ECHO SOUNDING

FOLLOWING on the Reports on Echo Sounding issued by the International Hydrographic Bureau in its Special Publications No. 1 of December, 1923, and No. 3 of October, 1924, the present Special Publication of this Bureau is intended to complete the information already given on the subject and to bring to the notice of its Members extracts from and summaries of various recent articles concerning new methods of sounding

I. — General principle of Acoustic Sounding.

The general principle of the acoustic method consists in general of substituting for direct measurement of the depth itself an indirect evaluation thereof by means of the time taken by a sound wave to travel over this depth or, to be more exact, over a submarine path which is connected with the depth by a well known formula.

Thus for the measurement of a length, which up till now has been made with a fixed relative approximation, the measurement of an interval of time is substituted and it is absolutely necessary that this time measurement be precise.

With regard to Hydrography and Oceanography it is generally the case that measurement must be made through sea-water, and therefore it is on the precise knowledge of the speed of propagation of sound through the sea that the problem is more or less based.

At the end of the present publication some data will be given as to the velocity of sound in water according to recent experiments and discussions on the subject which have been received up to the present time, but first the practical conditions under which the instruments have been devised will be considered and particularly the apparatus which has been adopted with the special object of measuring the elapsed time.

Generally speaking sound travels through sea water at an average velocity of 1500 metres (4900 ft.) per second. Consequently by the acoustic method of sounding very great depths can be reached in a relatively brief space of time and the usual depths of about from 70 to 100 metres (38 to 54 fathoms) will be reached in a fraction of a second. It is this rapidity of sounding by the acoustic method which formed its principal attraction from the beginning.

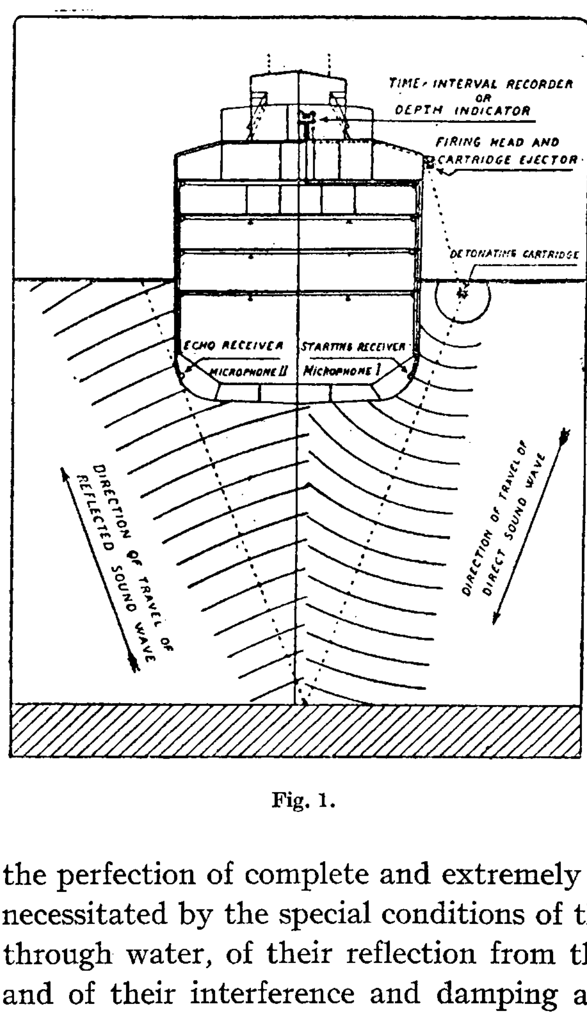


Fig. 1.

The research work undertaken nearly fifteen years ago soon met with serious difficulties due principally to the necessity for measuring extremely short intervals of time, — of about 1/1000th second in order to attain sufficient precision in the depth, for instance to within about 1 or 2 metres (1/2 or 1 fathom).

Hard work, constant effort, considerable expenditure of money together with ingenuity and the great advances made in modern technique have, however, resulted in the perfection of complete and extremely sensitive apparatus such as was necessitated by the special conditions of the propagation of sound waves through water, of their reflection from the bottom and from obstacles and of their interference and damping after a somewhat long distance.

The sketch opposite gives an idea of the apparatus and of the propagation of the sound-waves (Fig. 1).

In order to obtain a sounding a submarine spherical wave, or group of waves, is produced (either by means of the vibrations of a submarine bell, or by the explosion of a cartridge) ; the wave, following the path indicated on the figure, first of all acts on the departing receiver (microphone I) then after being reflected by the bottom, the returning wave (or echo) acts on its return on the arrival receiver (microphone II).

Microphone I starts the chronometer. Microphone II stops it.

The distance travelled by the wave is deduced from the interval of time thus measured taking the velocity of the sound wave through water to be constant and known at the time of the sounding From the situation of the receivers on board, for instance, from the distance between them $2l$ and from the known distance of immersion h, the total depth can be deduced from the formula :

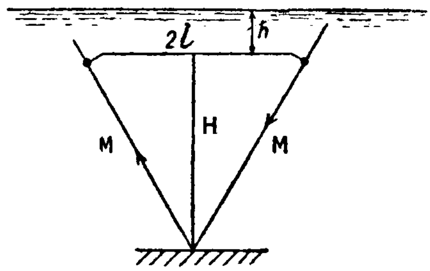


Fig. 2.

$$S = h + H = h + \sqrt{M^2 - l^2}$$

$$2\,M = V \times t$$

$$S = h + \sqrt{\frac{1}{4} V^2 t^2 - l^2}$$

Since the velocity of sound in water is in the vicinity of 1500 metres per second we have approximately :

$$S = h + \sqrt{560{,}000\, t^2 - l^2}$$

and in order to measure a depth within 0.25 metres (10 ins.) an accuracy of 1/3000th of a second in the measurement of t. is required.

Depths of about 5 metres (3 fathoms) will be measured in 1/140th of a second.

The starting and stopping of the recorder must be accomplished in a lapse of time which is so short that it necessitates, on the one hand, the use of relays without delay action, and, on the other hand, excludes the employment of the non-continuous or alternating movements usually used in horometry.

The methods of construction of the various types of chronomicrometers will now be reviewed.

II. — Description of various instruments used for the direct evaluation of the intervals.

1. — Fessenden's Apparatus.

This apparatus, a sketch of which is reproduced (Fig. 3) was described

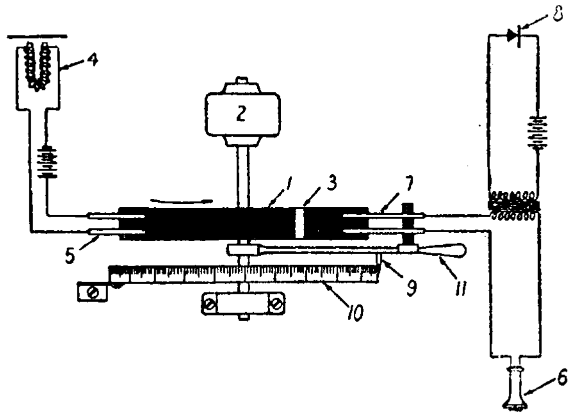


Fig. 3. — Appareil de Fessenden

in detail on page 48 (Fig. 1) of Special Publication No. 3 (page 94 of the *Hydrographic Review*, Vol. II, No. 1).

2. — Admiral Somerville's Apparatus and that of the British Admiralty.

These apparatuses, which approximate closely in principle to the preceding, and with which the British Admiralty has experimented, appear to have proved satisfactory, according to a report made by Mr. F. E. Smith, Director of Scientific Research to the Admiralty.

Figure 4 shows the construction of the Echo-Sounder of the British Admiralty. The transmitter (10) is fixed onto the outer skin of the vessel and consists of a steel membrane 5 inches (12.7 centimetres) in diameter; it is caused to vibrate by a spring electric hammer kept separated from the membrane by a solenoid the circuit of which is automatically interrupted every half second for 1/400th of a second.

The tone emitted has 1250 vibrations. The receiver is an aperiodical microphone by W. Bragg. A motor giving 1/8 H. P. at 1200 revolutions per minute moves, every half second exactly, the axle (1) which carries discs (2) and (3) and has a centrifugal governor. Once in each revolution each of the discs interrupts the closed circuits (8) and (9) by means of the insulated keys (4) and (5), and of the pairs of brushes (6) and (7).

The transmitter (10) is in the circuit (8) which is connected to the main electric circuit of the ship, whilst the brushes (7) (onto the circuit of which is branched in parallel the telephone (11)) are connected to a coil inductively coupled with the circuit of the receiving microphone (12).

Each interruption in the circuit of the distributor causes the emission of a sonic signal, which, however, is not heard through the telephone (11) during the short interval of time while the circuit (9) remains dis-

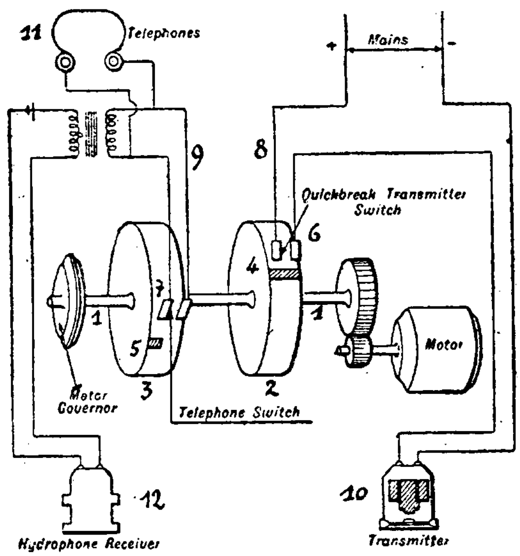


Fig. 4. — British Admiralty Apparatus.

connected by brushes (7). No sound is heard in the telephone except when the direct wave coming from the transmitter or the echo from the bottom of the sea strikes the receiver at the brief instant when one of the brushes (7) is situated on the insulated key (5). By moving the pair of brushes (7), which is effected with a handlever, the arrival of the direct waves or that of the echo may be heard in the telephone, and by measuring the amount of movement the measurement of the interval of time between the two arrivals (or the depth) is obtained. The transmitter and the receiver are so near to one another that their respective distances may be taken as nil and if there be a difference of 24° between the positions of the brushes when receiving the echo and the direct wave, an interval of time of $\frac{1}{2} \cdot \frac{24}{360} = \frac{1}{30}$ of a second is obtained which, with 1500 metres of velocity of propagation, gives a path of 50 metres (164 ft.) or a depth of 25 metres (13 3/4 fathoms).

While the American Sonic Depth Finder is scarcely utilisable for depths of less than 75 metres (41 fathoms), the British Echo Sounder gives good results for depths from 16 to 64 metres (8 3/4 to 35 fms.).

Comparison of soundings in these small depths shows that the depths obtained by echo are a little less than those obtained by lead. The difference varies between 0 and 23 feet (7 metres) and on an average is from 6 to 10 feet (2 to 3 metres).

In great depths the number of revolutions must be taken carefully into account, for 360° in 1/2 a second corresponds to a depth of 375 metres (205 fathoms), and it is most advisable to distinguish carefully between a depth of h metres and a depth of $h + n\ 375$ metres, n being a whole number.

This apparatus has the great advantage of being selective in the following manner, it reduces to a very short interval of time the necessary period of awaiting the echo, it avoids most disturbances and inconveniences due to noise on board the ship.

3. — The « Fathometer » of the Submarine Signal C° of Boston.

This apparatus, also based on the same principle as that of FESSENDEN, differs from the above by the particular feature only, *viz.* the angle to be measured is observed by means of a lighted index composed of a Geissler tube which turns with the disc and which is illuminated when it receives the reflected acoustic signal.

4. — Spitz's Apparatus.

An outline of this apparatus is shown in the attached figure 5 and it

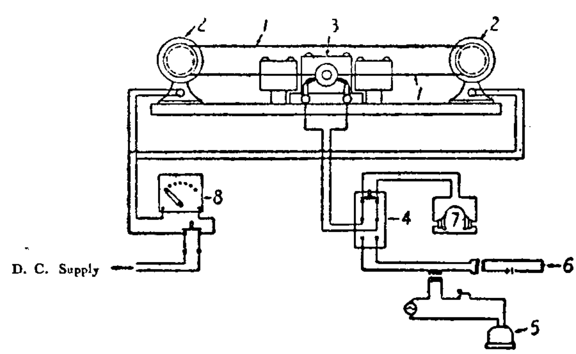


Fig. 5. — Spitz's Apparatus.

was described on page 49 (Fig. 2) of Special Publication No. 3 (page 95 of the *Hydrographic Review*, Vol. II, No. 1).

5. — Langevin's Apparatus.

A description of various models has already been given on pages 39 to 45 of Special Publication No. 3 (pages 75 to 91 of the *Hydrographic Review,* Vol. II, No. 1).

6. — Apparatus by Ingénieur Hydrographe Marti.

In 1919, M. MARTI, of the French Hydrographic Service, read a paper at the Académie des Sciences describing the first experiments undertaken by him ; the sonic source originally consisted of an explosion of a charge of powder.

From this first paper, which is important from the point of view of application to hydrography, it is learnt that echo sounding (which was then being employed for greater depths ; *i. e.* up to 4000 meters (2200 fms.) is subject to errors owing to the uncertainty as to the velocity of propagation of sound, due to imperfect knowledge of the temperature of the various layers of water traversed.

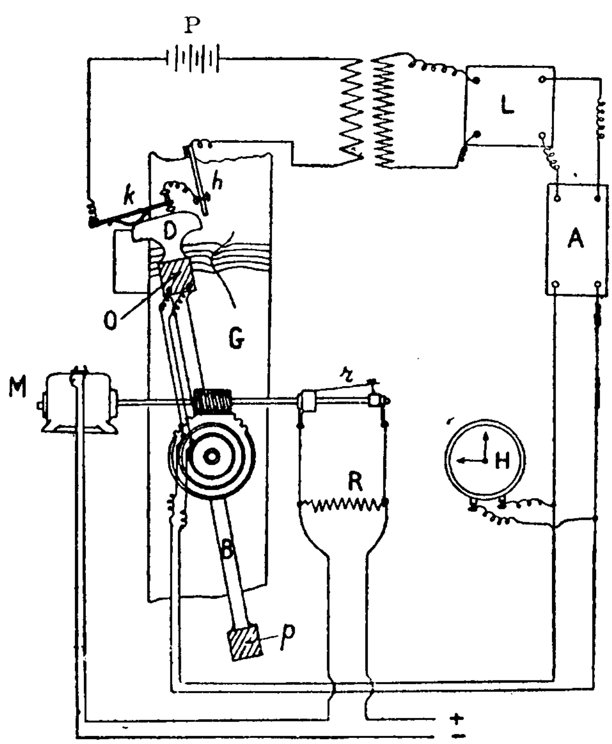


Fig. 6. — Diagram of apparatus by Ing. Hyd. Marti.

Such errors have, in any given area, a systematic character which must always be taken into account in hydrographic surveys, for which purpose the temperature at determined points should be ascertained and the values thus found applied to points situated in the vicinity. A closer study of submarine temperatures at various stations might reduce such errors in the future.

The finished apparatus, a sketch of which is given in Fig. 6 and, according to the patent which has been taken out in France, no longer employs an explosive transmitter, but an electrical transmitter of the LANGEVIN type, such as has been described, which serves the two purposes of transmitting the waves and of receiving the echo produced by the bottom. The interval of time which elapses between the two signals is measured by means of a very ingenious arrangement : a constant speed motor *M*, controlled by means of a centrifugal governor *r*, which introduces resistance *R* as soon as a definite speed is exceeded, rotates, by means of an endless screw fixed onto the shaft, a wheel to the axle of which is attached an arm *B*, which carries on one side an extremely sensitive oscillograph *O* and on the other side a counterweight *p*.

A smoked paper recording strip *G* moves below the plane in which the arm *B* is situated and, when not attracted, the stylus of the oscillograph draws arcs of circles on this strip. The wires of the oscillograph are connected by means of two concentric rings on the wheel of the arm *B*, and by the corresponding brushes, with the amplifier *A* and with the transmitter-receiver represented in outline by *L*. Thus a current passes through the oscillograph both when the sound signal is emitted and when it returns and this causes the stylus to deviate under both circumstances. The arcs drawn by the stylus show waves at emission and return of the sound waves, and the distance separating the initial points of these wavy lines is obviously in proportion to the elapsed time and consequently to the depth of water.

The cam *D* by acting on the double contact *H* and *K* causes the emission of the sound at the exact instant when the stylus of the oscillograph is on the edge of the recording strip ; when sounding in great depths the emission may be advanced by a definitely determined space of time, in order that the second indentation shall always fall on to the recording strip. (The battery and the electric circuits of the receiving-oscillator are shown conventionally by *P* and *L*)

By joining the initial points of those indentations which were produced in the record by the reception of the echo by the oscillograph, a profile of the bottom of the sea is obtained and obviously the depth can be deduced therefrom.

A clock *H* short-circuits the oscillograph at regular intervals so that a record of signals is missing from time to time, which makes it possible to ascertain the relative situation of the soundings taking into account the course and speed of the ship.

The methods of sounding based on the precise determination of the interval of time which occurs between the departure of a sound signal and the reception of the echo thereof requires the use of special apparatus of high precision for measuring relatively brief intervals of time.

Similarly the emission of successive sound signals with equal rythmic cadence, as well as the continuous steady movement of a recording strip, cylinder or disc, give rise to new problems in connection with the study of clock mechanism and chronometry.

Of such mechanisms " constant speed motors ", or rather motors the speed of which varies but slightly between certain known limits, may be used at the same time for driving the apparatus and to make the required relative measurement of the intervals of time. Such motors (called " constant speed " motors) are in general use today in a great number of automatic devices into which the factors of speed and time enter such as, for instance, the apparatus for tracing the courses of ships.

Thus it may be useful to give some brief descriptions of the various devices which have been considered.

7. — Constant speed motor of the British Admiralty.

The Experimental Section of the Admiralty at Teddington has developed a type of chronometer which reads to 1/1000th of a second; the mechanism of the apparatus is extremely simple and the results obtained are most satisfactory.

It consists of a soft iron rotor turning in ball bearings into which rotor are cut 10 cavities corresponding to 10 teeth (Fig. 7).

The inductor consists of two iron discs provided with 10 teeth between which is inserted a coil of copper wire which surrounds the rotor.

The current from an electric battery is sent through this coil at intervals of 1/50th of a second by means of a tuning fork electro-magnetically excited and which, at each vibration closes the contact opposite with one of the prongs. In this way the speed of the motor is controlled 50 times per second. The fly wheel *V* is fixed to the axle of the motor and transmits its rotation to a small wheel which may be applied to its periphery by means of a suitable relay *R*; the axle of this wheel *r* carries an index by which the number of thousandths of a second during which wheel *r*. remains pressed against wheel *V*, can be read on dial *Q*.

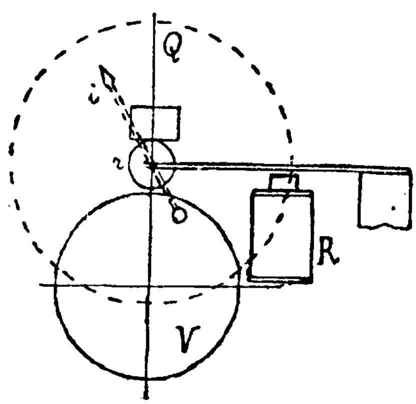


Fig. 7. — Constant Speed Motor of the British Admiralty.

Normally the index is held fast because a brake presses against it and this brake is represented in the figure.

The apparatus works with great regularity and allows experiments on the transmission of sound analogous to those now dealt with to be carried out.

8. — Constant speed regulator.

Another type of constant speed regulator, of which several models have been produced by the " Société des Etablissements Henry Lepaute ", 17, rue Desnouettes, Paris (XVI), is constructed (as shown in Fig. 8) to utilise the action of a prong of a tuning fork maintained in vibration electrically (*D*) in order to push wheel *R* in the direction of the arrow the periphery of which wheel is in the form of a sinusoide.

The sinusoidale oscillation of the tuning fork is thus transferred into a continuous motion of rotation around the axis *O*.

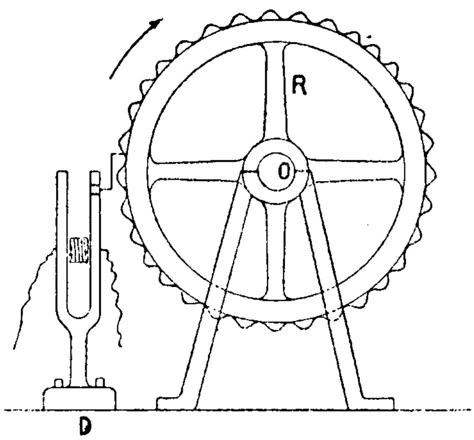


Fig. 8. — Constant Speed Regulator.

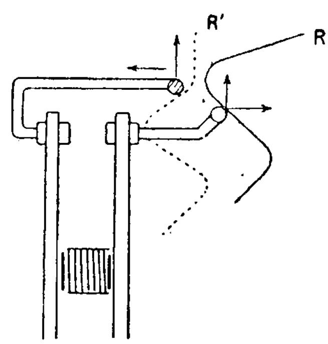


Fig. 9.

The second prong of the tuning fork acts on the wheel *R'* identical to *R* and firmly fixed on the same axle, but the projections of which are displaced about 1/2 period in relation to those of *R* so that if the first prong of the tuning fork tends to communicate to the wheel an undue acceleration, the second prong of the tuning fork acts in opposition thus checking the whole (Fig. 9) and the converse occurs during the following 1/2 period. The common axle of the wheels is mounted on ball bearings and thus the motion is continuous.

9. — Constant speed motor of the « Sonic Depth Finder » of the Navy of the United States of America.

In the acoustic-sounder of the Navy of the United States of America the constant speed of the disc (as illustrated in Fig. 10 and which was described on page 67 of Special Publication No. 3 and in the *Hydrographic Review*, Vol. II, No. 1, page 113), is maintained by means of a tuning fork. Fig. 11, which represents the circuits of the " Sonic Depth Finder " shows also the principle of the device. The electric motor fed by the shunt circuit shown on the upper right hand side of the drawing, is roughly regulated by the rheostat shown on the left. In addition to the winding for continuous current, it is wound for single phase alternating current, in the same manner as an ordinary rotating transformer. The alternating current which is collected on the rings on the right hand side of the motor is used to feed transformer P, the secondary of which, at every half vibration of an electrically worked tuning fork, closes the circuit of a 100 watt incandescent lamp. In the figure a contact will be noticed on the upper prong of the tuning fork, which contact is inserted into the

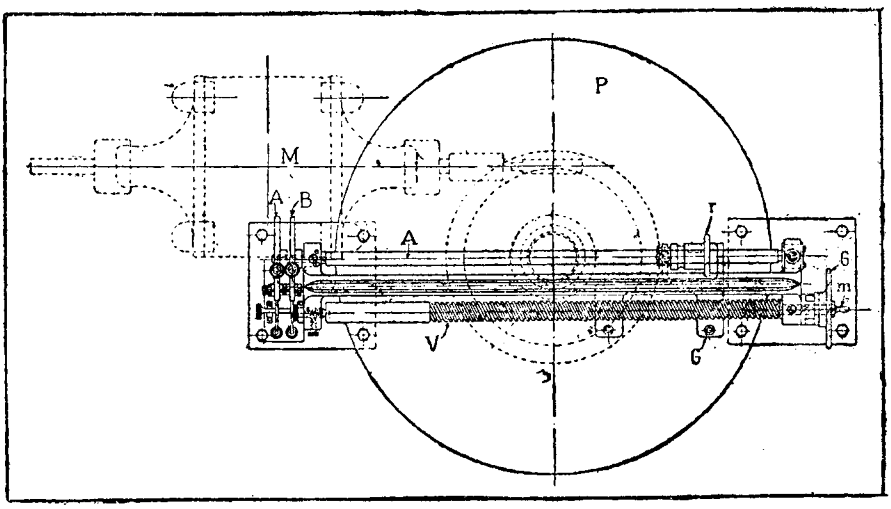


Fig. 10. — Plan of the « Sonic Depth Finder ».

continuous current circuit, and this maintains the vibration of the tuning fork. On the lower prong is a double contact which at every half vibration closes the circuit of the transformer on the lamp.

The energy which is absorbed by the lamp at each closing of the circuit depends on the electromotive force which acts in the alternating circuit at the instant of contact and this electromotive force depends on the difference of phase between the vibrations of the tuning fork and the oscillations of the alternating current. When contact occurs at the instant when the alternating current is at the phases 0° or 180°, the lamp does not absorb any energy ; as the motor accelerates the absorbed energy rises to a maximum, thus putting a brake on the motor, and finally a state of equilibrium exists between the accelerating couple due to the electromotive force of the continuous current and the retarding force due to the energy of the induced alternating electromotive force which is absorbed by the lamp, whereby a constant speed is ensured. By varying the charge, the above mentioned difference of phase also varies, but for a constant charge, that is to say, for a well defined position of the small wheel on the surface of the disc, the relation of phase corresponding to equilibrium is established in a very short time, and gives a constant and equal speed whatever be the charge applied within limits compatible with the use of the instrument.

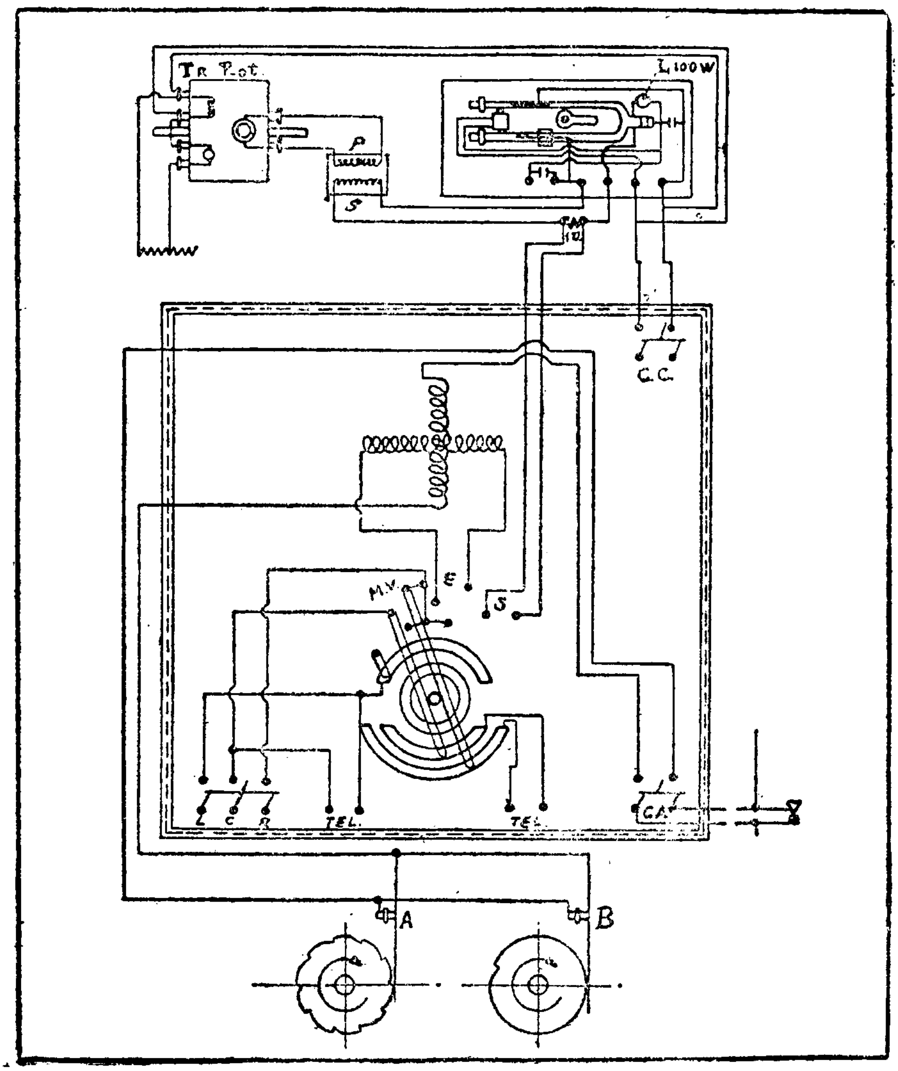


Fig. 11. — Diagram of circuits of the « Sonic Depth Finder ».

In figure 11 the circuit of the alternating current which feeds the oscillator is shown and this is closed by contacts *A* and *B* coming into play by means of two toothed cams — one with ten contacts per revolution and the other for a single contact per revolution — which turn with the small friction wheel. The current of the oscillator passes through the variometer, represented in the centre of the figure, which, as is shown, acts as a regulator for one of the telephones. The central switch is used ;

1st, in position *S* for connecting a pair of telephones shunted on one 1 ohm resistance inserted in the alternating circuit of the motor in order to ensure the synchronism of the tuning fork, — 2nd, in the position *E* for connecting one of the telephones to the terminals of the variometer for hearing the suitably damped signal at its departure and the other telephone to the terminals of the submerged receiver, — 3rd in the position MV for connecting the two telephones to the hydrophone in order to measure the angle which the reflected sound ray makes with the lines of

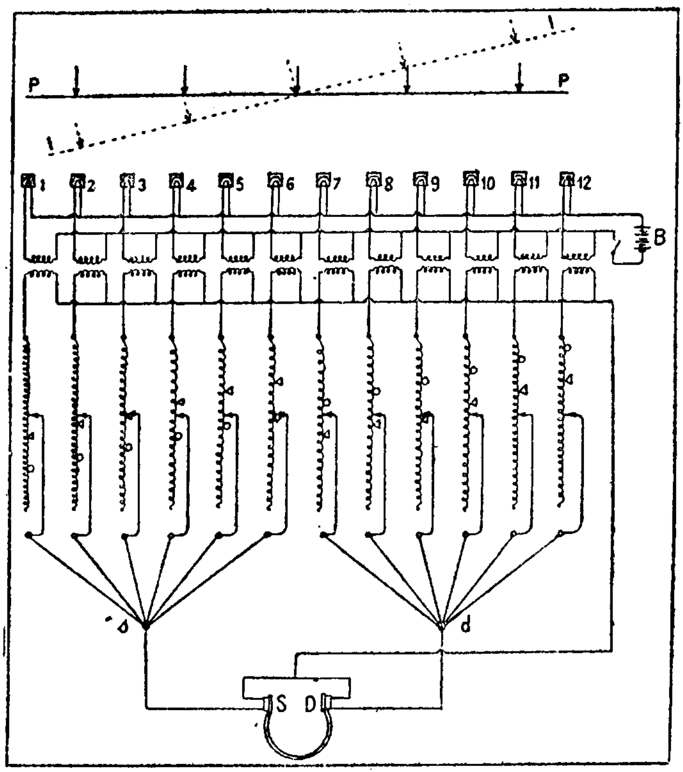


Fig. 12. — Diagram of MV Hydrophone (Multiple variable).

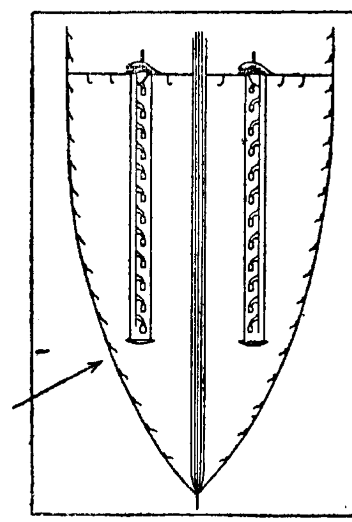


Fig. 13.

hydrophones (figures 12 and 13) which it is necessary to measure sometimes. (*See* method of the standing wave, Special Publication No. 3, page 61, and *Hydrographic Review*, Vol. II, No. 1, page 107.)

III. — Principle of the submarine sound receiver of the « Sonic Depth Finder ».

Dr. Havey C. Hayes writes, in an article published by the *Geographical Review* New-York, 1924, as regards this apparatus :

Several types of submarine sound receivers have been perfected, any one of which is commonly called a hydrophone. The type best suited for our purpose is called the " MV Hydrophone " (multiple-variable). It will be seen that this receiver can be " focussed " toward any direction wherein the operator may care to listen and that this results in intensifying the sound from the desired direction and at the same time weakening the response to sounds from other directions. The principle of operation of this device can be more readily understood by first considering how direction is determined by the unaided ears.

The sense of direction of sounds, the " binaural sense ", is largely dependent upon the difference in time of arrival of the sound at the two ears. If the sound waves stimulate the right ear first, one has the impression that the sound source is located to his right ; and, similarly, if the left ear is stimulated first, one gains the impression that the sound source is located to his left. Up to a certain point the angular bearing to the right or left of the sound source is judged to be greater as the interval between the time of arrival at the two ears becomes greater. When this time interval is zero, or in other words when the sound waves strike the two ears simultaneously, the sound source seems to be neither to the right nor left. One may then have the impression that the sound comes from ahead or overhead or behind or in fact from any point in the plane that is a perpendicular bisector of the straight line joining the two ears. A sound that stimulates the two ears simultaneously is said to be " binaurally centered " and the source of such a sound is said to be located in the " binaural plane ". A straight line joining the two sound receptors (in this case the two ears) is commonly called the " binaural base line ", and the time interval between the arrival of a sound at the two receptors is called the " binaural interval ".

Restating the previous paragraph, we may say that the binaural sense enables us to judge the direction of a sound with respect to the binaural base line and that the definite impression we have of the direction of the sound is a result of the magnitude and sense of the binaural interval. A sound source is judged as lying in the binaural plane when the binaural interval is zero ; or in other words when the sound is binaurally centered.

The binaural interval is not much affected by turning the head slightly when the sound is directed parallel with the binaural base line, and as a result such directions cannot be judged with a high degree of accuracy. The change produced in the binaural interval for a slight turn of the head is greatest for sounds directed perpendicular to the binaural base line (for sounds that are binaurally centered), and as a result the direction of such sounds can be judged with greatest accuracy. The acuteness of the binaural sense for different individuals is surprisingly uniform and is such as to recognize a change in the binaural interval of the order of five millionths of a second.

The relation between the binaural interval and the direction of a sound is shown in figure 14 wherein numerals (1) and (2) represent the sound receptors (the ears), the vector (N) represents the direction of propagation of the sound, the line (2-3) represents the direction of the wave front, (L) represents the binaural base line, and (θ) represents the angle the vector (N) makes with (L). The binaural interval (t) is equal to the time required for the sound to travel the distance (3-1). This is equal to the binaural interval multiplied by (V) the velocity of the sound. Expressed as an equation this relation becomes :

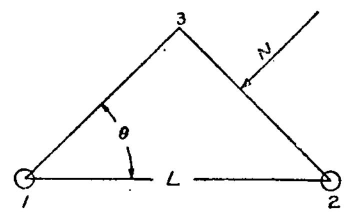


Fig. 14.

$$V \,.\, t = L \cos \theta, \tag{1}$$

$$\theta = \cos^{-1} \frac{V}{L} \cdot t = \cos^{-1} K \,.\, t. \tag{2}$$

Our sense of direction operates in accordance with this equation and has been developed under the particular conditions where (V) is the velocity of sound in air and (L) is the spacing between the two ears. Our ability to judge the direction of sounds in some medium other than air could not in general be depended upon, for the reason that the constant (K) of this equation would be changed through a change in the velocity of sound. If the ratio of (V) to (L) is kept constant, the ability to judge direction is independent of the medium. In the case of submarine sounds the velocity is nearly five times that in air, and as a result our ears would need to be spaced about five times as far apart if we were to employ them for determining the direction of such sounds. If the binaural constant (K) is made greater or smaller than its normal value, then the angle (θ) is judged to be smaller or greater, respectively, than it actually is.

The normal value of (K) is about 3.0×10^3, and the binaural sense is sufficiently acute to determine (t) to within 5×10^{-6} seconds. It follows that for binaurally centered sounds the value of $\theta = \frac{\pi}{2}$ to within a plus or minus error equal to the anticosine of .015, or to within about one degree. This error depends somewhat on the character of the sound, increasing with the purity and pitch, but is well within five degrees for any normal person.

It will now be shown that the error made in judging the direction of a binaurally centered sound can be reduced to a small fraction of a degree. It has been seen that this error ($\Delta\theta$) is represented by :

$$\Delta\theta = \cos^{-1} \frac{V \,.\, \Delta t}{L} \tag{3}$$

In the expression $\left(V \,.\, \frac{\Delta t}{L}\right)$ the factor (V) is fixed since it depends only upon the physical characteristics of the medium, and (Δt) is also fixed since it depends upon the acuteness of the binaural sense. But the factor (L) can be varied to suit our fancy by replacing the ears by two equal sound receptors that are connected, one to each ear respectively, through equal energy-conducting paths. Such an arrangement is shown in figure 15 wherein numerals (1) and (2) represent the two receptors, (3) and (4) represent the two telephone receivers or other means used to convey the sounds to the two ears, and (5) and (6) represent the two equal energy-conducting paths connecting each receptor with its respective ear. The sound can be binaurally centered by turning the two receptors so that the base line (L) is normal to the vector (N). The angle θ will then be $\frac{\pi}{2}$ to within an angle ($\Delta\theta$) represented in equation (3). This error will be inversely proportional to the value of (L). It will be seen that the MV Hydrophone takes advantage of this fact.

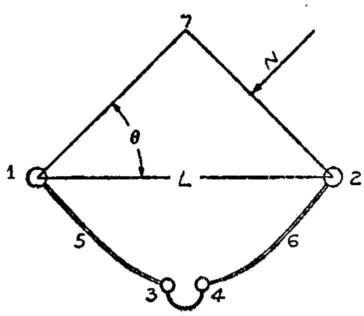


Fig. 15.

Referring again to figure 15, it will be seen that the sound could be binaurally centered by varying the time of energy transit across paths (5) and (6) as well as by rotating the base line (L). The difference in time of arrival of the sound at the two ears is evidently equal to the time required for sound to travel across the length (7-1). This distance, which may be called (S), is equal to the product of the velocity (V) and the binaural interval (t), or :

$$S = V \,.\, t, \tag{4}$$

and the time (t) is equal to the distance (S) divided by the velocity of sound. If the paths (5) and (6) are so designed that the time of energy transit across them can be increased or decreased uniformly and by known amounts, then, if they were adjusted until the time of transit across path (6) is (t) seconds greater than across (5), the sound would reach the two ears simultaneously and would be binaurally centered, the difference in time of transit across the two paths gives (t) and this multiplied by (V) determines the length (7-1), which together with the known value of (L) determines θ, the direction of the sound with respect to (L).

The process of binaurally centering a sound by varying the time of energy transit across the energy-conducting paths connecting the receptors to the ears is called " compensation ", and any device for accomplishing this is called a " compensator ".

The principle of operation of the MV Hydrophone can now be understood in connection with figure 16, wherein numerals (1) to (12) inclusive represent the receptors uniformly spaced along a straight line, numerals (1') to (12') represent the energy-conducting paths, the rectangle (C) through which all the energy paths pass, represents the compensator, and (R) and (L) represent the telephone receivers or other means for bringing the energy paths to the two ears. It is to be noted that half of the receptors connect with each ear respectively. The figure shows six, but more or less than this number can be employed. The compensator (C) is so designed that the response of all the receptors to sound from any direction (N) can be made to reach the two receivers (R) and (L) simultaneously by turning the wheel (W) of the compensator, and the scale (S) is calibrated to read the direction (θ) for any sound that is brought to a binaural center by turning the compensator handwheel. The intensity of any sound that is binaurally centered is relatively great for the reason that the responses to this sound of all the receptors reach their respective ear terminal in phase while the response to sounds from other directions is weakened through the process of wave interference. This results in weakening the local disturbing sounds caused by propellers, auxiliary machinery, and slapping of waves. The benefit resulting from the use of a multiplicity of receptors is therefore seen to be marked, since it intensifies the sounds desired and at the same time weakens those from other directions.

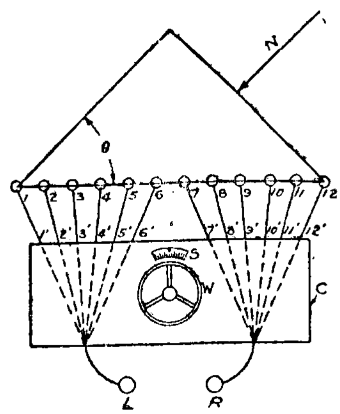


Fig. 16.

It is to be noted that the MV Hydrophone, as described, determines only the direction of a sound with respect to the line of receivers. The source might lie anywhere on the surface of a cone having its vertex at the center of the line of receivers, which is the axis of the cone, and making an angle (θ) with the axis. If the direction is determined with respect to a second line of receptors inclined to the first line, then the direction of the source is uniquely determined by the line of intersection of the two cones.

The actual installation carries two lines of the receivers so arranged that the direction of any sound can be determined with respect to the ship's keel and with respect to a direction athwartship, and this furnishes complete data for determining the direction uniquely.

The device is electrical throughout. Each sound receptor carries a microphone that is stimulated by the submarine sound waves, and within the compensator the electrical circuit of each receptor included a number of so-called electrical retardation units. The time of electrical transit of each circuit is varied by varying the number of these units included in the circuit. This is accomplished by turning a single hand-wheel. The electrical output from the receptors is brought to the ears and there transformed into sound by telephone receivers, one of which receives the output from half of the receptors and the other of which receives the output from the other half.

Sounding with the « Sonic Depth Finder ».

The sonic depth-finding apparatus enables a ship to take a sounding as often as desired while steaming steadily along her course. The minimum depth which can be determined by the sonic depth finder in its present form is 40 fathoms. The maximum is not known. The "*Guide*" has recently taken soundings to depths of over 5000 fathoms, and her personnel believe the installation is capable of sounding the greatest ocean depths.

The minimum depth is not limited to 40 fathoms and is being made 10 fathoms in a redesign of the apparatus. So far as its use in the Navy is concerned there is no need for reducing the minimum depth below 10 or even 40 fathoms for the reason that shallow soundings can be taken by measuring, with the MV Hydrophone, the angle which oscillator signals or propeller sounds (1) reflected from the sea bottom make with the ship's keel. There is no inherent reason why the apparatus cannot be designed to take soundings as shoal as 10 fathoms and probably less.

(1) *See* : I. H. B. Special Publication n° 3, page 54 and *Hydrographic Review*, Vol. II, No. 1, page 100.

The sounding data given by the sonic depth-finding apparatus consist of the distance to the reflecting surface along a direction perpendicular to this surface, together with the direction of the echo with respect to the ship's keel and also with respect to a direction athwartship. The keel and athwartship directions are perpendicular to each other and define a horizontal plane.

Obviously the distance factor, which has been designated as (H), is not the depth except when the sea bottom is horizontal. The depth underneath the ship will be greater than (H), and the depth above the reflecting surface will be less than (H), wherever the sea bottom is not horizontal. These relations are shown in figure 17, wherein (S-S) and (B-B) represent the sea surface and the sea bottom, and numerals (1), (2), (3) and (4) represent respectively the location of the ship, the point of reflection, the point on the surface vertically above the point of reflection and the point on the sea bottom vertically beneath the ship. The angle of dip which the direction (H) makes with the surface is represented by (δ), and the slope of the sea bottom is represented by (β). The angle of dip and the slope of the sea bottom are complementary angles, and therefore a measurement of (δ) serves to determine the slope of the sea bottom.

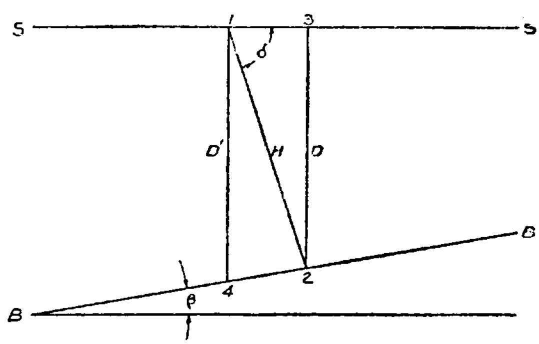


Fig. 17.

The hydrophone does not measure the angle (δ) directly but gives the angles φ and θ which the direction of the echo makes with the keel and athwartship directions respectively. The angle (δ) which the direction of the echo makes with the sea surface and α, the angle which this direction makes with the keel in an azimuth plane, bear the following relations to φ and θ :

$$\cos\delta = (\cos^2\theta + \cos^2\varphi)^{\frac{1}{2}} \tag{18}$$

$$\tan\alpha = \frac{\cos\theta}{\cos\varphi}. \tag{19}$$

From these relations it is possible to determine the value of (D), as shown in figure 17, through the relation.

$$D = H\sin\delta \tag{20}$$

and (D'), the depth beneath the ship, will be given by the relation :

$$D' = \frac{H}{\sin \delta} \tag{21}$$

providing the slope over the region including points (2) and (4) is constant.

Assuming a slope of 30 degrees for the sea bottom (a value that is doubtless abnormal) and a depth of 6000 fathoms, the horizontal distance between points (1) and (3) of figure 4 would be three miles. Under the best conditions a ship cannot know its position at sea to within a radius of two miles. The value of (H) can be shown to be very nearly equal to one half the sum of (D) and (D') for slopes less than 30 degrees, and as a result (H) represents the true depth at a point about midway between points (1) and (3) of figure 17. Therefore (H) always represents the true depth at some point within the area of uncertainty as regards the location of the ship when the location is determined by solar checks. From these considerations it appears that the value (H) serves as well for the preparation of charts and for purposes of navigation as does the more accurate value (D) unless some means is devised for more accurately locating a ship at sea.

Since the determination of (H) does not involve a knowledge of the direction of the echo the question naturally arises : Why not employ a much simpler receiver than the MV Hydrophone ? The answer is that very good sounding data can be taken with the simplest kind of submarine sound receiver consisting of a single receptor of the microphone type. However, even though a ship does not know its actual position on the chart to within two miles, it does not know its progress from hour to hour with sufficient accuracy to warrant all possible corrections of the sounding data for the purpose of developing or of identifying the profile of the sea bottom along the course traversed. Moreover, for many purposes the value of a profile is greatest when it defines the intersection of a plane that is perpendicular to the sea floor. The MV hydrophone enables the navigator to direct his course so that it will define such profiles. If the angle α is zero, the point of reflection lies in a vertical plane that includes the path of the ship, and this plane is perpendicular to the sea bottom. From equation (19) it will be seen that when α is zero θ is ninety degrees. Under such conditions $\cos \theta$ equals zero, and the angle (δ) becomes equal to φ. If therefore, the course of the surveying ship is directed so that θ equals $\frac{\pi}{2}$, as can be done if the MV Hydrophone is used for the receiver, the profile of the course has a definite meaning, and the computations relating to the sounding data are greatly simplified ; for then the complement of the angle φ gives directly the slope of the sea floor at the point of reflection.

There is one more reason, already mentioned, why it is desirable to use the MV Hydrophone, namely, that through its focusing power the intensity of its response to the echoes is strengthened while at the same time its response to the numerous local disturbing noises is weakened.

IV. — Behm's « Echo Sounding ».

The following is an extract from the publication *Tiddskrift for Sövaesen* (a Danish nautical periodical) August, 1924, and is an article compiled and translated by Commander SINDING of the Royal Danish Navy, which gives a report of trials carried out in Denmark with Behm's apparatus.

In 1923 a sounding apparatus was installed on board the Beacon-tender " Lövenörn " for trial. It was invented by the German physicist Mr. Alexander BEHM, and the method of operation is based on the reflection of sound waves from the bottom of the sea.

Owing to various circumstances the time for the trial was very much shortened, and an intended continuation of the experiments on board the Lighthouse-tender " Argus " had to be abandoned on account of the inventor's illness. It has therefore not been possible to obtain satisfactory experience in certain directions, for instance, with regard to the durability of the apparatus, but as the practical applicability seems proved, it may even now be of interest to the readers of this periodical to learn about an invention which, in its simplicity both as regards construction and working, is indubitably ingenious.

Before commencing the description, it might be appropriate to make a few general remarks.

It is a well-known fact that sound waves spread spherically with the sound producer as a centre. A sound wave, at any given moment, consequently would consist of a thin-walled globe shell of the condensed fluid in which the sound wave is produced. It has, for some time, been possible to photograph such sound waves in air, but when photographing sound waves in water BEHM had to use other methods, as it is a well-known fact that the rate of motion of sound in water is about 4 to 5 times as great as in air, or about 1435 m. (4700 ft.) per second.

The manner in which sound waves were photographed in water was briefly as follows : An electric spark was made to produce sound waves under water, and about 1 : 30,000 of a second later these sound waves were illuminated by another electric spark in such a manner that images thereof were thrown on to a sensitized plate.

A circular picture of the sound wave is produced, for the rays of light from the electric spark cut through the globe shell which, from an optical point of view, acts as a lens, while the rays passing through the cavity of the globe do not appear. Fig 18.

Very short intervals are dealt with. The lapse of time between two successive " oscillation wave shells " is about 1 : 1,435,000 of a second.

It was necessary to make these experiments in order to study acoustic conditions in water, and BEHM thereby established the premises for the practical adaptation of his method.

Thereafter it was possible to ascertain depths of water of about 2 to 3 m. (1 to 1 1/2 fms.) with an accuracy of about 1/4 m. (10 ins.) but in order to do so it was necessary to record a time curve and this was done by means of a special apparatus and a tuning fork vibrating at 1500 vibrations per second.

Although with this apparatus it was possible to illuminate, develop and fix the picture in a very short time, it was not suitable for practical use on board a ship, and it was not until after years of experiment that BEHM succeeded in constructing a mechanical apparatus which is able to record very small lapses of time with an accuracy of about 1 : 10,000 of a second by direct reading on a scale.

The principle of the Sounding.

Microphones are placed on both sides of the vessel below the surface of the water, of which one is a receiver and the other an echo-receiver.

By exploding a cartridge about 1/2 m. under water in front of the receiver, this is affected first and then the echo-receiver is affected by the sound wave coming up from the bottom.

It is the lapse of time between the respective moments at which the microphones are affected which is now measured, *i. e.* the time required by the sound waves in travelling from the receiver to the bottom and thence, as an echo, back to the echo-receiver.

The depth is then found by using the distance between the membranes — which membranes as a rule are placed at some distance from each other in a longitudinal direction in view of the transmission of the sound wave through the fabric of the ship, *etc.*, — and the measured lapse of time as arguments.

In practice the amount of swing of the chronomicrometer is compared

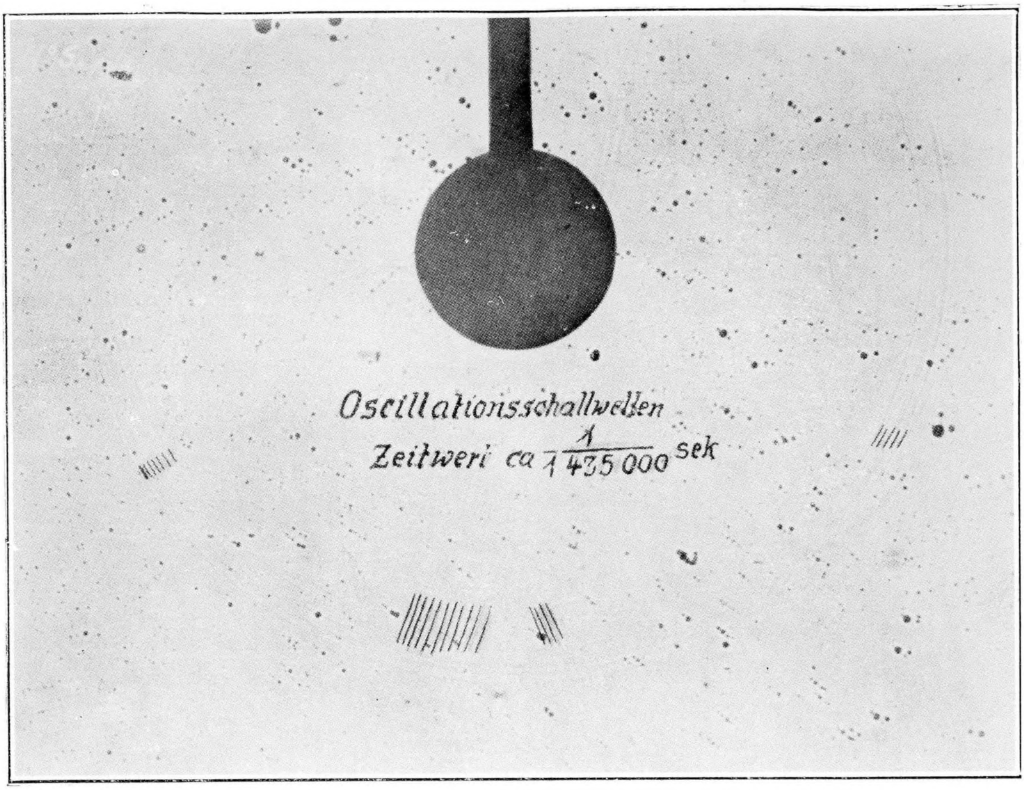


Fig. 18. — Sonic wave. Interval of time $\frac{1}{1.435.000}$ sec.

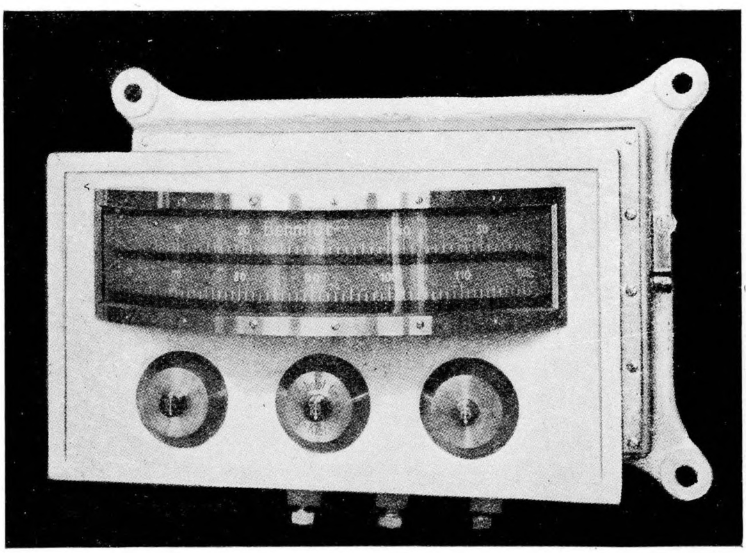


Fig. 21. — Behm measuring Apparatus.

with a depth measured in the ordinary way, and by several such comparisons the depth may be drawn graphically and marked on the scale of the measuring apparatus, and thus the depth is now read directly off the scale.

Arrangement of the Echo Sounding Apparatus.

The plant consists of the cartridge chamber (*K*) with pipe-line, firing-gear (*U*), chronomicrometer (*M*) as well as the microphones, which are not shown on the outline drawing.

Of these objects only the chronomicrometer will be described in detail as being the essence of the invention, while the other devices will only be described to such extent as is necessary for the understanding of the working of the sounding.

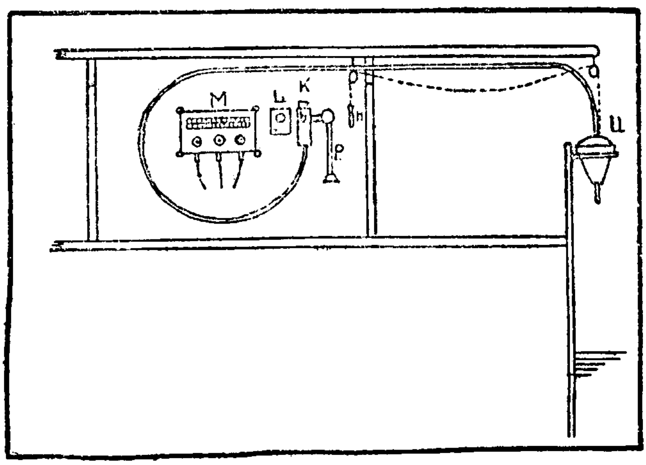


Fig. 19. — An outline of the Arrangement of the « Echolot » as it was installed in the chart-house of the « Lövenörn ».

The cartridge is placed in the cartridge chamber, which is closed with a lid, and then by means of the air-gun (*P*) it is blown through the pipe-line (the loop) and is caught by the firing-gear. Here the cartridge is held by three arms, which form contacts in such a way that the cartridge is fired by the closing of an electric circuit. By doing so the bottom part of the cartridge is launched into the water. This part is provided with a time-fuse which is adjusted in such a manner that it ignites two grammes of trinitrotoluol in the bottom end of the cartridge after a lapse of time which corresponds to the cartridge having reached 1/2 to 1 m. below the surface of the water.

By pulling the handle (*H*) the arms in the firing-gear are opened, which causes the cartridge case placed in it to fall out. Should it be forgotten to remove the case before a fresh cartridge is placed in the cartridge chamber, this will be indicated by a small lamp showing a red light. After having blown a fresh cartridge into the firing-gear, the continuity of the electric circuit may be ascertained by pressing on a small contact, if correct the little lamp will show light.

Chronomicrometer.

The most important part of the plant will now be examined more closely, the part in which the whole of the invention really lies, the mechanical chronomicrometer (*Der Kurzeitmesser*).

Seeing that in water sound waves move at a speed of 1435 m. a second, it will be appreciated that in order to show a depth under the ship of for instance 5 m. (16 1/2 ft.) the apparatus must be able to measure with accuracy a lapse of time of $\frac{2 \times 5}{1435}$ or about $\frac{1}{140}$ second.

Of course it is possible to measure with the greatest ease far smaller lapses of time, but on board ship the measuring appliances formerly used would not be suitable, for quick operation by people who are completely ignorant of such measuring is required. With BEHM's chronomicrometer the problem is solved, seeing that it acts by pressure on 3 buttons, in fact the simplest operation imaginable.

The construction will be seen from the plan, Figure 20.

A disc (1), which is balanced with the most complete accuracy and which revolves in ruby-bearings, is provided on its circumference with the armature (2), the nose (*N*) and teeth (Z). The armature can be affected by the electro-magnet (4 *a*).

When the armature has been attracted, the spring (6) will be bent and the nose (*N*) will close contact with the stop (5), thus closing the circuit through the microphone (I).

Round the spindle (3) is a weak spiral-spring (the balance spring), the object of which is to swing the disc back, so that the armature of the disc is again brought near enough to the electro-magnet to be attracted.

On the spindle is placed a small mirror by means of which the light from the lamp 11 is thrown on to the scale, where it appears as a narrow strip of light. The turning of the disc may thus be read off the scale.

The disc may be held by a brake consisting of a brake-block fitted on a spring (7). The brake may be affected by an electro-magnet (4 *b*), and when the brake is in its retracted — bent — position, the circuit through microphone (II) is closed.

The source of electricity is a battery with a potential of 8 volts and a consumption of current at the poles of the magnet of about 40 to 50 milliamperes.

Assume the apparatus to be in a " strained " position as shown in the figure, that is the spring (6) bent, the brake pulled back and the circuit through the microphones thus closed. If now microphone (I) be affected,

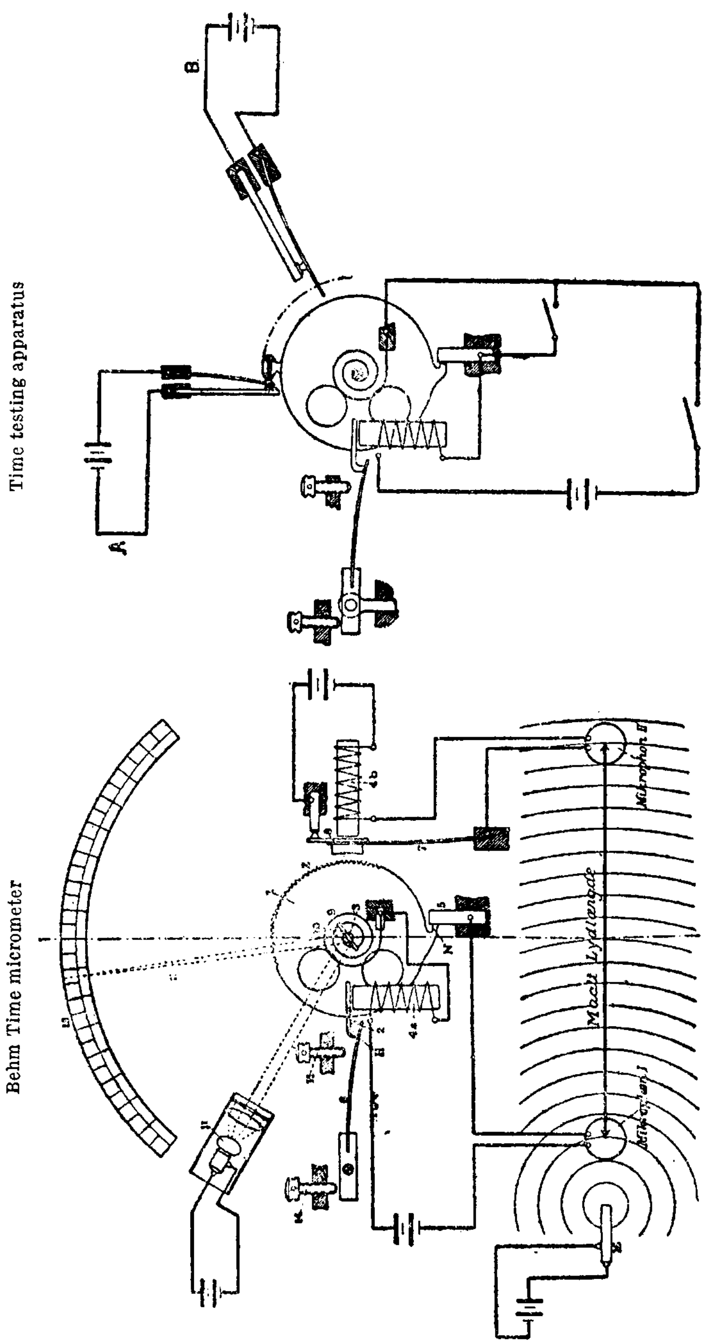


Fig. 20. — Length of sound measured.

the current in this circuit will be cut off, the spring (6) will give the disc an impulse, and it will turn until it is stopped by the brake. This takes place at the moment when microphone (II) is affected, as the circuit of the brake is then cut off, and the brakeblock is pressed against the teeth of the disc by its spring. The strip of light will leap to the graduation on the scale which corresponds to the lapse of time between the moments when the microphones are affected.

The measuring apparatus is provided with 3 buttons (*see* Fig. 21). The button to the left, No. 1, is the main switch, and by pressing it the batteries are connected and the lamp lit. By pressing the button in the middle, No. 2, the self-switches in the circuits of both microphones are short-circuited, which draws the brake back and the disc occupies its strained position. By pressing the button No. 3 the circuit is closed through the firing-gear (*Der Geber*, Fig. 22) by which the cartridge is ignited, and its bottom part is fired into the water.

As the batteries are in operation only for the few seconds during which button 1 is pressed down, they do not show much wear. It must, however, be possible to determine whether the batteries are constant, as the magnet coils must have a constant strength of current in view of the demagnetising of the cores and the strength of the magnetic field in which the moving parts operate.

For this purpose a controlling apparatus is used which is built into the same box as the chronomicrometer.

Control Apparatus.

The controlling apparatus (*see* plan Fig. 20) is the same, in principle, as the chronomicrometer itself. It consists of a receiving disc which may be affected by an electro-magnet and by a flat spring in the same manner as the chronomicrometer disc. An insulated tap is fitted on the edge of the disc and this is able to affect switches in 2 circuits. When the disc is " strained ", both contacts are closed, but if the disc is released by switching off the current through its electro-magnet, first one contact will be cut off, and after *a quite definite lapse of time* — the time required by the disc to turn from contact to contact — the next contact will be cut off.

If the circuit *A* be now connected with the circuit of the magnet coil (4 *a*), and circuit *B* with the circuit of the magnet coil (4 *b*), the switches of *A* and *B* will act as microphones I and II respectively :

The control is effected in the following manner :

A small lever on the side of the chronomicrometer box (*see* Fig. 21) marked " *L* " (" *Lot* " = sounding) and " *K* " (control) is turned down. The buttons are then pressed as for sounding. By pressing button No. 1 the circuits are closed, by pressing No. 2 the apparatuses are ,, strained ", and finally by pressing No. 3 the current in the magnet coil of the control is cut off, which causes the disc to turn under the influence of the spring, the switches in circuits *A* and *B* are affected, and the chronomicrometer is put into operation.

Consequently a strip of light will appear on the scale, and if the potential of the battery is the same, the strip of light will appear at the same graduation on the scale every time. This graduation is marked once for all. When the apparatus is changed over for control, a green glass is pushed in front of lamp (11). This strip of light on the scale thus becomes green and mistakes are avoided.

If the strip of light does not coincide with the marked graduation, the battery potential has changed and, by means of a key regulation, resistances may easily be added or removed, until the apparatus shows true.

Normally the control measurement is made once a day only.

Sounding operation.

The operation of taking a sounding is as follows :

A cartridge is placed in the cartridge chamber and blown through the pipe-loop into the firing-gear. Then button 1 is pressed and kept pressed down during the sounding. By pressing button 2 the apparatus s " strained ", after which button 3 is pressed. This causes the explosion to take place. First a little pop is heard as the bottom part of the cartridge is shot into water, and then a dull detonation, when the cartridge explodes below the surface of the water; the receiver is affected by the direct sound wave and thus the disc turns, then the echo-receiver is affected by the echo returned from the bottom of the sea, and thus the disc is stopped by the brake ; the strip of light then stands at that graduation of the scale which indicates the depth under the vessel.

It is possible to read the last sounding again later on by pressing button 1, which causes the streak of light to appear again.

During the sounding the lever on the side of the chronomicrometer box mentioned above must be placed at " L ".

Results of trials.

The Echo-Lot on board the " Lövenörn " operated exceedingly well. The soundings were checked when an opportunity occured with a control sounding, and the depths obtained always agreed (*see* Fig. 23). It was

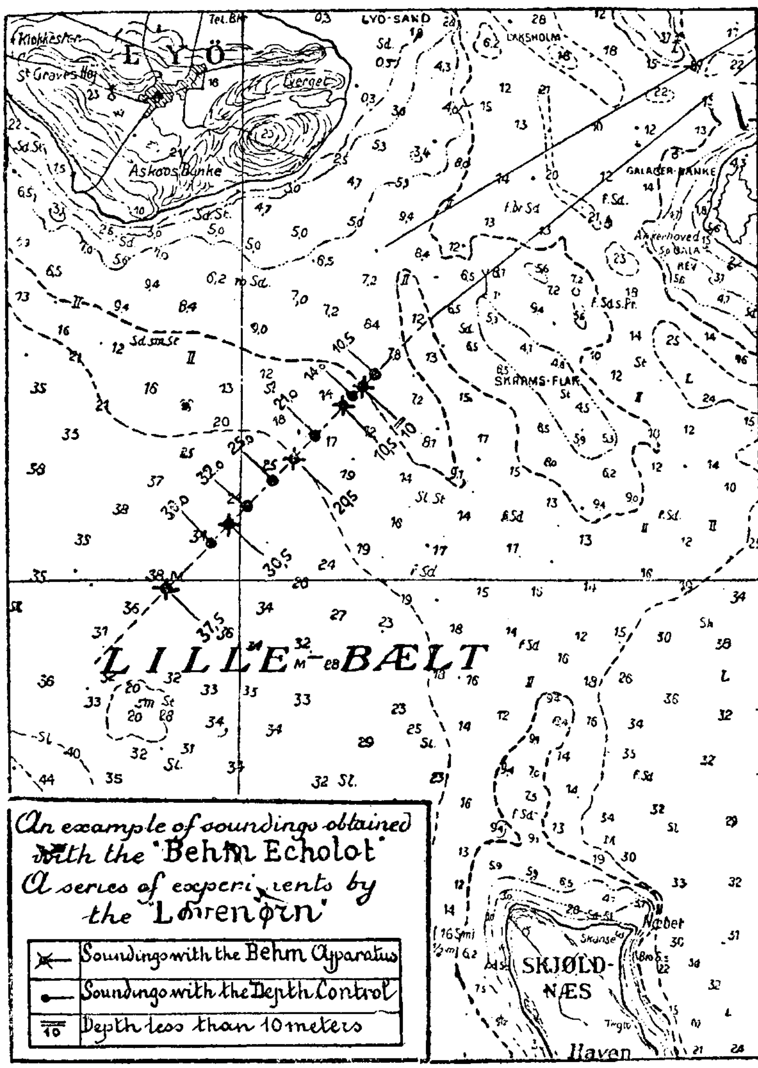
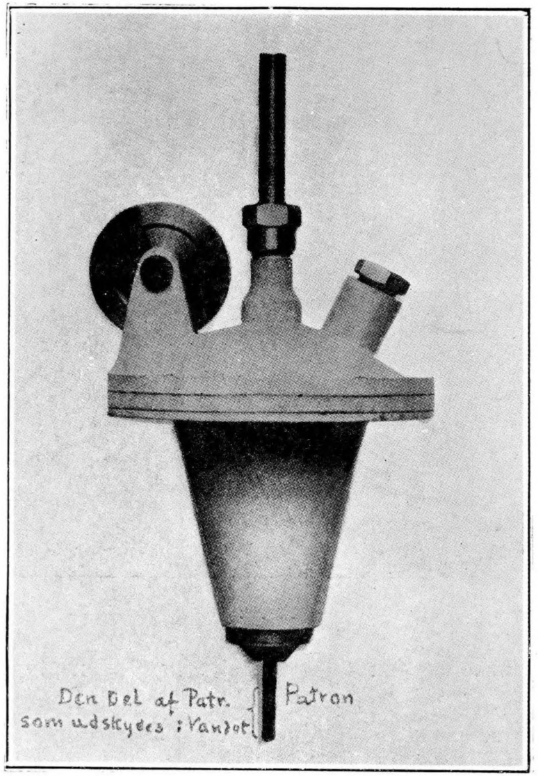


Fig. 23.

tested both in fine weather and during rolling, which latter did not interfere with the apparatus, but was exceedingly annoying to the inventor who was on board.

The smallest depth which the Echo-Lot was able to measure with the available cartridge was 8 m. (26 ft.) and the greatest depth 70 m. (38 fms.). There was, however, no opportunity to measure depths above 40 m. (22 fms.).



Part of the cartridge wich is expelled into water.

Cartridge.

Fig. 22.

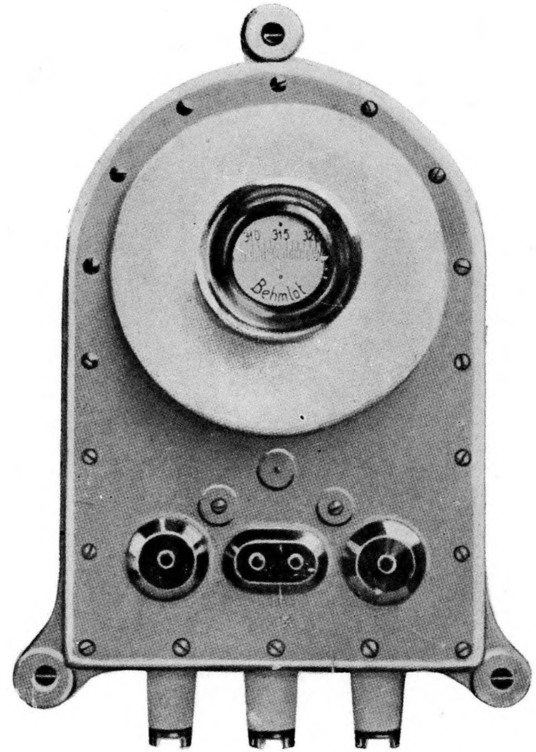


Fig. 28. — Outside view of Behm chronomicrometer for Sounding machine.
Type 2 (up to 750 m., 420 fthms).

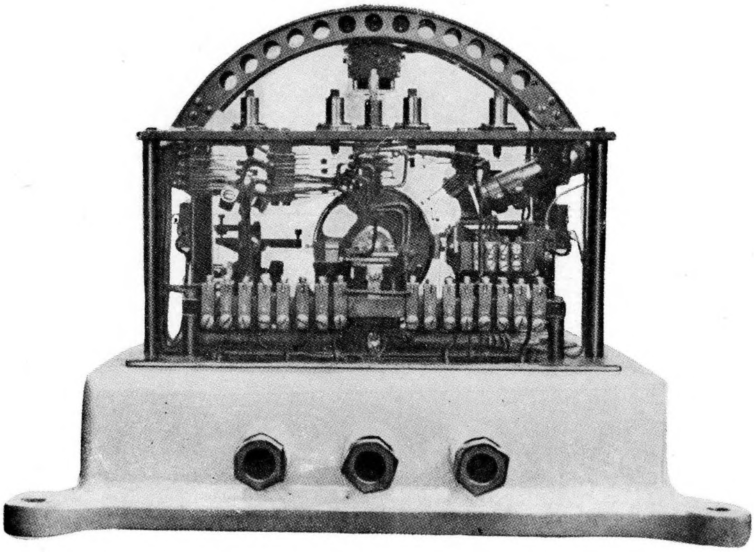


Fig. 25. — Inside view of Behm chronomicrometer for Sounding machine type 1 (up to 200 m., 110 fthms).

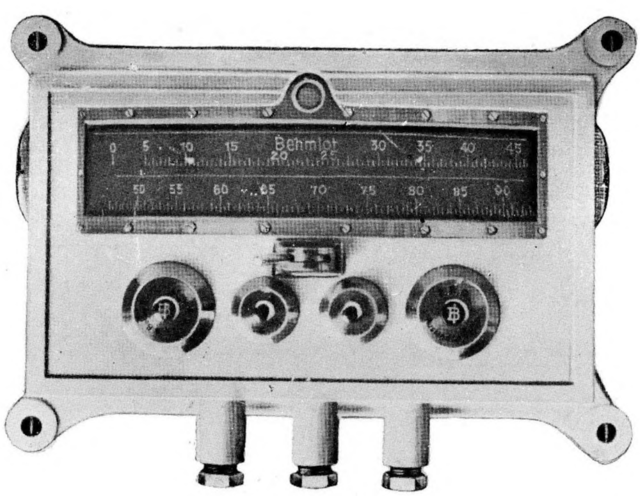


Fig. 27. — Outside view of Behm chronomicrometer for Sounding machine type 1 (up to 200 m., 110 fthms).

By using different cartridges it is possible to measure depths between about 5 m. (16 1/2 ft.) and 120 m. (65 1/2 fms.).

By experiment it appears that the nature of the bottom does not play any part, and that the echo off an oozy bottom even is sufficiently strong to affect the echo-receiver.

Discussion. — Advantages and disadvantages.

The seaman is conservative when it is a question of means of navigation. He prefers the simple methods inherited from his forefathers, methods which have stood the test of time and practice, and it is not easy to make him adopt all of a sudden something which is quite new and which has nothing in common with the old methods. But none can

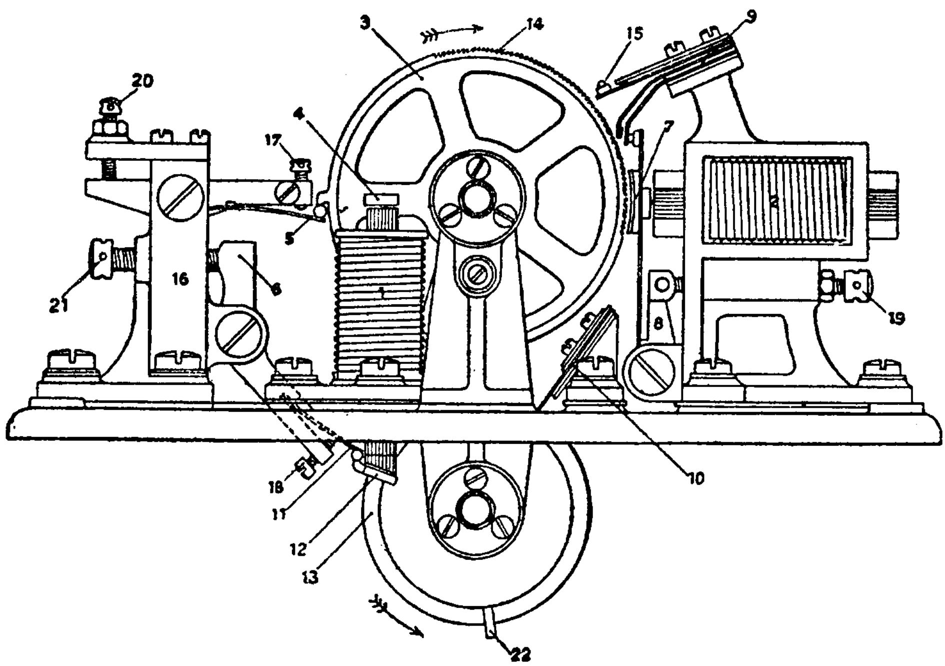


Fig. 24. — Inside view of the chronomicrometer for Behm sounding machine, Type 1.

escape his fate and the seaman is gradually forced to keep pace with developments. Whether this development is tantamount to safer navigation may remain an open question, for it is very likely that navigation becomes more audacious as the means of navigation become more developed. Who, only a few years ago, would have imagined it possible that, by means of a combination of a submerged bell and radio signals from a light-ship, it is feasible to ascertain the distance from them, a problem which also is based upon the speed of sound waves through water, yet now the appliances for this are installed in the "Graadyb" light-ship and are very much used by Danish steamers running between Esbjerg and British ports.

Seamen have been heard to say that one cannot trust a sounding apparatus which, by giving a reading which is but a fraction of a second wrong, may give wrong depths. In reply to this the question may be asked : " What is a short and what is a long time ? "— The seamen must get accustomed to the idea that 1/5 of a second (the longest period that the chronomicrometer is able to record) is a long time and he must get used to relying on the chronomicrometer to work with an accuracy of 1/10,000 of a second in the same manner as he gets used to relying on the accuracy of the daily working of the chronometer. (In depth 1/5 of a second corresponds to about 150 m. (82 fms.), 1/10.000 of a second to about 0.07 m. (2-3/4 ins.)).

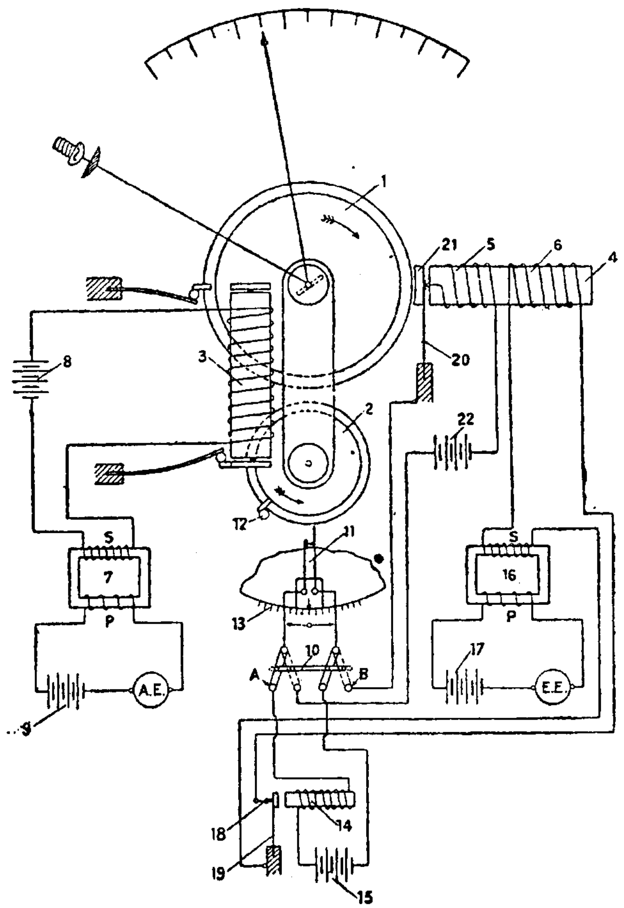


Fig. 26. — Electric circuit of the chronomicrometer of Behm Sounding Machine, type 1,

There are yet others who think that an instrument which has to work, with such great accuracy, under the influence of a spring is too dependent on the maintenance of constant tension by the spring. But they rely on the chronometer even through its springs have to work for years, whereas the springs of the chronomicrometer are bent only during the few seconds required for the operation of the sounding.

It is believed that that which tells against the Behm Echo-Lot must be sought elsewhere. Of course it cannot ascertain the nature of the bottom, its first cost is higher, the installation must be adapted to the particular vessel into which it is placed and docking of the ship may be necessary for this.

It must, however, be noted that the daily working of the apparatus is not expensive, seeing that the cartridges may be manufactured at the same price as ordinary shooting cartridges.

The advantages of the Behm Echo-Lot are the following :

1. A sounding is taken, no matter what be the depth, in a few seconds.

2. The sounding is taken by the Officer of the Watch from the chart-house or the wheel-house, and the crew need not be summoned or exposed to any risk in bad weather.

3. The depth is obtained over the lee-side right under the vessel, and at the moment the sounding is taken (not 2 to 8 minutes after the vessel has passed this depth).

4. There will be no reluctance to sound, for the operation requires no work.

Figures 24 and 25 show the interior mechanism of the chronomicrometer of the Behm's Sounder, type 1 (up to 200 meters).

Figure 26 shows the arrangement of the electric circuits.

Figure 27 illustrates the exterior aspect of the recorder.

Behm's Sounder, type 2.

Figure 28 is an outside view of Behm's Sounder, type 2, with the projection of the depth scale reading up to 750 meters (410 fathoms).

Figures 29 and 30 show interior views of this type of Behm's Sounder : the first is a full face view showing the graduations of the divided limb ; the second is a side view in which can be seen the optical arrangement for projecting the suitable division of the scale and the index on a screen, marked 16.

This apparatus is also made with a hand and dial (Fig. 31) divided into 360 degrees.

Behm's Sounder, type 3.

Figure 32 shows the arrangement of Behm's Sounder, type 3 (for great depths). A third scale *c* (of which the sketch on the right illustrates the method of optical projection), is added to the scales *a* and *b* of Sounder Type 1.

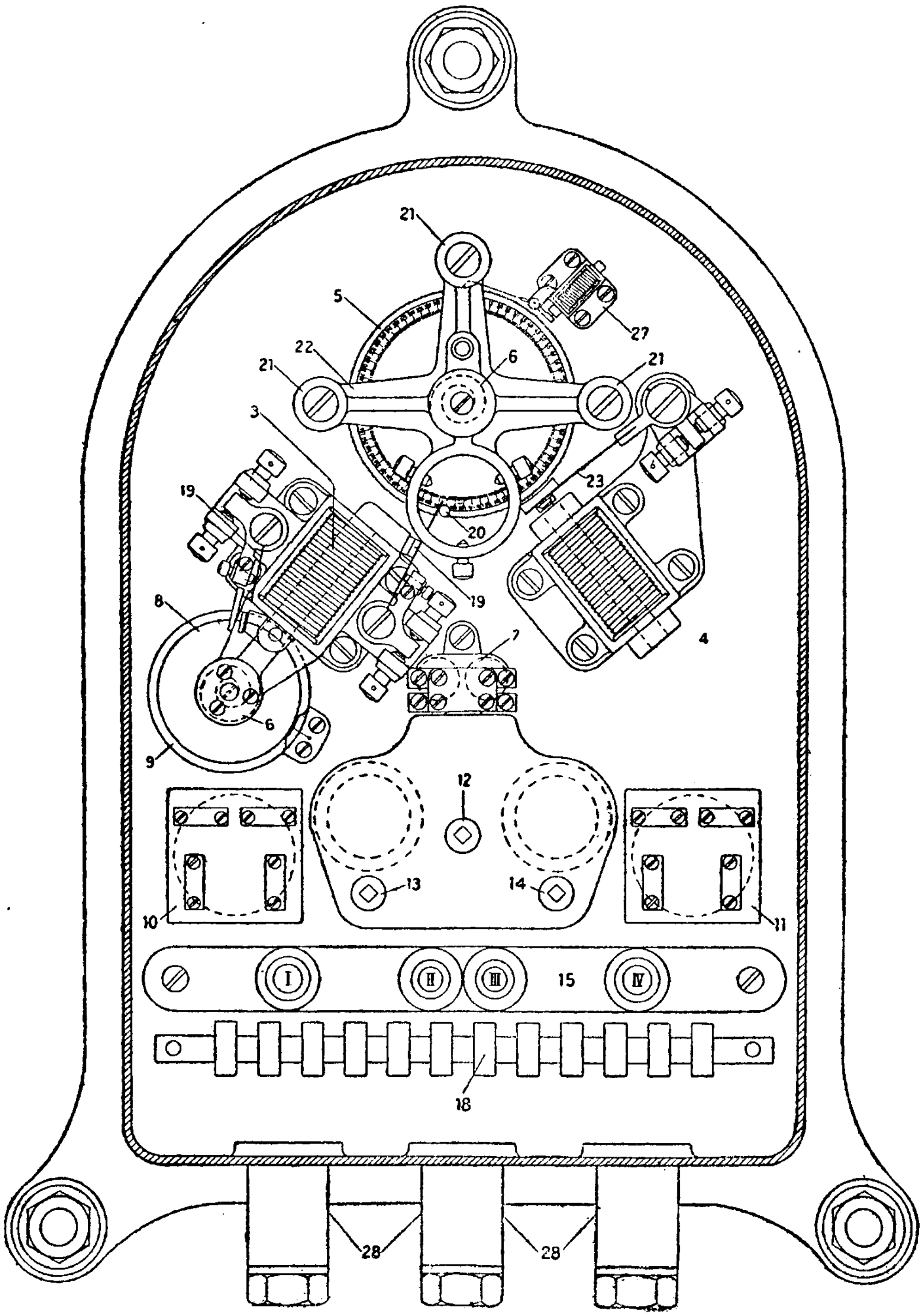


Fig. 29. — Interior view of the chronomicrometer for Behm Sounding Machine, type 2 (front view).

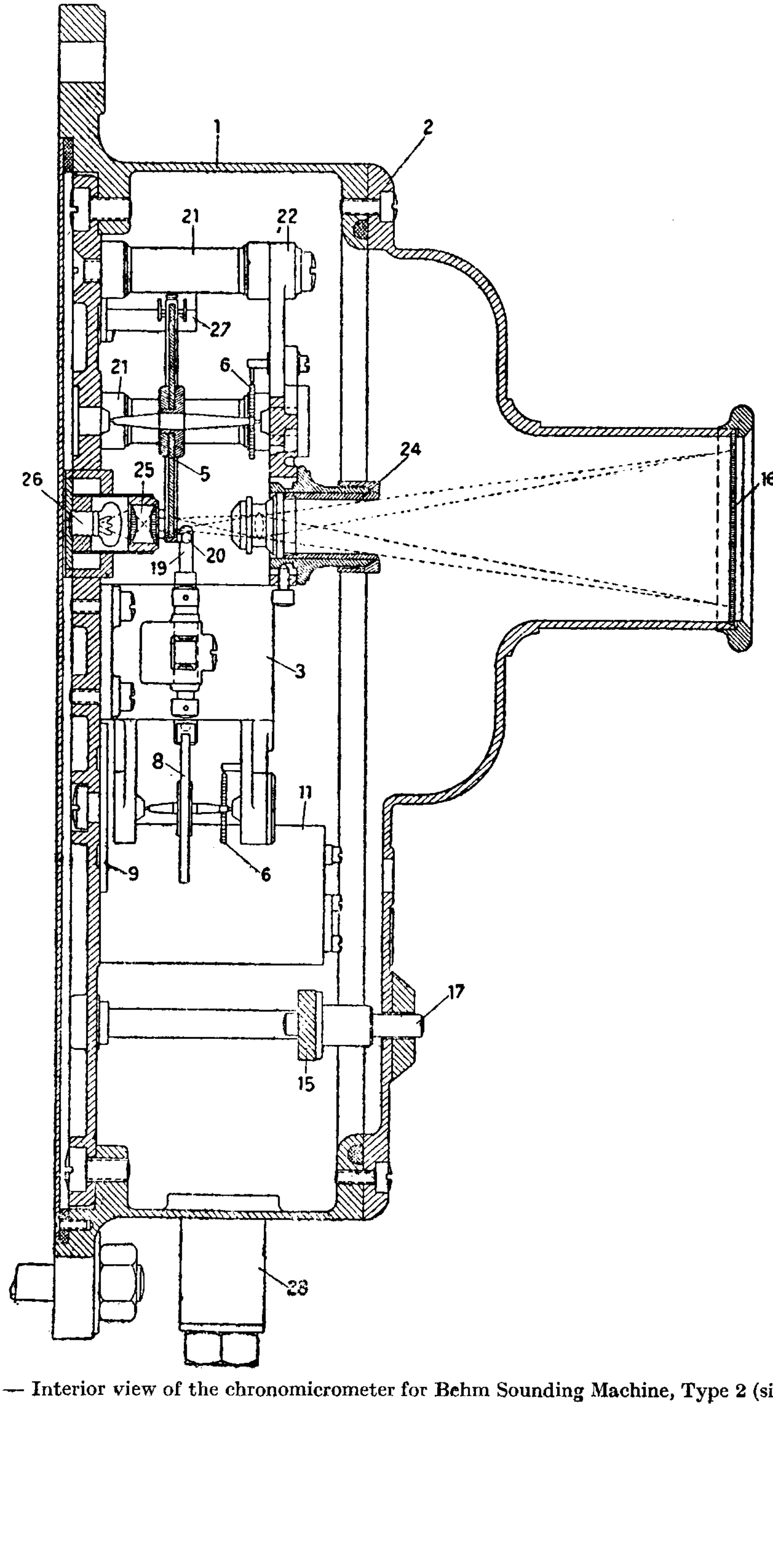


Fig. 30. — Interior view of the chronomicrometer for Behm Sounding Machine, Type 2 (side view).

The Installation of Microphones on Board.

It may be remarked that, as a rule, the starting and the echo-receiving microphones, are placed on opposite sides of the ship, so that the latter is practically within the " sound-shadow " cast by the great bulk of the ship. The meaning of this can best be appreciated from an examination of Fig. 1 (above). Here we have on the right hand side of the great bulk of the ship a source of generation of sound-waves. Naturally, the ship will obstruct those waves which travel in its direction and will cast a shadow — *i. e.* a sound-shadow — behind it, so that an ear or microphone placed within the shadow will be far less affected than would one

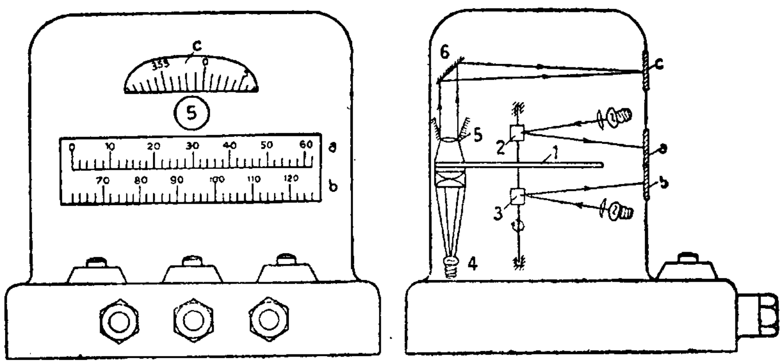


Fig. 32. — Diagram of plant of the chronomicrometer for Behm Sounding Machine, Type 3.

at the same distance from the source of generation of the sound-wave, but otherwise so situated that the bulk of the ship did not intervene. Thus, by placing the echo-receiving microphone within the sound-shadow cast by the ship, it becomes responsive only to the unobstructed sound-wave which reaches it after reflection from the sea bottom.

In certain cases, the ship's hull does not form a sufficient screen, that is to say, does not cast a sufficiently sharp shadow to enable the echo-receiving microphone to be adequately protected from the direct action of the detonating cartridge, and, in such case, the Time-interval-recorder is provided with an auxiliary device or relay which interrupts the circuit of the echo-receiving microphone for a brief interval of time, long enough for the sound-wave to have reached it by the shorter paths and to have died away ; that is to say, the echo-receiving microphone is made inoperative until all the direct waves have passed it, and is then made operative so as to be ready to receive the reflected wave from the sea bottom and to act upon this message as soon as it is received.

The pointer appears to spring instant an eously from the zero position

Fig. 31. — Behm Sounding machine with indicator. Patented in Germany and in Foreign countries.

on the scale to that graduation which show the true depth immediately the sound of the detonation is heard.

The two heads of the screws which are seen on the left part of Figure 20 are used for adjusting the tension of the spring and to limit the impulse given. The catch at (5) Figure 20 insures the fixed position of the zero, as well as the necessary tension for the impulse. The action caused by the dilation and contraction of the various parts due to changes in temperature is reciprocally neutralised.

During the measurement, friction of the air on the wheel of the chronomicrometer remains constant.

It may be mentioned in passing that the microphone receivers can be fixed internally in the ship hard up against the ship's plating without the necessity of drilling the hull.

Demonstration Apparatus.

Demonstrations have been given with this apparatus at the works of Messrs KELVIN, BOTTOMLEY and BAIRD at Kelvingrove; Hither Green, London, S. E. Experiments were carried out with sound waves travelling in air.

The starting and stopping microphones (the stopping microphone corresponds to the echo-receiving microphone) were first placed 6 feet (2 metres) apart, and a sound-wave was generated near the first microphone by firing a toy pistol. The sound arrived at the first microphone and started the time-interval-recorder; it then travelled 6 feet, reached the second microphone, and stopped the recorder. The time-interval measured was, therefore the time taken for the sound to travel over the distance of 6 feet which separated the microphones; this time-interval is, approximately, a 170th part of a second.

The distance between the microphones was then increased foot by foot, and the increase was clearly shown on the time-interval-recorder. The increase in the time-interval corresponding to one foot of space in air is only a 1000th part of a second.

The distance between microphones was then increased in steps up to 48 yards (44 metres) and the time-interval-recorder showed accurately the varying distances for each setting of the microphones; many readings were taken for each setting and the results showed that the instrument was thoroughly consistent.

Further experiments were made by sending sound-waves along a colum of air enclosed in an iron pipe, one microphone being fixed near each end. A sound-wave generated at one end affected the microphone at that end and, travelling along the air column, eventually reached the second microphone. By enclosing the column of air or gas within a suitable tube, the effect on the rate of propagation of the sound-wave due to varying the density of the gas through which it was propagated could be observed on the time-interval-recorder. Thus, with air at ordinary atmospheric temperature, a definite reading was obtained — as a matter of fact, the time occupied was almost exactly a 100th of a second for the sound to travel from one end of the tube to the other. When, however, the air was heated, or the tube was filled with coal gas, or CO_2, or other medium, a corresponding change in the speed of propagation resulted, hence also the time-interval for the sound-wave to travel along the

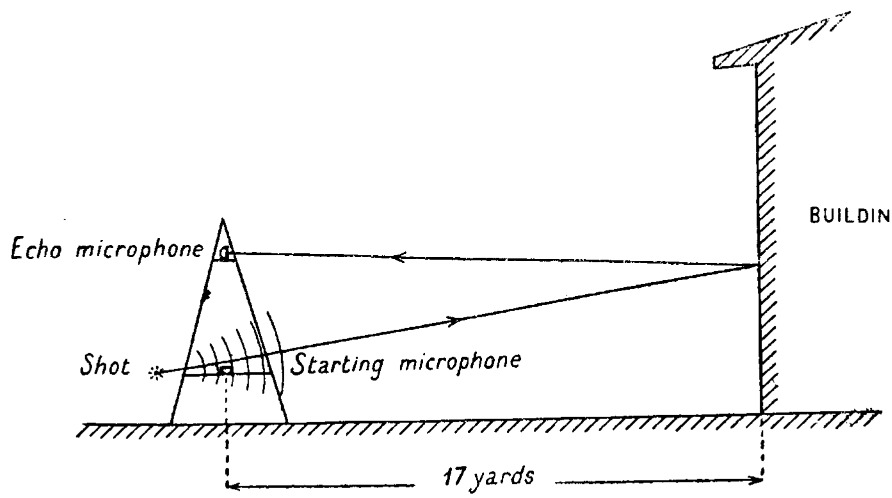


Fig. 33.

length of the column from one microphone to the other, and this was at once indicated by the reading on the time-interval-recorder.

In still another experiment the instrument was used as an echo-sounder in air, but the path of the sound-wave was horizontal instead of vertical. Two microphones were mounted on a scaffold about 50 feet (15 metres) from the face of a building (*see* Fig. 33). A sound-wave was generated at the first microphone which started the recorder. For this experiment, the time-interval-recorder was provided with the special relay device, already referred to, which cut the echo-receiving-microphone out of action for a definite but very short period of time. Thus, referring to Fig. 33, the echo-receiver was put out of action for a length of time sufficient for the sound to travel by the direct path, from the point where the shot was fired to the echo-receiver, and was thereafter put into circuit to be ready for receiving the echo by the time it had returned from the face of the building 50 feet distant. This exactly corresponded to the case of sounding at sea, except that measurements were taken horizontally instead of vertically. The definiteness of the results obtained, the simplicity and rapidity of operation, and the robustness of the whole apparatus left no doubt that the BEHM Echo-Sounder has arrived at such a stage of development that it can be classed in the category of practical navigational devices.

Use for Aerial Sounding.

It is interesting to learn that an apparatus of this type was installed on the Reparation Zeppelin Z. R. 3 during her trial flights over Germany. The instrument was used as a depth-sounder in air instead of in water, that is to say, it indicated the height of the airship above the ground.

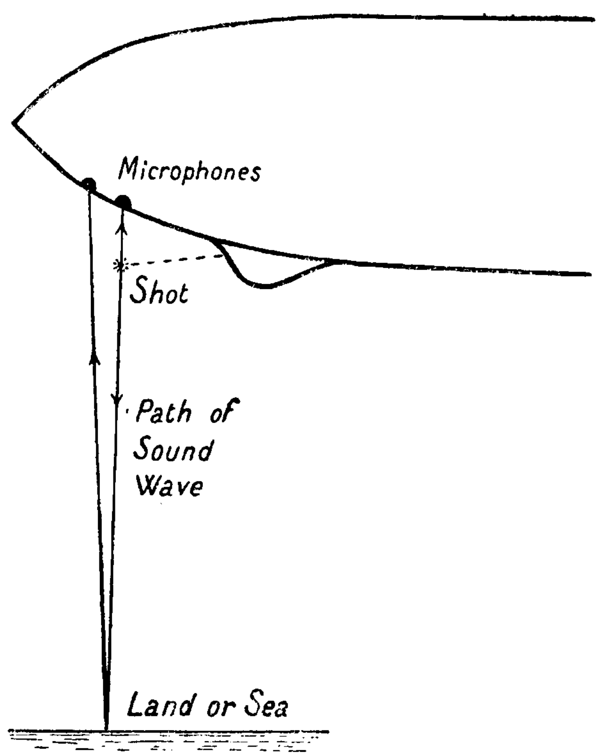


Fig. 34.

Fig. 34 represents diagrammatically the arrangement employed. As will be seen, the starting and the echo-receiving microphones were placed close together, and the relay device, already described, was employed. In other respects the action was precisely that illustrated in Fig. 33 and demonstrated at Messrs KELVIN, BOTTOMLEY and BAIRD's KELVINGROVE Works. The results were entirely successful and satisfactory, observations being taken at speed up to 100 kilometres per hour (54 1/4 knots).

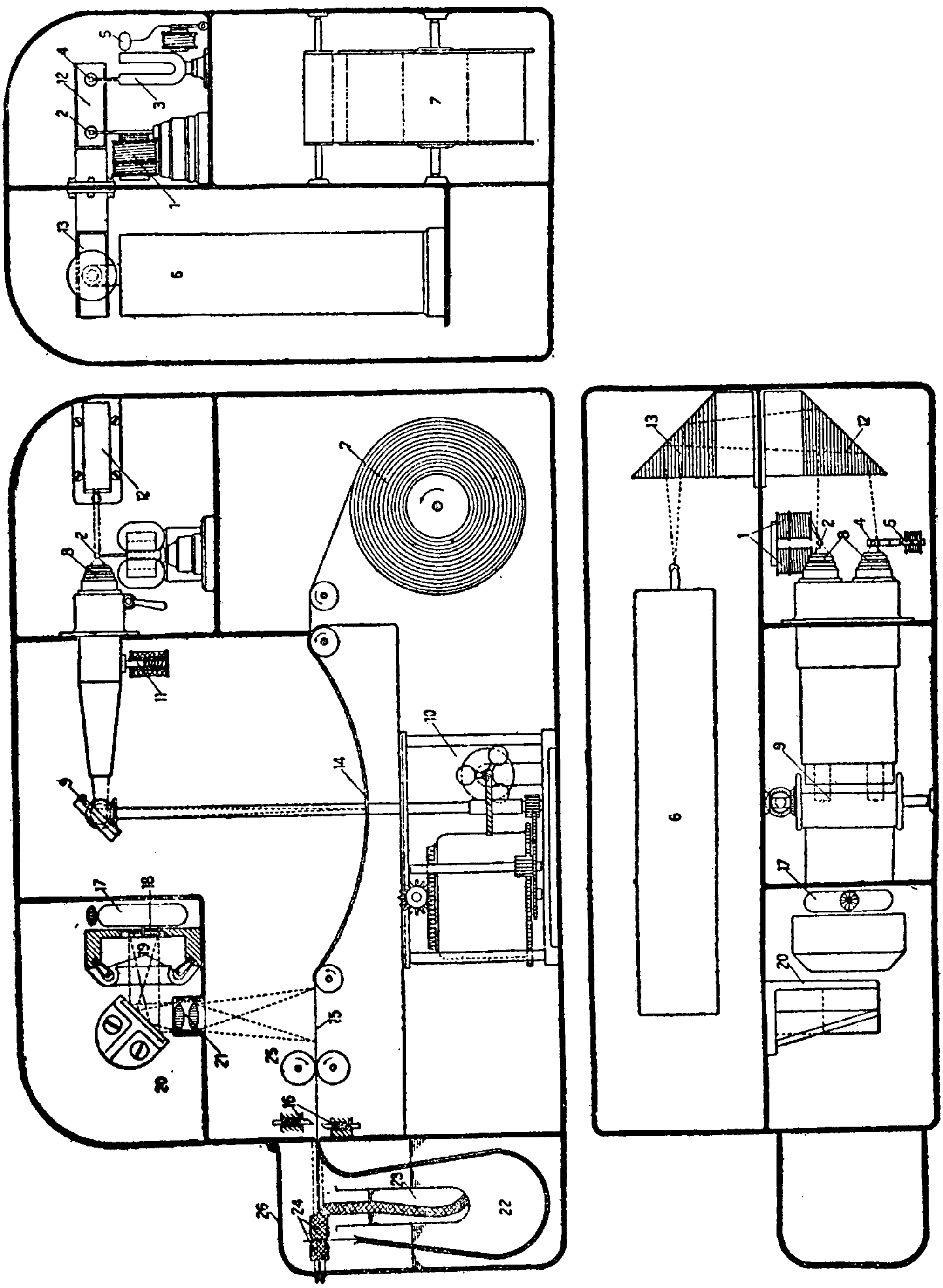


Fig. 35. — Diagram of plant of Behm Sounder with photographic recorder.

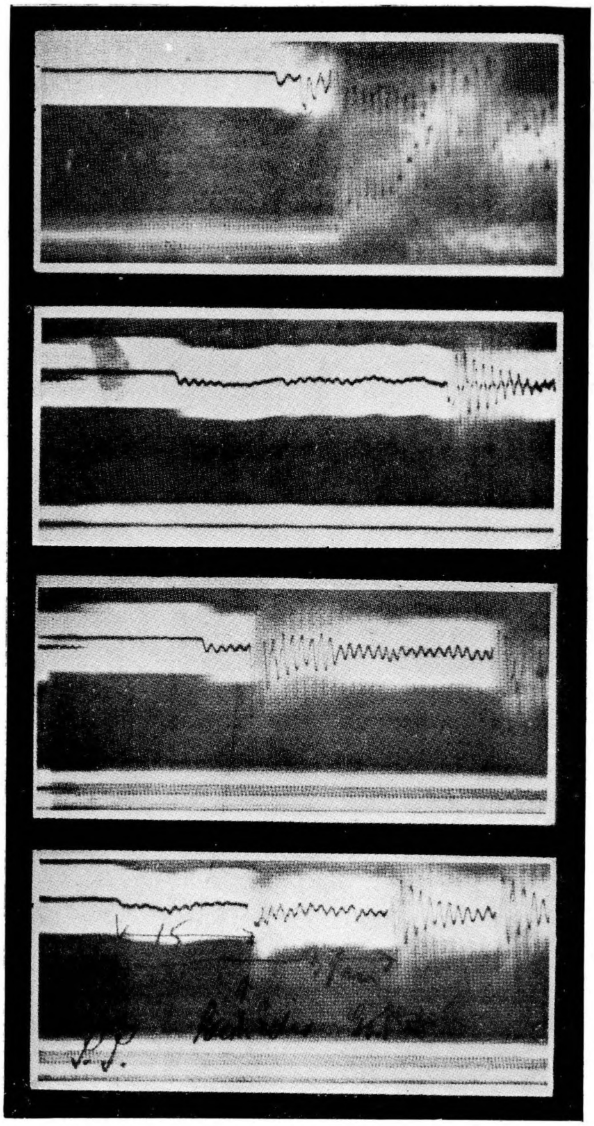


Fig. 36. — Photographic record as given by Behm sounding machine.

It is noteworthy that automatic and direct-reading records were obtained in spite of the noise and vibrations inseparable from the powerful motors used for the propulsion of airships of this character.

The following results were obtained:

READINGS OF BEHM'S SOUNDER (IN DEGREES)	HEIGHT ACCORDING TO THE BAROMETER
347°	525 ft. 160 metres.
310°	460 " 140 "
307°	445 " 135 "
311°	460 " 140 "

It is understood that Messrs. KELVIN, BOTTOMLEY and BAIRD intended to give further demonstrations of this interesting device during the early part of 1925.

Behm's Sounding Machine with Photographic Recorder.

The plate (Fig. 35) is a diagram of the arrangement of the Behm's Sounding Machine with photographic record (for all depths from 6 meters (20 feet) to 1000 meters (3285 feet)).

An arc lamp acting as a point-like source of light (6) projects a beam through reflecting prisms (13) and (12) towards the two lenses (2)

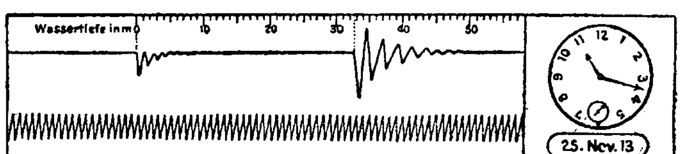


Fig. 37. — Diagram of photographic record by Behm Sounding Apparatus.

and (4). The rod which carries lens (2) may be made to vibrate laterally by means of the electro-magnet (1), the small coil of which is connected to the starting microphone, the larger coil being connected to the microphone which receives the echo. Lens (4) is carried by the prong of a tuning fork which is set into synchronous transversal vibration by the striker (5) of the electro-magnet.

After reflection of the beam by the revolving mirror (9) which moves by means of the clock mechanism (10), the two microscope objectives (8) act in parallel to produce a photographic image on the film, which moves in the circular path (14). The coil (7) is large enough to make about 500 negatives in average depths.

Figure 36 gives examples of records on films.

Figure 37 shows, on the other hand, the manner of reckoning depth in meters from the time registered by the tuning fork. A circular group of lamps (19) throws an image of the dial of the pocket watch (17) at (15) by means of the photographic objective (21) and the mirror (20).

Scissors (16) cut the film after every sounding at every turn of the crank (25), and the piece cut off is pushed into an U-shaped basin containing the developing bath (22), where it remains about 10 seconds. The tank (23) contains the fixing bath, which acts on the film by means of a pad with a wick (24).

Behm's Acoustical Method (Behm Ohrlot).

As we have seen above the hull of a ship cannot give sufficient shelter to the arrival microphone in shallow water. This shelter is, of course, increased as the dimensions of the ship increase, and in order to enlarge it the two microphones may be placed at each extremity of the ship, which allows heavier charges to be used in the cartridges and consequently greater depths can be reached, but then, the inherent noises due to the motion of the ship, and particularly those of the propeller, make clear reception of the echo less easy.

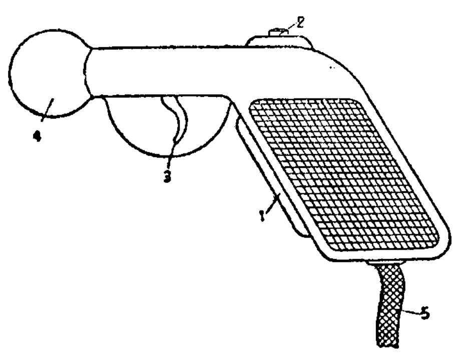


Fig. 38. — Dumb pistol with universal joint.

Consequently, Dr. BEHM conceived the idea of using a relay device and developed a special method which he called the method of " Acoustic Sounding ", which allows great depths to be attained by using one of the three last models of the apparatus. A telephone receiver is connected with the receiver circuit in order that the echo may be heard, and this occurs very shortly after the detonation of the charge. The relay cuts out the receiver for a very short interval at departure, and thus even heavier charges may be used.

Figure 38 shows a sort of dumb pistol with ball and socket attachment (4), which is used for starting the action. The main contact (1) is closed by the grip of the hand on the pistol ; (2) is used for firing and (3) is the trigger which starts the apparatus working.

Figure 39 shows yet another recording device : the stylus (4) presses lightly on the band of special paper, which unrolls in the direction

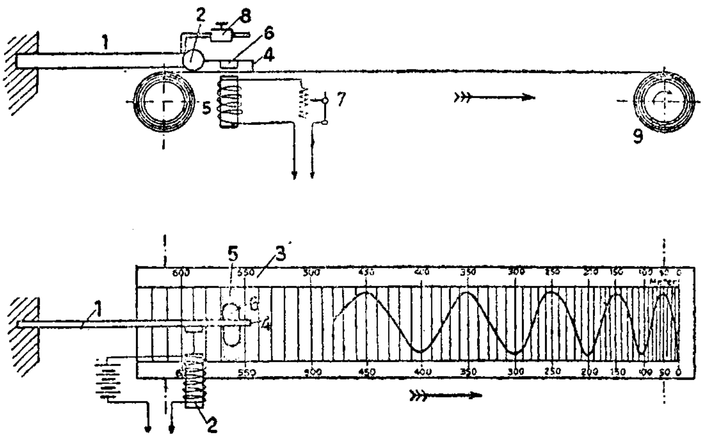


Fig. 39.— Another recording device.

of the arrow by means of an adjustable electro magnet (5), and ceases to press on the paper on the arrival of the echo.

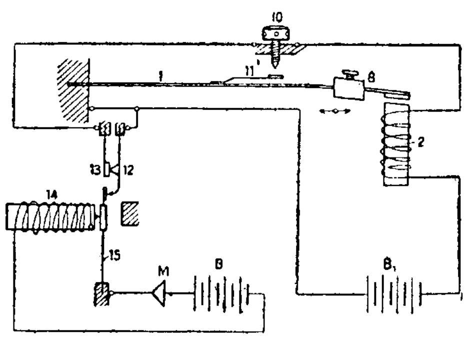


Fig. 40. — Another recording device.

For sounding in great depths, it is necessary to have a stronger device such as that shown in Figure 40 where the stylus and the band are not shown.

Practical Results.

The four following tables show some comparative soundings obtained in 1924, by the German steamer " Hansa " of the Hamburg-America Line ; they are extracted from the detailed report of the " Deutsche Seewarte " in the *Annalen der Hydrographie und maritimen Meteorologie* (Parts XI and XII) written by Doctor Bruno Schulz.

30th April 1924.

TIME	POSITION		DEPTH			REMARKS
	LAT. N.	LONG. E.	BEHM SOUNDER	THOMSON SOUNDER	FROM CHART	
3.50	51°23 1/2'	2° 0 1/2'	41.0	40.0	39	
4.25	51°17 1/2'	1°52'	39.0	"	38	
4.55	51°11 1/2'	1°41 1/2'	41.0	40.5	39	
5.20	51° 9'	1°34'	45.5	40.2	45	Passed East Goodwin.
5.30	51° 7 1/2'	1°30'	23.5	"	27	
5.33	"	"	55.0	"	49	
5.36	South Foreland abeam		53.0	"	44	
6.30	In the Channel		30.0	"	27	
7.25	"	"	35.0		31-35	

7th May 1924.

TIME	POSITION		DEPTH			REMARKS
	LAT. N.	LONG. W.	BEHM SOUNDER	THOMSON SOUNDER	FROM CHART	
10.00	43°47'	59°53'	86.5	"	54	
10.15			50.5	"	"	
10.30			43.5	"	36	
10.45			35.0	"	32	
10.55	Sable Island Lt.-ship abeam		31.0	"	27	
11.15			26.5	"	27	
11.30			31.0	"	25	
11.55			25.5	"	"	
12.00	43°57'	60°35'	24.0	"	32	
0.15			24.5	"	32	
0.30			27.5	"	36	
0.35			31.0	"	43	
0.45			33.0	"	70	
1.00	43°59'	60°56'	35.5	"	"	
1.15			44.0	"	"	
1.30			52.0	50	72	
1.45			58.5	"	"	
2.00	44°3'	61°18'	89.0	"	"	

29th May 1924.

TIME	POSITION		DEPTH			REMARKS
	LAT. N.	LONG. E.	BEHM SOUNDER	THOMSON SOUNDER	FROM CHART	
9.30	,,	,,	28.5	,,	28	
10.00	,,	,,	25.5	,,	24, 26	
10.30	,,	,,	24.5	,,	,,	
11.00	,,	,,	25.5	,,	27, 26, 22	
11.45	,,	,,	29.5	,,	29	
12.00	" Haaks " Lt.-ship abeam 0.2 mile.		26.5	,,	,,	
12.08	,,	,,	26.0	,,	26	
2.0	,,	,,	25.0	,,	23, 24	2.23 : passed Terschelling Lt.-ship.
2.30	,,	,,	26.5	,,	29, 22	
3.00	,,	,,	30.5	,,	22	
4.05	,,	,,	25.0	,,	28, 21	
5.17	,,	,,	28.0	,,	25, 26	
7.30	,,	,,	24.5	,,	22, 24	
7.45	,, Norderney Lt.-ship " abeam 1/4 mile.		25.5	,,	22	

DATE	N. LAT.	W. LONG.	SEC.	DEPTHS m.	DEPTHS SHOWN BY THE CHART
2. V. 8^h15	48°30′	18°40′	5.4	4050	4150
4. V. 12^h Noon	45° 9′	34°44′	5.4	4050	4370, 4280, 3750, 2740
4. V. 4^h	44°55′	35°45′	5.4	4050	»
7. V. 8^h	43°30′	58°50′	2.5	1850	1860
22. V. 5^h45 .	40°30′	55°30′	6.9	5200	5197
23. V. 10^h	40°30′	49°40′	4.8	3600	3800
24. V. 5^h	43°38′	39°10′	5.6	4200	2743, 3658, 4572, 4389
25. V. 4^h	46° 4′	30°44′	4.4	3300	3383, 3219, 3017, 3767
26. V. 8^h	47°25′	24°43′	5.4	4050	3237, 3904, 3153, 3576
26. V. 4^h	47°50′	22° 0′	5.6	4200	4190
27. V. 8^h	49° 6′	15° 8′	5.8	4350	In agreement with the Charts.
27. V. 12^h Noon	49°30′	13°32′	2.0	1500	
27. V. 4^h20	49°35′	12° 0′	1.3	975	
27. V. 4^h40			1.0	750	

III. — « Bomb » of the Signal Gesellschaft of Kiel.

This German Company has elaborated a small bomb, a section of which is shown in Figure 41, by means of which a special form of sonic sounding can be carried out and on which a few remarks are necessary.

The figure on the left shows the small bomb in the safety position ; the striker is prevented from striking the cap situated beneath it, either by means of pin (G) which may be withdrawn at the moment of throwing the bomb overboard, or by a projection on the lever (*B*) which engages, by means of a loop and a ring, in a fixed point of the nose cap of the bomb.

The figure on the right shows the bomb after it has been thrown, when the nose, after pressing a moment on the bottom of the sea, has been able to disengage the escaping lever.

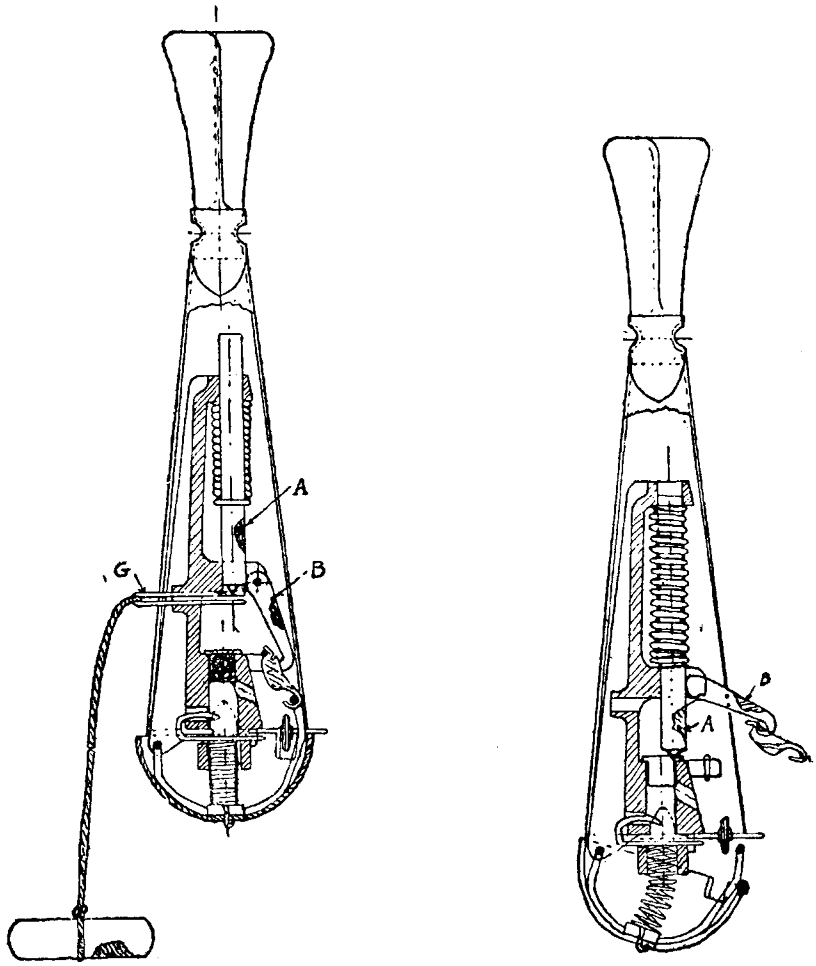


Fig. 41. — Bomb.

The bomb is fitted with vanes which maintain it in a vertical position and which, by their shape, ensure with precision a constant speed of descent through the water.

When a bomb of this type falls into water at first its rate of descent is accelerated up to the moment when the resistance of water exactly balances the weight of the bomb. From this moment, which is reached in a very short time, the bomb proceeds with a constant speed which for the bomb in question is about 1 fathom (2 meters) per second.

If a stop watch is started the moment the bomb enters the water and is stopped the instant the explosion is heard (with a submarine receiving microphone) the time taken by the sound to reach the microphone being neglected, the duration of sinking is immediately obtained, which duration multiplied by the constant speed of descent for the bomb employed, allows the depth of water to be ascertained.

Such bombs have given good results in practice with a very small percentage of miss-fires; many trials were made during the surveying cruise of the "*Magnaghi*" in 1924, and other surveying vessels of the Royal Italian Navy, with fair success, depths up to 200 metres (109 fathoms) being reached with the ordinary noise on board and the engines working; and up to 400 metres (219 fathoms) with the engines stopped. By launching two bombs together a depth up to 800 metres (438 fathoms), may be recorded but beyond that, no advantage was obtained by launching more than two.

The relative error noted in comparison with the lead was found to be less than 1 metre in 92 % of soundings and never exceeded 2 metres 50 (8 1/4 ft.). The number of bombs which do not explode, as well as that of bombs the explosion of which was not recorded, obviously increased as the depth increased, but on the whole, from the point of view of navigation, this process was found to be effective and of great practical use.

V. — Echo Soundings by the Royal Italian Navy.

Figure 42 shows a small electrically fired bomb, constructed by the Directory of Artillery at the Arsenal of Spezia, which has been utilised for echo soundings on board the "*San Marco*". A microphone and an automatic recorder register the sound of the explosion of the cartridge at the departure and of its echo.

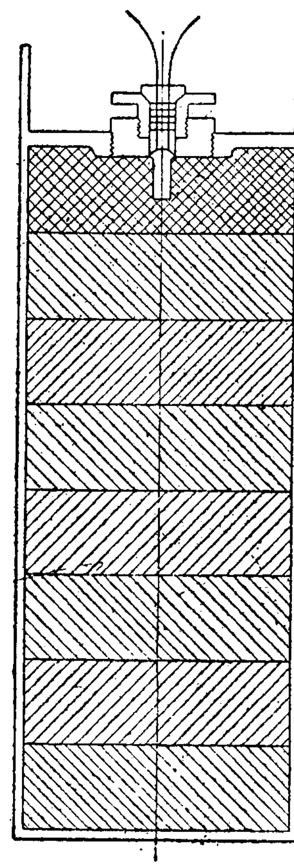


Fig. 42. — Electrically fired Bomb used by the R. Italian Navy.

Lieutenant Georgio Cicogna states in the *Rivista Marittima* of December, 1924 and January, 1925, that the necessary conditions are as follows:

1. Great sensitiveness of the hydrophones,
2. Sufficient degree of selection in order to eliminate extraneous noises,

3. Efficiently of the self-registering apparatus,
4. The recorder must register to 1/200th of a second.
5. Sufficient acoustic range of the explosion,
6. Appropriate bottom for giving a reflection of the sound approximately in a vertical direction.

In order to obtain a clear echo it has been found that the cartridge should be submerged from 7 to 10 metres (23 to 33 ft.) and that the sharpness of successive echos may depend also on the rapidity of detonation of the charge; a maximum of 2 kilogrammes of trinitrotoluol was found sufficient to give three returns of the echo in a depth of 4500 metres (2460 fathoms) which corresponds to a path of 27,000 metres (14,760 fathoms).

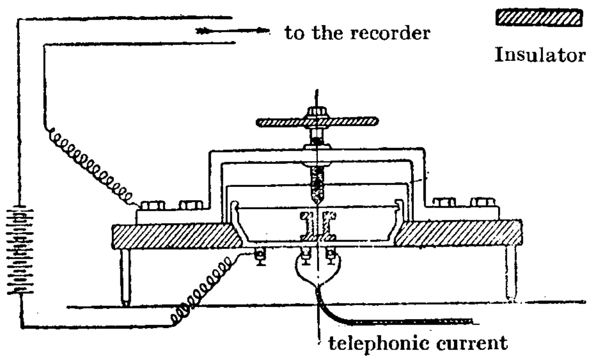


Fig. 43. — Micrometer screw contact.

The arrangement and the devices employed are quite simple.

The recorder produced by the Italian Hydrographic Institute is able to register to 1/100th and even to 1/1000th of a second, by means of a special chronograph of the " Cavignato " type, but more rapidly than

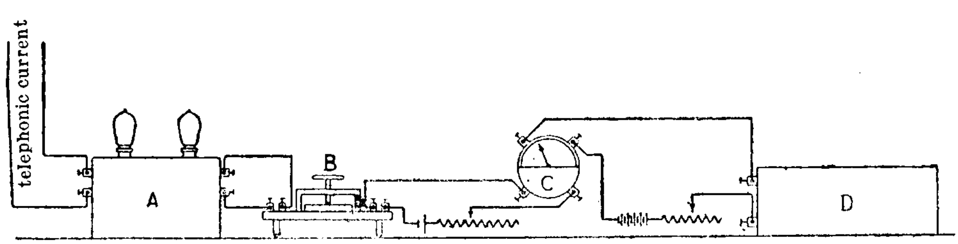


Fig. 44. — A. 2 valve amplifier; B. Telephonic relays; C. Electromagnetic relays with voltmeter; D. self-recording chronograph.

this, to which is added a governor consisting of a vibrating blade, devised by Cavaliere R. Kolschitter; an interval of one second is represented on the paper by a length of about 170 millimetres (6.7 ins.). The motor of the chronograph is driven by a weight, the apparatus works on board ship at a perfectly constant speed provided that the ship is not rolling more than 10 degrees.

The telephonic receiver is fitted with a contact provided with a micrometer screw; its width is 1/10th of a millimetre (0.004 inch). The latter is shown in Fig. 43 and produces in the circuit sufficient vibration to set the relay in action.

A diagram of one of the devices employed for receiving is shown in Figure 44.

Types in *italics* show *soundings as given on charts* and **heavy types** show **soundings by echo.**

Dephts in FATHOMS

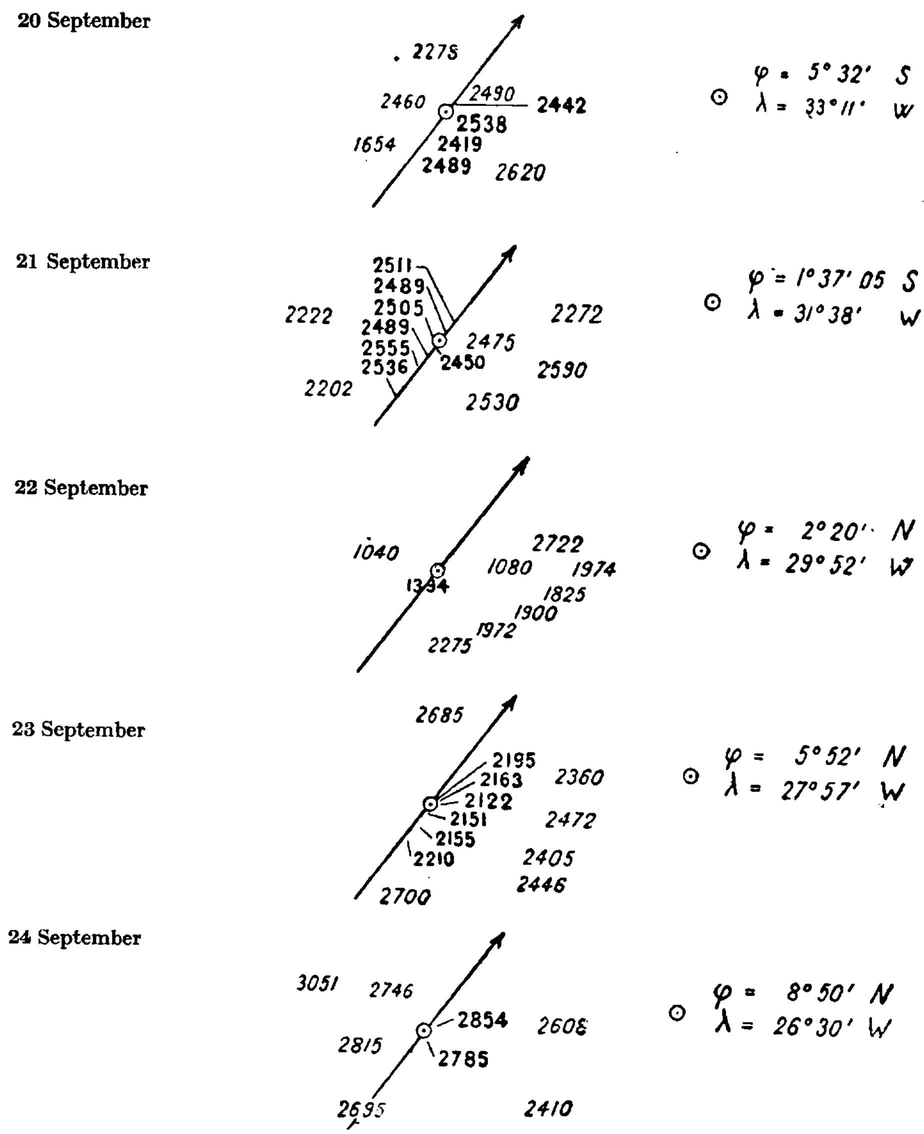


Fig. 45. — Diagram of Soundings taken.

Deep sea soundings were obtained during the cruise to South America in 1924, based on two successive returns of the echo ; they are shown in Fig. 45.

It must be remarked that when the ship is moving in the direction of the arrow AB (Fig. 46) the sound received follows the path ACB. The angle α is of the value given by the approximate formula :

$$\tan \alpha = \frac{\frac{nI}{4}}{P}$$

in which n is the speed in knots and I the time elapsed between the record of the explosion and of its echo, and P, is the depth.

The value of this angle is always so small that the corrections to be made to the measurements, even in great depths, do not attain one metre.

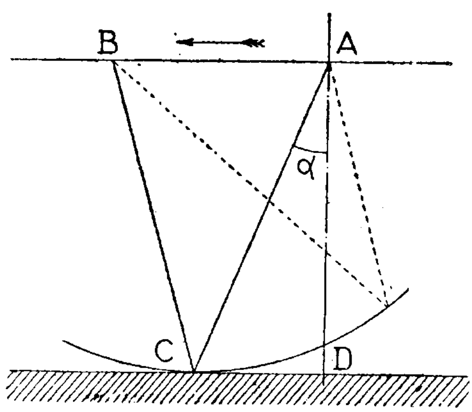


Fig. 46.

By employing two hydrophones simultaneously, one vertical and the other horizontal, close to each other, and by connecting them in opposition on the same circuit of the ammeter, the noises of the ship may be eliminated, while the echo strikes full onto the horizontal hydrophone and scarcely acts on the vertical hydrophone, which is reaches at an angle of barely a few degrees. It was found necessary to replace the pen of the auto-recorder by a small funnel, containing fluid ink and terminated by a silk thread which leaves a very light trace on the paper band (Fig. 47).

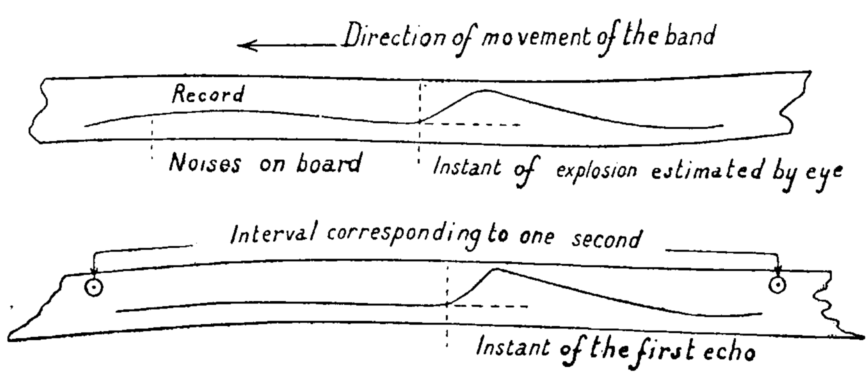


Fig. 47.

The moment which should be taken for registering is the point where the curve leaves the tangent to its former direction.

VI. — Velocity of propagation of Sound through Sea-water.

It has been stated above that the accuracy of acoustic sounding is determined partly by the accuracy with which the velocity of travel of sound in salt water is known.

As early as 1827 J. C. COLLADON and J. K. F. STURM measured the speed of the propagation of sound through the waters of the Lake of Geneva over a base 13 kilometres (14,215 yards) in length at a temperature of 8°1 centigrade (46° Fahr.), and found the value of 1435 metres (4708 ft.) with an estimated accuracy of ± 24 metres (78 1/2 ft.), which agrees fairly well with the value deduced from the formula $V = \frac{1}{\sqrt{\mu\rho}}$ in which ρ represents the density of the liquid and μ the coefficient of adiabatic compressibility, *i. e.* the variation in the unit of volume for a difference of one unit of pressure.

During the last few years much new research and many experiments in direct measurement through open water have been carried out by various nations. They were made in connection with various problems of submarine ranging, in order to determine more exactly the velocity of propagation of sound waves through sea-water.

At Cherbourg in 1919, Ingenieur Hydrographe MARTI, working with a base 900 metres (2953 feet) long has obtained a value for the velocity of propagation of sound through sea-water under definite physical conditions, and has adopted for normal conditions — *i. e.* for a temperature of 15° centigrade (58 1/2° Fahr.) and a salinity such that the density at 0° C. (32° Fahr.) is $D^0_4 = 1.026$ (which represents according to the tables of LANDOLT and BÖRNSTEIN a salinity of 32.35 per 1000) — the value 1504.15 metres (4934.966 feet) which he estimates to have an accuracy of ± 0.50 metre (1.64 feet).

The velocity of the sound varies with the temperature of the water, its salinity and the pressure, that is to say, with the depth. The theoretical formula $V = \frac{1}{\sqrt{\mu\rho}}$ from which is deduced $\frac{dV}{V} = -\frac{1}{2}\left(\frac{d\mu}{\mu} + \frac{d\rho}{\rho}\right)$ permits the separate influence of each one of the above factors to be analysed (salinity, temperature, depth) both on the density ρ and on the coefficient of compressibility μ.

By introducing the data extracted from the *Recueils des Constantes physiques* into graphs, we can trace the curves showing the relative variations $\frac{d\mu}{\mu}$ and $\frac{d\rho}{\rho}$ in functions of each of the above factors

Fig. 48. — Diagram by Ing. Hyd. Marti.

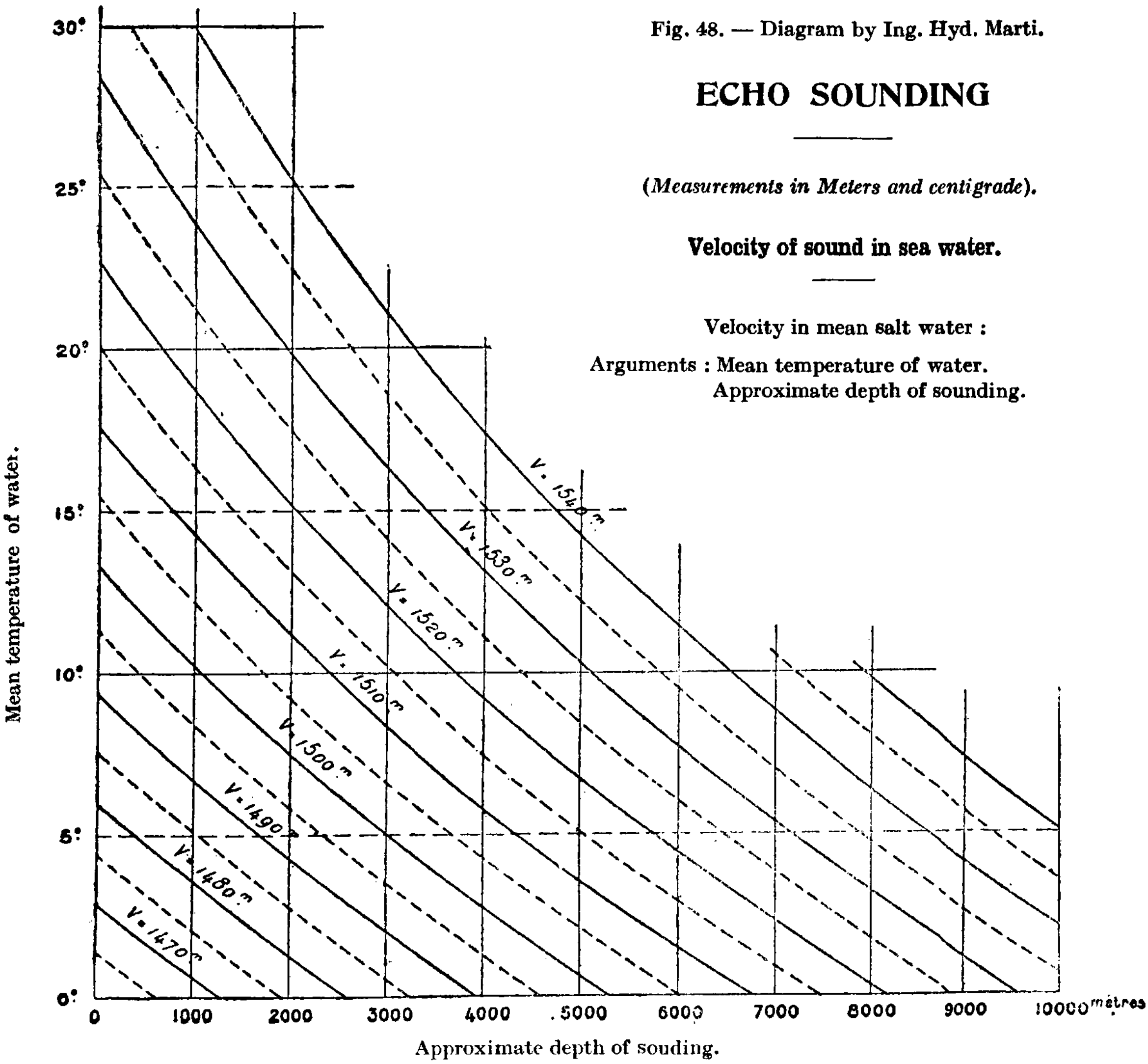
ECHO SOUNDING

(Measurements in Meters and centigrade).

Velocity of sound in sea water.

Velocity in mean salt water :

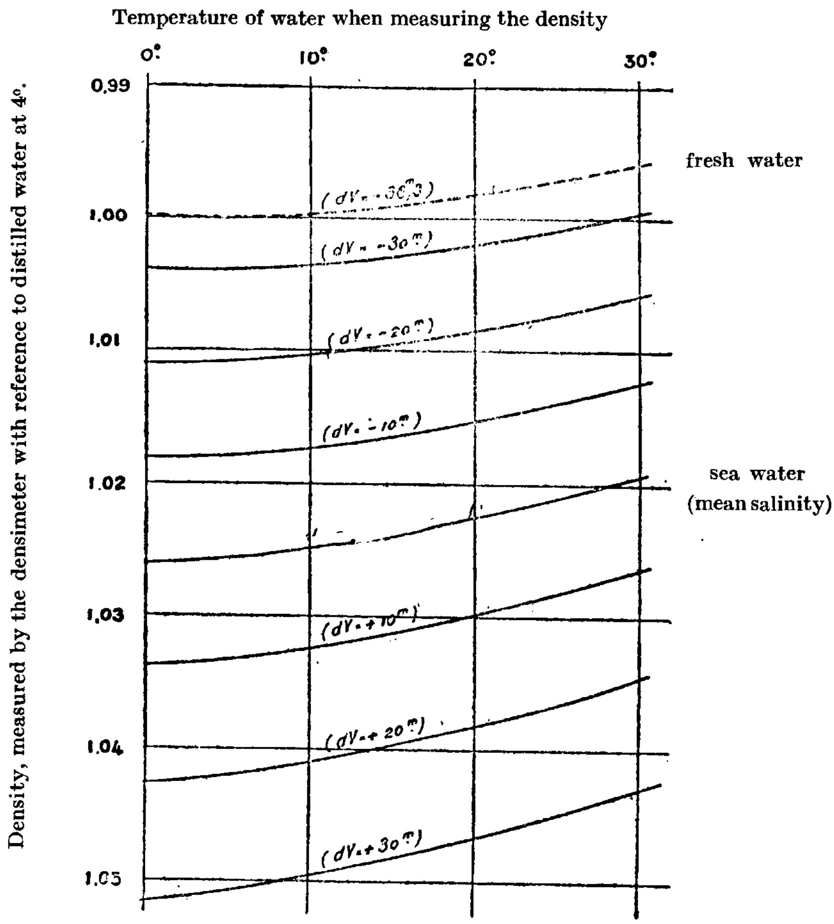
Arguments : Mean temperature of water.
Approximate depth of sounding.



EXAMPLE :

Soundings are taken in about 3.000 m.; the estimated mean temperature being 7°, a sample of water gave a density of 1.024 at temperature 11°.

Velocity of sound for mean salinity..............................	1.506 m.
Correction for salinity	— 1 m.
Velocity to be adopted..	1.505 m.



Correction of Salinity. — Take a point the coordinates of which are : density of water, measured with the densimeter with reference to distilled water at 4° and the temperature of water when measuring the density : read at this point the salinity correction and add it (algebraically) to the velocity of sound.

and half the total gives the corresponding variation of the velocity V.

A detailed analysis of this process will be found in the French *Annales Hydrographiques*, Vol. 705 of 1920, pages 165 to 179.

The accompanying table (Fig. 48) indicates a practical method for assembling these curves.

The accuracy of the values resulting from this graph is difficult to estimate because the knowledge of the physical data of the sea in various regions and at various depths (temperature, salinity, *etc.* and their variations) is far from being perfect and continuous observations are still required ; therefore when a small departure is made from the conditions under which the values used to construct the above table were established (15° centigrade, mean salinity, vicinity of the surface) errors must be expected and they may be important.

The following data, for example, show the error in a sounding as a function of the depth, and of an error in estimation of the velocity of sound.

DEPTH IN METRES	ERROR IN VELOCITY OF SOUND IN METRES PER SECOND							
	2	10	15	20	25	30	35	40
1,000	3	7	10	13	17	20	23	27
2,000	7	13	20	27	33	40	47	53
3,000	10	20	30	40	50	60	70	80
4,000	13	27	40	53	67	80	93	107
5,000	17	33	50	67	83	100	117	133
6,000	20	40	60	80	100	120	140	160
7,000	23	47	70	93	117	140	163	186
8,000	27	53	80	107	142	160	187	222

In average depths, *viz.* of 22 fathoms (40 metres), with an error in dV of 0.002 V in the velocity of sound, we would obtain the depth with an error of $\pm$ 3 inches (8 centimetres) only, which is of interest from the point of view of hydrography. In the same way it would be advantageous to know the density ρ to at least several units of the fourth place of decimals.

The density of sea-water, the temperature, salinity and depth of which are known, may be calculated from the Tables of BJERKNES (Martin KNUDSEN) which also take into account the effect of pressure (*See Annalen der Hydrographie*, 1922, Tables 18 and 19, and *Annalen der Hydrographie*, 1923, page 278, Table 3, and *Annalen der Hydrographie*, 1924, page 281, Table 4.)

The value of μ (for isothermic compression) may be deduced from the empirical formulae of V. W. ECKMAN or of TAIT, which were established from piezometric observations in the laboratory and at sea.

The formulae as well as tables A, B, C, D and V, which facilitate the calculation in practice will be found in the *Annalen der Hydrographie*, 1924, pages 81, 70, 91 and 92.

From measurements made at different temperatures in St. Margarets Bay, Messrs. WOOD and BROWNE give for the velocity of sound in sea-water the formula (metric);

$$V = 1450 + 4206t - 0.0366t^2 + 1.137\,(S-35) \text{ metres per second,}$$

in which S represents the salinity in units per 1000.

Taking into account the several formulae, a comparative table of the values obtained for the velocity, by means of various methods and by direct measurement, may de drawn up.

For normal sea-water ($\rho = 1.026$) the following table gives, according to Dr. H. MAURER, the average for a layer between the surface and the depth h, such as may be deduced from various methods (mM according to MARTI, mT according to TAIT, mB according to BJERKNES, mGB according to WOOD and BROWNE, mE according to ECKMAN, m = average.

	DEPTH h	0	750	1500	2250	3000
$t = 0^o$	m_M	1460	1467	1472	1477	1483
	m_T	1433	1439	1445	1451	1456
	m_B	1427	1439	1450	1458	1463
	m_{WB}	1447				
	m_E	1442				
	m	1442	1448	1456	1462	1467
$t = 5^o$	m_M	1477	1483	1488	1494	1500
	m_T	1458	1464	1470	1475	1480
	m_B	1450	1461	1470	1479	1487
	m_{WB}	1467				
	m_E	1463				
	m	1464	1469	1476	1483	1489
$t = 10^o$	m_M	1492	1498	1503	1508	1514
	m_T	1482	1488	1493	1498	1503
	m_B	1470	1479	1487	1495	1503
	m_{WB}	1486				
	m_E	1481				
	m	1483	1488	1494	1500	1507
$t = 15^o$	m_M	1504	1510	1516	1522	1527
	m_T	1505	1510	1515	1519	1523
	m_B	1485	1494	1502	1510	1517
	m_{WB}	1502				
	m_E	1497				
	m	1499	1505	1511	1517	1522

The difference between the calculated values and those which were obtained by direct measurement may be explained by the presence of gases dissolved in the sea-water.

The next table gives, according to Dr. Arnold SCHUMACHER, the variation of the various constants and of the velocity for great depths and for various types of sea-water. Approximate formula : —

$V = 1445 + 4.46t - 0.0615t^2 + (1.2 - 0.015t)(S - 35)$.

	m	Mean temperature between 0 and m metres °	Mean salinity between 0 and m metres p. 100	Mean density between 0 and m metres	$\mu \times 10^8$ at m metres	Mean value of $\mu 10^8$ between 0 and m metres	Mean value of velocity V. between 0 and m metres (m/sec)
Mediterranean between Balearic Islands and Sardinia	500	12.8	38.4	1.0302	4306	4333	1497
	1000	12.9	38.4	313	4273	4310	1500
	1500	12.9	38.4	330	4329	4290	1503
	2000	12.9	38.4	335	4208	4275	1505
North Atlantic Ocean approxim. 46° N — 13° W	100	11.8	35.5	1.0273	4380	4380	1491
	200	11.5	35.5	276	4378	4380	1491
	400	11.2	35.5	281	4368	4376	1491
	600	10.9	35.5	286	4360	4373	1491
	800	10.6	35.5	291	4353	4368	1492
	1000	10.4	35.5	296	4342	4362	1492
	1500	9.4	35.5	309	4326	4353	1493
	2000	8.2	35.4	321	4315	4344	1493
	3000	6.6	35.3	335	4277	4328	1495
	4300	5.3	35.2	382	4208	4300	1496
North Atlantic Ocean (tropics) approxim. 25° N — 37° W.	100	22.9	37.2	1.0258	4222	4222	1519
	200	21.7	37.1	264	4230	4223	1519
	400	19.4	36.8	272	4252	4232	1517
	600	17.4	36.5	280	4284	4244	1514
	800	15.8	36.2	285	4266	4253	1512
	1000	14.3	36.0	292	4272	4255	1511
	1500	11.6	35.7	307	4285	4263	1508
	2000	9.9	35.6	320	4284	4269	1506
	3000	7.7	35.4	345	4257	4269	1504
	5100	5.7	35.2	384	4163	4244	1506
North Atlantic Ocean (Equator) approxim. 4° N — 28° W.	100	25.9	35.3	1.0236	4214	4215	1522
	200	21.3	35.4	253	4228	4222	1520
	400	16.2	35.2	268	4295	4249	1514
	600	13.2	»	»	»	4270	»
	800	11.3	34.9	285	4346	4287	1506
	1000	9.9	34.9	292	4356	4300	1504
	1500	8.0	34.8	307	4359	4319	1499
	4300	4.6	34.9	365	4239	4310	1500
South Atlantic Ocean (Wedell sea) approxim. 46° S — 28° W.	100	— 1.7	34.3	1.0279	4706	4711	1437
	200	— 1.2	34.5	282	4682	4702	1439
	400	— 0.4	34.6	287	4640	4681	1441
	600	— 0.1	34.6	292	4619	4664	1443
	800	0.0	34.6	294	4601	4650	1445
	1000	0.0	34.6	301	4582	4638	1447
	1500	0.1	34.7	313	4541	4612	1450
	2000	0.0	34.8	325	4507	4590	1453
	5000	— 0.2	34.7	395	4302	4479	1465

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