three degrees or less, and the greatest difference amounted to five degrees. It must be noted that the probable error of depths obtained by unprotected thermometers is about ± 5 metres for depths less than about 1000 metres, and that the surface wire angle as measured on the ship with a clinometer is only accurate within ± 5 degrees. There is therefore a certain amount of latitude in drawing the depth difference curves when the cast is not a very deep one, so that in most cases in the present instance it would be possible to reduce the differences between the gauge angles and the calculated wire angles below three degrees slightly adjusting the curves yet keeping them within the probable error of the thermometric depths.

At one station to the east of Bear Island two nearly identical casts down to 400 metres were made in quick succession, the only difference being in the depths of the wire-angle gauges. These were staggered on the two casts so as to give the wire angle at four different points: some above and some between the water bottles. The two sets of thermometric depths agreed within two metres, so that the two casts could be regarded as one. The calculated wire angles all differed from the observed by no more than two degrees.

At another station where the sounding was 475 metres it was desired to lower a cast in bad weather so that the bottom bottle was at 450 metres. When this amount of wire had been let out the wire angle at the surface measured 25 degrees, and it was decided to let out a further 50 metres of wire so that the bottom bottle should be near its required depth, assuming the wire to have a straight line form. On hoisting up the series, the bottom bottle was found to have been lying in mud on the bottom, although the surface wire angle had increased to nearly 40° while waiting for the thermometers to reach the temperatures of their surroundings. The wire-angle gauge at 150 metres showed that at that depth the wire angle was only nine degrees. Although the calculated wire angle here was 14 degrees, there remains a considerable amount of latitude in which to adjust the depth difference curve in this case, as the wire angle was changing very rapidly in the top 200 metres of water.

In order to test the behaviour of the compass fitted in the later type of gauge, a one metre stramin net was attached to the hydrowire just above the terminal weight to act as a drogue. The wire-angle gauge was attached to the wire close to the drogue so that the compass reading would allow the direction of the drogue to be obtained. Duplicate lowerings gave directions differing by up to 25 degrees. The directions obtained at some places showed that the bottom water was moving in a different direction to the surface water.

It would appear from this cruise that the wire-angle gauge is a useful accessory to the unprotected thermometer in determining the depths of sampling in serial observations. Not only can it be used to obtain the shape of the wire between the bottles fitted with unprotected thermometers, it can also assist in giving the shape of the depth difference curve between the surface and the shallowest bottle. At present the surface wire angle is apt to be a crude measurement owing to the movement of the ship. This movement will have a much smaller effect on gauges attached to the wire below the surface, and it should thus be possible to obtain a more accurate measurement of the wire angle near the surface at more than one point. Moreover, at very shallow depths the percentage error of the unprotected thermometers increases quickly as the depth decreases, so that a series of wire-angle gauges is likely to give a more accurate estimation of the shape of a wire down to 200 metres than are unprotected thermometers.

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