THE CALIBRATION OF THE VERTICAL LOG CURRENT-METER.

(Extract from *Fisheries Notice* N° 26, published by the British Ministry of Agriculture and Fisheries, August 1939).

A description of the vertical log current-meter is given in the above mentioned Notice, published by the Fisheries Laboratory of Lowestoft. We had already given a summary of this instruments in the article written by J.N. CARRUTHERS, D. Sc., F. Inst. P., which appeared in the *Hydrographic Review,* Vol. XII, N° 2, November 1935, pages 62 to 76.

Since that time, the current-meter has rendered valuable services and has been utilised for measuring currents from light-vessels in the Channel and the North Sea during the winter of 1938-39. Ten instruments have been in practically constant use on 4 British, 4 Dutch, 1 Danish and 1 French light-vessels.

We will not repeat below the description of the current-meter, given by the author in the above mentioned Review, but we reproduce from *Fisheries Notice* N° 26 the whole chapter containing general data on the calibration of this type of instrument and that which records the effects of the movements of the observing vessel.

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THE MEANING OF AND NEED FOR CALIBRATION.

There is a matter to which more than passing attention should be paid, although it will not usually concern observers in English lightvessels when they are working on behalf of the Fisheries Department. We refer to what is known as "calibration", and the matter is dealt with here to make this booklet complete, and to enable observers to appreciate the meaning of something they may conceivably be asked to do at some time or another. We have in mind the desirability of enabling readers to understand the meaning and use of a so-called calibration curve and which serves to let it be known at what speed the water is travelling past the ship at any time. We can best illustrate the remarks which it is necessary to make, by referring to an instrument with which most people are either reasonably familiar, or at least must have seen at some time or another.

A quite usual piece of equipment at meteorological stations is the instrument known as the cup anemometer. Exposed freely mounted on the top of a mast, this consists of a set of cups which spin round in the wind. There is no difficulty in fitting a counting mechanism to record the number of revolutions made by the cups in a certain time, but it is necessary to know either, (1) what the number of cup revolutions made in a short time means in terms of wind speed, or (2) what mileage "run of the wind" is implied by the number of cup revolutions put on during a considerable interval of time. Just as the meteorologist wants to know how many "miiles of wind" must have passed his instrument in a certain time, so do we need to learn how many "miles of water" must have passed an anchored vessel from which we have been observing. It will later be seen that the Vertical Log lets us know both the speed of the stream passing the ship at any time, and the mileage travel of the water over a considerable interval of time. This it does because its registering part is always in view, and because we possess the curve to which we have just referred.

The meteorologist has the simpler task because his instrument is rigidly mounted and performs no movements as a whole. In the case of the marine current-meter, there are the plungings of the ship to consider in wild weather. We shall speak of that later; meantime we shall cotinue to illustrate our remarks by reference to wind-measuring instruments, to which some current-meters would be comparable if only they could be worked mounted on the top of a stout post driven into the seafloor.

The relationship between cup turns and wind speed or travel is found by the process known as calibration. The wind varies greatly in speed over a wide range, and it is, therefore, necessary to know whether the number of cup revolutions put on for a mile of wind is the same for all speeds of air movement which the instrument will have to measure. It is highly desirable that it should be so, or very nearly so. If an instrument is so good that this is the case, it can be said to have "straight line calibration"; if not possessed of this quality, it is necessary to be able to convert from cup revolutions *per* unit of time into miles *per* hour, by referring to a suitable calibration table or curve. We shall say what is meant by these terms a little further on, and shall explain how to use the curve made for the Vertical Log which appears in this booklet.

When the relation between cup revolutions and miles of air movement is the same (or very nearly the same) over all wind speeds which the instrument is intended to measure, then it is possible, by means of a gearing, to make the instrument record miles of wind directly instead of just registering revolutions. If the cup anemometer tested is found not to have straight line calibration, one of two things is necessary:— either one is able to put up with a certain amount of inaccuracy and assume that the same relation between revolutions and miles holds all the time nearly enough, or one has to prepare and use a calibration curve or table, as will be explained.

Suppose that a meteorological station were supplied with a rotating cup anemometer (wind meter) about which nothing was known concerning the relationship between revolutions and miles. The people who had to use it could find this out for themselves (that is, they could calibrate it) in the following manner. They could wait for a perfectly calm day and then take the untested instrument in a car, capable of a very good turn of speed, to a long stretch of empty straight road. They could mark out a mile of road and then mount the instrument on a short pole standing vertically up from the car. Their next step would be to run along the mile of road several times with the speedometer kept on the 10 m.p.h. mark, having entered the measured mile at the speed at which they intended to cover it. They would next do runs at 15, 20, 25, 30 .... miles *per* hour and so on. Each time they did the mile run, they would note down the appropriate readings of the instrument's counter. If the speed capabilities of the car permitted it, they could find out how many revolutions were put on *per* mile of travel through still air, over a range of speeds up to 100 miles *per* hour. They could assume that they had done what amounted to the same thing as testing a stationary instrument in a wind tunnel over a range of wind speeds equal to the car speeds at which they had travelled.

If they found that the instrument put on the same number of revolutions (or very nearly the same) at all speeds, they would not really need to do any more testing if they intended to use it only to record wind travel over a considerable period — that is, if they intended to read it only a few times each day. But if they often needed to obtain wind speeds from the instrument, it would pay them to proceed further with their tests. It would be very convenient to possess a graph connecting cup revolution speed and wind speed; if an instrument was found to be by no means possessed of straight line calibration, such a graph would be absolutely essential. Let it be supposed that the tests described showed that the number of cup revolutions *per* mile of travel varied a good deal with car speed. Then, the people carrying out the tests could take a sheet of paper and tick off inches up the left side and write down the car speeds there like this; 10 m.p.h. at one inch up, 15 at two inches up, 20 at three inches up.... and so on. Along the bottom of the sheet (left to right) they could make a scale of revolutions in a similar way. Suppose that when they ran at 10 miles an hour the instruments had put on 500 revolutions; they would draw a horizontal line across the sheet from left to right starting from the 10 p.m.h. point on the left-hand edge. They would then draw a vertical line up the sheet from the point on the bottom edge which stood for 500 revolutions, and would make a dot where the two lines crossed. They would repeat this by connecting 15 p.m.h. and say 520 revolutions.... or whatever the figure was; then 20 miles an hour and perhaps 550 revolutions.... and so on. When they had finished, they would join the dots together by a line and they would then have one sort of calibration curve, but it would be of limited usefulness only, as will be explained. The fact that the relationship between cup revolutions and wind run varied so much with wind speed would mean that it would be unsafe to read the counter only at longish intervals (every so many hours) if it were desired to convert the revolutions put on into mileage run of wind. An observer using an instrument which had behaved under test as has been supposed would not be able to use just one figure to convert revolutions into miles unless he were willing to risk considerably inaccuracy.

If however, the meteorological instrument tested in the way described had yielded a curve which was very little removed from being a straight line, an observer would be safe in making the conversion by using only one figure — no matter how infrequently he read the counter.

He would also be able to learn at what speed the air was moving whenever he wished. Knowing that a " mile of wind " always meant the same number of cup revolutions (say 500) within a very little, he could, as often as he wished, find how many minutes it took for the counter to put on that number of revolutions. It would then be a very simple step to work out the speed of the wind. He could remove all need for even simple calculations by drawing up a table connecting wind speed with time taken to put on 500 revolutions. Better still, he could make a graph from which he could swiftly read off the one from the other. If he had such a graph he would really be in need of nothing more, but it is more convenient and more usual to prepare and use a graph which takes account of revolutions *per* unit of time and not time *per* so many revolutions. Now the Vertical Log current meter is an instrument provided with cups which are turned by the moving water, moreover, the revolutions made by the cups are registered on counters which are always in view. It is possible to prepare and use with it a graph of the former kind, and we have such a curve connecting cup speed and water speed. But, the Vertical Log is possessed of straight line calibration within a very little. This means that it would be possible, if desired, and if expense did not matter, to fit its counters with a gearing so that they would read directly in miles. It means too, that it would be possible to convert revolutions to miles even though the counters were read only very infrequently. It will be seen that this possibility is the basis of the method of use adopted.

An explanation will now be given to show how it is possible to prepare a calibration curve of the most useful kind — a graph connecting cup revolutions *per* unit of time and wind speed. Keeping in mind the wind instrument for the time being, it will be assumed that the first kind of test made (running a mile at different speeds) had given the results mentioned already. It should be remarked, however, that the results in question show a much greater variation with wind speed than one would expect to obtain with a good instrument. The curve made from them in the way already described would really only serve one purpose. The observer could draw a straight line which was nearest to the curve, that is, he could draw the straight line which ran most evenly through the dots. Then he could drop a vertical line from its middle-point to the bottom edge of his paper. Where this line ran into the scale of revolutions he could read off the figure. He could take that figure as being the single figure, easily-obtained, for use in converting revolutions to miles if he only intended to read the instrument at longish intervals of time, and if the purpose he had in view permitted him to accept the inaccuracy involved.

To prepare the most useful kind of calibration curve to which reference has been made, it would be necessary to repeat the tests in the motor-car in a different manner. Instead of running the car for a fixed distance at constant speed, it would have to be run for a fixed time at a constant speed. It will easily be understood that the whole range of speed could be worked again, and that one could finish up with the desired curve connecting revolutions *per* so many minutes and miles *per* hour. If convenient (and for many purposes it would be so) the curve could connect cup revolutions *per* ten minutes and wind speed in miles *per* hour.

Clearly, by using such a curve properly, one could get results of wind run over long periods which would be free enough from error, even though the relationship of revolutions to miles varied noticeably with wind speed. True wind speed could be obtained at frequent intervals and the average speed worked out over a whole day. This would make it possible for wind travel in the course of the day to be calculated reliably, because, as has been said in other words, the speed of air movement could be obtained quite accurately at any moment, whether the instrument concerned had straight line calibration or not. It happens that, as already stated, the Vertical Log current-meter has (within a very little) a constant relationship between cup revolutions and water movement. In its case, therefore, a conversion curve is really necessary only if stream speed needs to be read off from time to time; if it is only desired to convert revolutions per day into miles of water movement, a curve is not necessary. The importance of this will be realised later when two ways of using the instrument are described. Dutch users of the Vertical Log employ it in a way which involves reference to a calibration curve, and it is to them that we owe the curve which appears on the figure.

THE CALIBRATION OF CURRENT-METERS.

We have applied our remarks on calibration to wind-measuring instruments quite intentionally. Such meteorological instruments are rigidly mounted, whereas current-meters are usually suspended in the sea from wires, electric cables, ropes or chains according to their nature. Later something will be said about the effects on the registration of current-meters due to plungings and other movements of the anchored observing vessel, particularly at times of wild weather. For the present we may mention that current-meters can be calibrated in various ways. A customary manner is not greatly unlike that supposed to have been adopted in the case of the cup anomometer of which we have been speaking. A usual method is to hang a current-meter from the travelling gantry which runs above the ship-testing tank used for making experiments with wax models of ships' hulls. This gantry runs on lines along the sides of the pool and observers can ride on it. Clearly, they can obtain all the data they wish to enable them to prepare a calibration curve, if the rate of travel of the gantry can be varied to cover the range of speeds of the streams in which the instrument is to be used. In this way thorough calibration tests have been made of various types of current-meter which can conveniently be towed in the manner described. Such tank-tested instruments can in turn be used when need arises to calibrate such a current-meter as the Vertical Log which cannot be towed through the still water of a testing tank. As will be seen later, the current-meter concerned is far too cumbersome and needs too great a depth of water to be amenable to tank tests. It is, however, free from the fault of registering as currents the movements of the observing ship, and calibration tests like the first "fixed distance" tests mentioned above in the case of the anemometer were made quite simply under actual working conditions. A log-line was prepared with a very accurately measured length equal to one-twentieth of a sea-mile marked off on it. An ample length of free line was allowed between the measured length and the log-ship. The latter was a deep-riding object which "took a very good grip" of the water, and the marked line was of the length stated under the conditions of strain imposed upon it when actually in use. Having suitably suspended the Vertical Log current-meter in the water to plumb the same depth as the drifting log-ship, the number of revolutions put on by the counter of the instrument for a run of the log-line was noted for all speeds of stream met with over a period of about three days. In this way account was taken of stream speeds up to about 3 1/2 knots, and beyond that speed the instrument has not yet been tested. Many scores of runs were made and the instrument was modified over and over again in small details until the times was reached when the cups always turned the same number of times with very little variation indeed. Thus it became possible to convert revolutions to miles when it was intended to read the counters only once or twice a day. It happened that the instrument was taken into use by Dutch coastal survey engineers, and they were able, with the excellent facilities at their command, to prepare a calibration curve of the cup-speed to water-speed type. This they did by comparing the behaviour of the Vertical Log with that of very accurate electrically-recording current-meters which had themselves been very reliably calibrated earlier in ship testing tanks. The curve which they prepared was very little removed from being a straight line, and from it we obtained an average value for converting revolutions to miles. This was found to be in complete agreement with what had been discovered in the course of the log-line tests. That the Dutch testing curve was so nearly a straight line was extremely satisfactory, but, had it not been so, the Vertical Log would still have served to give correct speeds of water movement. This it would have done because it has the unusal feature that its revolution-recording counter is always visible to an observer. Thus, "revolutions *per* ten minutes" can be read off whenever desired, and whether the testing curve were straight or far from it, an observer could have found the stream speed on referring to it. The fact that the testing curve is so very nearly a straight line permits the Vertical Log to be used in two different ways (if necessary at the same time) as will be described. This matter of calibration has been described at length for a very good reason. As already stated, the current-meter can be read at all times on deck. This fits it to supply information at any moment as to the speed and direction of set being experienced by fog-bound ships navigating narrow waterways in the neighbourhood of an observing lightvessel. That is important, and the information may one day be considered sufficiently valuable to warrant the provision of the arrangements which would be necessary.

EFFECTS OF THE MOVEMENTS OF THE OBSERVING VESSEL.

Various well-known current-meters record the revolutions made by either a set of cups or a propeller which rotates when the submerged instrument has set itself head to stream after having been lowered to the desired depth on a line, a wire, or an electric cable. It is not intended to give here any detailed description of instruments other that the Vertical Log, but it is considered of interest to dwell upon certain undesirable features of a number of instruments — features which the Vertical Log was specially designed to exclude. Let us consider the behaviour of a cup or propeller instrument which is completely self-contained in that all its working parts are right out of sight under water when it is in use. This may be illustrated by referring to one type only, and for this purpose the Drift Indicator with which Fisheries Notice N° 17 dealt will be considered. That instrument has a set of cups and, when these have been rotated by the stream a certain number of times, a small bronze ball is made to fall from a hopper and run down a magnetised "needle" to drop into one or other of the compartments in a radially-divided box beneath. The magnetized needle or compass always throws falling balls towards magnetic north, but the instrument heads in different directions according to the set of the stream. It is possible when the instrument is hauled in after being in operation for three days (the usual period) to say how many "miles of water" have flowed past the ship towards various directions in the time. Let it be supposed that the instrument has been in use for three days during which the sea has been flat calm, and let it be assumed that there have been no movements of the ship towards and from its anchor. Under such circumstances the record could be accepted without any misgivings, if only it were known that the movements of the cups had never been interfered with by weed or other material in the water. When the weather was bad and the ship lively, certain doubts would necessarily be entertained about the reliability of the results however. Every big lift of the ship would mean that the instrument would be dragged up through the water for a certain distance. It could by no means be assumed that the cup faces would remain vertical either during the lifts or the succeeding plunges. It is almost certain that the cups would perform quite a lot of revolutions which had no relation to the horizontal movement of water past the ship. It is more than likely, too, that the balls dropped in consequence of such lifts and dives of the instrument would be fairly freely distributed all round the compass. The fact that the instrument would have registered a large number of revolutions having no meaning in terms of current would be a serious nuisance. Then, too, there must be considered the chance that the ship might move towards and from its anchor over distances big enough to matter. This it would do if there were any pulsations in strength of stream at short time intervals. Such movements would not matter if, in the long run, they evened themselves out. They might well do so when a strong stream was running which varied only slightly in strength. In such a case the instrument might remain always heading the stream correctly and, at a moment when the stream eased a little, the instrument would be carried towards the anchor — to fall back from it when the stream strengthened again. The movements of the instrument over the sea bottom might well compensate exactly for the pulsations of the stream. At times when the stream was not running strongly, however, the instrument might, when towed bodily through the water by the moving ship, swing about a good deal and not by any means always head the weak stream. Under such conditions it is highly probable that there would be some measure of registration of spurious current.

Now, when very careful observations of current are being made at sea with accurate instruments, all sorts of corrections are made for ship movements. Also, with one much-used meter, use is made of messenger weights which are sent down the suspension wire to start and stop the instrument and to operate a guard door. The latter protects the propeller from any damage due to the impact of weed or other drifting material during descent, ascent, and periods when the instrument is not working. Such precautions are of course most admirable, but they can have little interest to those who are concerned with observations which have to go on for months on end under all conditions of weather, and under constant risk of impact of weed, etc., The Drift-Indicator could and did work for months on end year after year, and its shortcomings could obviously not be overcome by resorting to the use of any of the fairweather instruments employable only under conditions which permit all sorts of corrections and allowances to be made. To obtain such non-stop records of water movement as are needed for fishery research purposes, it was necessary to possess some instrument which could work under all conditions of weather and dirty water.

It was necessary to design a completely new instrument having the features earlier mentioned and the purpose of the remarks just made has been to show the meaning and importance of that feature.

The measuring unit of the Vertical Log consists of two parts — an under-water one in the form of a set of very heavy cups which are turned by the stream, and a registering part well above water near the ship's rail and always in view. The two have a non-rigid connection between them which is a length of chain. It results that the lifting and diving of the cups, consequent upon movements of the observing vessel, effect no registration at all, no matter how lively the movements may be. The direction of stream is viewed by eye and no difficulty arises owing to movements of the ship towards and from its anchor.

All the explanations have now been given which are thought necessary to enable seamen to realise the main problems facing those who wish to carry out continuous observations on water movements in the sea all the year round, and to appreciate the particular features of the simple and very strong instrument considered satisfactory for the purpose.