

NOTE ON ACOUSTIC SOUNDING

by

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CHAPTER I.

BRIEF HISTORY.

It is already quite a long time since physicists, having observed the remarkable permeability of water to sonic waves, suggested the use of these waves to solve various problems in connection with the increase in safety of navigation. Sounding, or in other words the determination of the depth of water near the vessel, seems particularly to lend itself to solution without difficulty, by measuring the time which a sound wave, emitted by a vessel, takes to go to the bottom of the sea and to return to the surface, after having been echoed from the bottom. This suggestion, which appears to have been made by ARAGO in 1807, does not seem to have been subjected to tests, and thus was entirely forgotten.

Recent events have brought the possibility of using submarine sonic waves to the front again.

After the loss of the great liner *Titanic*, the bottom of which was ripped out by an iceberg in 1912, it was suggested that these waves should be used to locate floating ice, it being thought that the presence of these formidable dangers might be detected by means of echos from the submerged parts, which are generally of large dimensions, when a submarine sonic emission was made; to ascertain the direction of the ice-berg it was proposed, moreover, to send out this emission by means of waves of very high frequency (even beyond the limit of perception of the human ear) in order to obtain pencils of waves which would be propagated nearly in a straight line by reduction of the effect of diffraction. This was the origin of the ultra sounds which Messrs. LANGEVIN and CHIŁOWSKI succeeded in developing beyond the experimental stage some few years later.

Submarine warfare also caused the Allied vessels to utilise the sonic waves which are propagated in the liquid mass of the sea, for the presence of submarines was detected by the rhythmical noise made by their propellers, and it was hoped that it would be possible to find these vessels by means of ultra sounds as had previously been proposed in connection with ice-bergs. It is true that the results obtained before the end of the War in connection with the two latter problems were not of great help to those at which our adversaries fired torpedos, but at least the research made in connection therewith eventually gave some small result by making the possible conditions of use of submarine acoustics known to a certain extent, and this was of considerable value to the searchers who, after the War, worked along these lines.

It was in 1919 that we in France began to study acoustic sounding. It is true that we hoped at that time to succeed some day in determining the depth of water by measuring the time which separates the making of a noise below water, and the arrival of its echo from the bottom of the sea, but we certainly did not expect, during our researches, to meet such a group of valuable considerations as those which characterized the birth of sonic sounding, and which, in fact, are the cause of its rapid development.

The first trials were made in May, 1919, in the Channel on board small vessels (submarine chasers and small torpedo-boats) which the Naval Command of the First *Arrondissement* kindly placed at our disposal. The gear employed was the usual apparatus which every investigator has to improvise: an odd collection of instruments used in analogous research, and of improvised apparatus made by the means available on board the ship. For making the sonic waves small electric caps were detonated. The first experiments, which were carried out in water which was too shallow, failed, for the receiving apparatus, violently affected by the emitted wave, had not yet returned to rest when the echo came back; but by going into deeper water (60 metres = 197 feet), the echo was clearly distinguished from the emission; the result, which was graphically inscribed by styles on smoked paper, was indisputable. Shortly afterwards the same results were obtained, using the same apparatus, over the Casquets Deep (North-westward of the Cotentin Peninsula) at a depth of 160 metres (525 feet), and this in a very

rough sea and with the ship steaming from 8 to 10 knots, the receiving microphone having been secured to a float which was towed at a short distance.

The results of these first trials, when received in Paris, greatly interested certain persons, and the Chief of the Government Submarine Cable Service gave us the use of the cable vessel *Charente* in order to carry out experiments in deep water.

The trip which this vessel took in August 1919 gave us the opportunity to obtain very correct soundings in the Bay of Biscay, in depths of 4000 metres (2190 fathoms), by means of detonated charges of about 40 grams (62 grains) of explosive. This was sufficient to show the great value of this new method of sounding and the report which we then made to the *Académie des Sciences* seems to be the point of departure of research along these lines in certain foreign countries. However, Dr. BEHM, in Germany, made it known a little later that the experiments, which he had been making in this direction for some years, had made it possible for him to have obtained similar results already, though only in smaller depths.

Thereafter there was a rapid extension of this new method. The *Centre d'Etudes* of the French Navy succeeded in 1920, off Toulon, in sounding very satisfactorily at average depths by means of combined emitting and receiving ultra-sonic appliances, constructed by M. LANGEVIN; thenceforward appliances were built to exploit the two variants known in France, *viz.* sounding by detonation, and ultra-sonic sounding. Shortly afterwards it was learnt, first, that in America the *Submarine Signal Company*, had made a sounding appliance which used the FESSENDEN oscillator as the source of sound, this oscillator being a sort of submarine siren which was used earlier for signalling during fog for coastal navigation purposes, and, second, that in Great Britain the Admiralty had constructed a similar appliance which employed a hammer striking on a metal diaphragm as the source of sound. Finally, quite recently in France, also, a sounding appliance using blows of a hammer was constructed.

At the present time (1930) the solutions put forward for sounding acoustically may be grouped into three classes:

a) *Those which use a very loud noise*, much damped, practically a single pressure-wave similar to that given when a rifle is fired; its strength being the only means of distinguishing the echo from the parasitic noises which always accompany a ship underway. Herein may be classed the French and German solutions which use detonations and the American, British and French methods of sounding by means of blows of a hammer.

b) *Those which use audible sound*, namely the sustained vibration of a frequency of about one thousand oscillations per second, which may be compared to that of a whistle or a siren, the oscillatory nature of the sound being utilized to distinguish the echo, by means of resonating appliances, from the parasitic noises of the ship. So far only the American solution, using the oscillator, can be classed herein.

c) *Those which use a similar sound but one which is inaudible* on account of the fact that the frequency is too great (*e.g.* a sound due to 50,000 oscillations per second), resonance being naturally used also to receive the echo. Herein may be classed the French solution termed ultra-sonic sounding.

All these solutions are based on the direct determination of the interval of time taken by the sonic wave to reach the bottom of the sea and return, after being echoed by the bottom; this interval is usually referred to as the "echo interval". A few other solutions based on indirect measurements of the same interval, applicable mainly to soundings in shoal water, have not yet succeeded in coming into practical use; they will not be referred to here (*).

CHAPTER II.

GENERAL CONDITIONS FOR THE USE OF SOUNDING BY MEASURING THE ECHO INTERVAL.

1. SELECTION OF VELOCITY OF SOUND

VALUE OF THE VELOCITY.

The velocity of sound in sea water was not known exactly when the study of sonic

(*) In this connection see "*Present state of Acoustic Sounding*" by Professor TENANI, which appeared in the Italian *Rivista Maritima*, November 1924.

sounding was first taken up. The well-known determination by COLLADON and STURM in 1827, made in Lake Geneva, applied only to fresh water at a temperature of 8° C. (46° F.). But the salinity, the temperature and also the pressure of the liquid (and consequently the depth at which the waves are propagated) have a certain influence on the velocity of sound. It was necessary, therefore, to carry out a new determination under physical conditions of the liquid approximating to those which are usually found when at sea, and further, to determine the laws of variation of velocity as a function of the three factors, temperature, salinity and pressure.

In July 1919 we made a determination, which was as correct as possible, of the velocity of sound in Cherbourg Roads at average values of temperature and salinity (15° C. (58-1/2° F.), and 35 grams of salt per litre), the waves being propagated at a shallow depth. This was the first and the easiest part of the work.

The laws of variation of the velocity had still to be determined. To do this accurately is evidently a considerable undertaking, whether done in a laboratory or directly at sea. As we considered that this was not worth while we simply drew up approximate theoretical laws for the variation of velocity. Using as a basis the influence of the three factors, temperature, salinity and pressure (determined long ago by laboratory experiments) on, first, the density of the liquid d , and, second, on its coefficient of compressibility c , we deduced, by the formula $V = \sqrt{\frac{1}{dc}}$, the probable influence of these

factors on the velocity of sound V . The result of this research was published, together with a report on the determination of velocity carried out at Cherbourg, in the *Annales Hydrographiques*, 1919-1920. The laws for variation given therein are obviously only approximate (*); nevertheless, the determinations made since then in Great Britain, Germany and the United States, at somewhat different temperatures, have confirmed them quite satisfactorily, and thus it may be said that, in so far as the influence of the temperature is concerned, they are sufficiently accurate for the present applications of submarine acoustics. It is probable that the same is the case for the influence of salinity and pressure.

VELOCITY WHICH SHOULD BE ADOPTED FOR SOUNDING.

In order to take accurate soundings by sound it is theoretically necessary to determine the temperatures and salinities of the different layers of the water at the very place and moment of the determination of the echo interval, after which a species of integration would give the depth; anyway this integration might be reduced to the finding of a mean velocity which, multiplied by the echo interval, would give the depth.

But, luckily, the physical conditions are generally such that the average velocity to be used for the purpose vary but little from a single value (1,500 metres per second), the temperature of the water usually decreasing with the depth, the increase in the velocity which is due to the increase of pressure is thus practically compensated by the decrease in velocity due to the lowering of the temperature. It is only in taking very deep soundings that the velocity of sound differs materially from the value 1,500 metres, as the temperature of the water is nearly constant (4° C. = 39° F.) in great depths and the increase of velocity due to the increase of pressure is, therefore, not compensated there.

The velocity of 1,500 metres, which is, therefore, usually fairly close to the velocity which must be employed, has been adopted as the only velocity for making the graduations used in the various instruments for measuring the echo interval. These instruments give an approximate value of the depth by direct reading. The corrections to be applied to their readings are always small and may be given with all requisite accuracy by

(* In principle it may be assumed that the velocity of sound in sea water, the mean of which is 1,500 metres (4,921 feet) per second (water at 15° C. and containing 35 grams of salt per litre, and near the surface):—

Increases about 2.5 metres as the temperature increases 1° C. ; increases about 1 metre as the salinity increases 1 gram per litre ; and increases about 1.5 metres for each ten atmospheres of increase of pressure, i.e. for each increase of 100 metres in the depth at which the waves are propagated.

tables or simple diagrams constructed with the arguments (a) mean temperature and salinity of the layers and (b) approximate depth of the sounding (*).

EFFECT OF BOTTOM RELIEF.

The depth given by sonic sounding is really the shortest distance from the ship to the bottom, and it is only when the bottom is flat and horizontal that it coincides exactly with the depth. When the bottom is sloping (and more generally when it is uneven) a correction must be applied to the depth obtained in order to get the true depth. This correction, which, as a rule, is always positive since the true depth is always greater than the shortest distance from the ship to the bottom as measured acoustically, is generally insignificant in average depths, for the slope of the bottom under these conditions is generally slight. On the other hand it may not be negligible in great depths.

In order to calculate this correction the slope of the bottom under the ship must be known, and this is easily found if a chart of the area has already been made but, if the soundings being taken are intended for the purpose of making the chart of the area, it is obvious that the only way is to use successive approximations. Besides, if only a single sounding has been taken, and even if but a single line of soundings be taken without knowing the direction thereof with reference to the contour lines of the bottom, it is impossible to calculate the correction (**).

Thus sonic sounding in great depths, while giving the seaman a definite quantity representing the shortest distance from the ship to the bottom, does not always give him the exact depth of water until a correction has been added, which takes some time

(*) A diagram of this sort is at the end of "Note sur le sondage aux grandes profondeurs par détonations", published in the Annales Hydrographiques, 1923-1924.

(**) In certain cases it is absolutely impossible to determine the correction to be applied to sonic soundings in order to obtain the true depth. Thus the depth in the thalweg of certain particularly deep submarine ravines cannot be obtained by the sonic method as the echos from the edges of the ravine, which will return first, will mask the echo from the bottom of the ravine (fig. 1) even supposing that this echo will be sufficiently loud to be recorded.

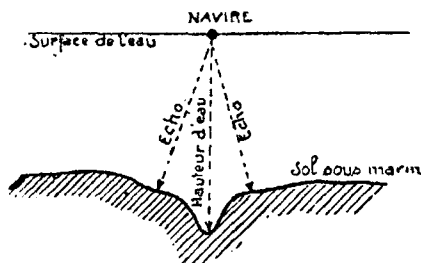


FIG. 1

Generally speaking, in deep water sonic sounding will give but a general impression of the submarine relief, as the small bulges, as well as the small depressions (should these exist), are smoothed out. This state of affairs can scarcely be considered a disadvantage in view of the present use of sounding in great depths.

As for the property, said to pertain to appliances using ultra-sounds, viz: to take true vertical soundings, it cannot be put forward in the present case in favour of this particular form of acoustic sounding, for it has been demonstrated that ultra-sonic appliances usually give some other value than the exact depth of water over a sloping bottom. When the bottom has a moderate slope these appliances also give the shortest distance from the ship to the bottom. When the slope is considerable the echos received spread themselves over a considerable period of time, doubtless because parts of the bottom which are at different distances from the ship send back echos of approximately the same intensity, for example, from a part in a direction approximately vertical to the bottom, and thus favourable for strong echos but in which the appliance emits but little energy, and in directions approximately vertical from the ship, in which the appliance emits with great energy, but from which only feeble echos will return on account of the obliquity of the reflecting surface. Finally when the slope of the bottom is really great, then the ultra-sonic appliance no longer works.

to find, and it happens even that the seaman cannot know the exact depth although it may be fairly close to the echo distance recorded. This has the appearance of being a serious disadvantage in the new method of sounding.

A closer study of the matter shows that it is wrong to insist on obtaining the true depth of water. In fact the shortest distance from the ship to the bottom is as much a characteristic of the place as the true depth of water, and consequently, it would be perfectly admissible that the figures shown on the charts should be sonic soundings which are not corrected for the slope of the bottom; special type might be used for the figures obtained from sonic soundings with a view to avoiding confusion with older soundings taken by lead and line. This would do away with a difficulty which was met with from the very beginning when sounding by the sonic method in deep water over a sloping bottom.

DEFINITE PROPOSALS FOR THE SELECTION OF A VELOCITY OF SOUND FOR ACOUSTIC SOUNDING

The practical use of the new method of sounding can be still further simplified in the difficult case under consideration, *viz.* sounding in deep water. It is a fact that, in a given area, the seasonal variations in temperature and salinity affect the superficial layers of the water only, and, therefore, they have but an absolutely insignificant effect on the determination of the depth of the oceans. Thus, if erroneous mean velocities are used for calculating depths, the errors which are due thereto at any given place are the same at all times of the year, provided that the same erroneous value of velocity is always used.

This important statement makes it possible to consider the calculation of depth by means of a mean velocity of sound which would be used everywhere and at all depths, though obviously errors will sometimes occur in such determinations of depth. Anyway, the difference between the real depth and the depth calculated in this way would never be found in ordinary navigation because users of the charts would always make the same error as that which was made when the chart was drawn up.

As early as in 1927 a proposal of this sort, put forward by Germany, was submitted to the International Hydrographic Bureau at Monaco. More recently the International Congress on Oceanography and Hydrography, held at Seville in 1929, considered an absolutely similar proposal put forward by France. According to this proposal it would be assumed, for the purpose of sonic sounding, that the velocity of sound is, everywhere and always, 1,500 metres (4,921 feet) per second. This is, in fact, but a proposal to

draw up charts giving "echo intervals", the unit of time being $\frac{1}{750}$ of a second which, in most cases, corresponds to a depth very close to one metre (*).

A close examination of this proposal shows that the errors which it would introduce do not exceed, in practice, a fiftieth of the depth. Thus this is but a very small error which will be entirely unsuspected in ordinary sounding so long as acoustic appliances are used, since their readings will always agree with the indications on the chart. The above proposal really must be adopted, sooner or later, or so it seems, for its simplicity makes possible the great extension of the remarkable method with which we are dealing. In order to make the explanation given below more simple it will be assumed that this really has been adopted.

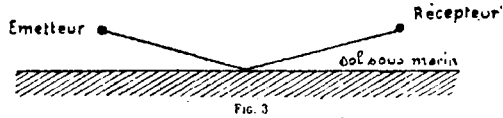
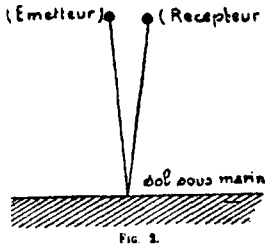
2. CONDITIONS PROPERLY SO CALLED, FOR THE USE OF SONIC SOUNDING

RELATIVE POSITIONS OF THE EMITTER AND THE RECEIVER.

Distinction should be made between (a) the case where the sonic wave is emitted and its echo received by the same apparatus (or where the emitter of the wave and the echo receiver are very close to each other, which comes to the same thing), and (b) the case, which is much more used, where the two appliances are at some distance from each other.

(*) An echo interval of one second corresponds to a sonic distance equal to half the distance covered by the sonic wave in one second, i.e. $\frac{1,500}{2} = 750$ metres.

When the emitter and receiver are one and the same the depth under such appliance is directly proportional to the echo interval. This is the best method and the only use made thereof at the present time is in sounding by ultra sounds, in which an acoustic apparatus is used which acts both as emitter and receiver. The depth recorded by sound must obviously be increased by a fixed quantity, namely the depth at which the emitter-receiver lies.



When, however, the remitter and the receiver are at a certain distance from each other the formula which gives the depth below the appliance from the echo interval is no longer linear; the two quantities are proportional to each other at great depths only when the angle of reflection from the bottom is practically a right angle (Fig. 2). The sensitiveness of the appliance for determining depth becomes less in shallow water, for the reflection from the bottom is very oblique (Fig. 3). This is obviously a disadvantage because it is particularly in shallow waters that more accurate soundings are required. Generally attempts are made to diminish the troublesome effects of this by reducing the distance which separates the emitter from the receiver as much as possible (*). Of course, the readings of the acoustic appliance must be increased by a figure which is determined by the depth at which the emitter and receiver lie; it is usually estimated that the depth is the same, or very nearly the same, for both, and the readings obtained are increased by a quantity equal to the mean depth of the two.

METHOD OF NOTING THE MOMENT OF EMISSION IN APPLIANCE FOR MEASURING THE " ECHO INTERVAL ".

When the emitter and receiver are one and the same or very close to each other the appliance for measuring the echo interval which is attached to them is obviously set into action without delay at the moment of emission of the wave; this is yet another reason why this is the best method. Certain instruments, using an emitter and a receiver at some distance from each other, note the instant of emission of the wave on the appliance for measuring the echo interval by means of an electric attachment (this is the method used in sounding by the oscillator, as practised in America), or else by installing a small supplementary receiver of low sensitiveness in the close vicinity of the emitter (this is the method used in sounding by detonations, as practised in Germany).

Other instruments of this sort merely record the instant of emission of the wave on the appliance for measuring the echo interval by means of the receiver which receives the echo. Arrangements are made so that the receiver shall receive the wave at its emission, but with its intensity considerably reduced; there is no difficulty in doing this for it can be arranged by receiving the somewhat attenuated wave which finds its way round the hull by diffraction or, as is more usual, by utilizing the parasitic wave which runs through the frame of the ship when the emitter is started (this parasitic wave tra-

(*) In most cases the distance between the emitter and the receiver is required on account of the necessity of protecting the latter, to a certain extent, against the violent action of the wave in the vicinity of the emitting appliance and against the resonances of various sorts which follow the emitting wave, and whose seat is obviously mainly in those parts of the ship surrounding the emitting apparatus. The best arrangement to reduce the distance between the emitter and the receiver is generally to use the hull of the ship as a screen between the two; thus their distance can usually be reduced to the bare width of the ship, say from about 10 to 20 metres (35-65 feet).

vels much faster than that through the water, as the velocity of sound in steel is about 5,000 metres (16,500 feet) per second). This method is used in sounding with hammer blows in France and Great Britain. Naturally allowance is made for the fixed lag with which the receiver notes the emission of the wave.

ACCURACY OF THE DETERMINATIONS OF DEPTH.

The accuracy obtained in determining the depth is usually quite sufficient for the requirements of navigation; the instruments make it easy to read off depths to within a fathom, and some of them, even, to within a metre. For hydrographic work it was obviously desirable to reach greater accuracy, at any rate in soundings in shallow water. Ultra-sonic sounding appliances give this greater accuracy; they usually are marked in metres, sometimes in half metres, but this latter is by no means quite reliable for the absolute elimination of all systematic errors in the measuring of the echo interval is by no means easy, particularly when it comes to the point of obtaining an accuracy greater than one thousandth of a second (*).

DEPTH LIMITS FOR THE USE OF SONIC SOUNDING.

Generally speaking it is difficult to take soundings by acoustic methods in shallow water for, in these circumstances, the echo comes back very close on the emission of the wave and thus measurement of the echo interval by means of a single receiving apparatus, such as is used by most of the appliances of the present day, is not possible unless this receiving appliance can be brought to rest in the very short interval which separates the emission from the return of the echo.

Likewise it is difficult to sound by sonic methods in great depths, for the power of the acoustic appliance which can be used is obviously limited, and thus it happens frequently that but feeble echos have to be used.

Fortunately, in shallow water, the echoes are powerful, and thus the sensitiveness of the receiving appliance becomes of secondary consideration, and can be sacrificed in order to obtain the rapid damping which is necessary under these conditions; on the other hand, in great depths, the echo does not return to the ship until a relatively long while after the emission of the wave; it is the damping of the receiver which becomes a secondary consideration and thus can be sacrificed for the much greater sensitiveness required in this case. The desire to give suppleness to appliances in order to make them utilizable over a wide range of depths has induced those who make research on this subject to construct instruments which may be adjusted to suit the circumstances.

The appliances so far constructed have practically all got the same limit for sounding in shallow water; they sound without difficulty as soon as the depth under their emitters exceeds about 20 metres (65 feet), they even permit the echos to be distinguished with about 10 metres below them, but sounding in five metres with sonic sounding machines, which necessitates a return to rest of the whole of the receiving appliance in less than one 150th of a second, must, at any rate for the present, be considered extremely difficult to attain.

In deep sea sounding the limits of the various instruments are far from being the same however. Those sounding by hammer blows will reach depths of 500 metres in fine weather, sounding by ultra sounds or by explosion produced by a rifle down to 1,000 metres, sounding by oscillators down to 3,000 metres, but for regular sounding in very great depths (from 8,000 to 10,000 metres) sounding by detonation must be employed as this is the only means the power of which is not limited since, obviously, this can be increased by increasing the explosive charge used (**).

Thus, whatever efforts may have been made to extend as far as possible the limits of sounding with such instruments, no instrument has yet been constructed which will take soundings at all depths. This should not be astonishing for, as in all acoustic phenomena, the intensity of the echo decreases in proportion to the square of the distance (in this case the square of the depth); consequently, to obtain the same echo at

(*) *An error of one thousandth of a second in measurement of the echo interval gives an error of 75 cm. (30 inches) in the depth.*

(**) *In any case but relatively minute quantities of explosive are necessary for sounding in the greatest depths, say 10,000 metres; at this depth a charge of 100 grams is sufficient under all circumstances.*

the greatest depths (10,000 metres) as at the smallest depths (10 metres) a million times more energy must be used; acoustic emitters and receivers so far constructed are unable to deal with such a wide range of power.

DIFFICULTIES MET WITH IN PRACTICAL USE OF SONIC SOUNDING.

As was seen above sonic sounding, in itself, raises a certain number of difficulties due, for example, to the great velocity of the waves used and to the extent of the range of depth which it is desired to record. When it comes to the actual use of this method it happens, occasionally and unfortunately, that other difficulties arise, due to the unfavourable conditions in which it has to be used very frequently, and it is necessary to issue a warning against a belief that, in practice, sonic methods allow soundings to be taken at all depths, at all speeds of the vessel and in any weather.

Generally speaking, it will be noticed that all sonic sounding appliances are more or less sensitive to the shaking and vibrations of all sorts which occur in a ship when she is moving at high speed. Obviously there is no fixed rule which will give the speed limit within which any given apparatus may be used for sounding; shape and thickness of the hull of the ship, the position of the receiving appliance on the hull, the draft of the ship, the balancing of the engines, *etc.*, each is a factor which has its influence. The only rule is that, generally, so long as the ship is moving at a moderate speed, *i.e.* when she seems to slide without effort through the water, sonic sounding instruments will act very nearly as well as when the ship has stopped, but when the speed becomes such that the engines have to exert a considerable effort in order to maintain it, an enormous number of vibrations begin throughout the hull, and under these circumstances acoustic appliances are nearly always more or less interfered with. Ultra-sonic sounding appliances appear to be those which are least affected by the vibrations due to the speed of the vessel, and this doubtless is because these vibrations are mainly at relatively low frequency. Certain vessels take soundings by ultra sonic methods regularly at speeds over 20 knots, but it must be added that similar results have been obtained recently with appliances using hammer blows.

In addition all acoustic sounding appliances are more or less sensitive to the movement of the sea. It is true that, in most cases, it has been possible to eliminate, in the instruments themselves, all the inconvenient influence of oscillations which may be imparted to them, but the vessel as a whole is affected by the movement of the sea and in bad weather becomes the seat of vibrations of all sorts which did not exist when the sea was calm. These vibrations have the same effect on sonic sounding appliances as a too high speed of the vessel.

Besides, the movement of the sea frequently has a still more serious influence which, unless certain precautions are taken, may go so far as to stop the use of the sounding instruments entirely. When the vessel has longitudinal oscillations (pitching) it causes a part of the water which is highly charged with air bubbles, which always form round the cutwater (usually referred to as the "bow-wave"), to pass under the bottom at times, whereas in calm weather the water charged with air bubbles usually passes round near the surface on both sides of the vessel. This effect of the pitching of the vessel which was of no consequence before, is naturally more pronounced in vessels of shallow draft, but its extent depends, also, very largely on the shape of the fore part of the hull of the vessel. When they get underneath the hull the air bubbles become rapidly scattered, for those which are against the skin of the vessel are dragged along to a certain extent with the vessel, whereas others remain still in the water; thus they form underneath the vessel a sort of flat cloud in contact with which the hull is sliding. Now clouds of air bubbles are just as opaque to sound as are clouds of dust to visibility, each air bubble being a compressible point which damps the variations of pressure in the liquid during the passage of sound waves, *i.e.* of acoustic energy; thus sounding appliances built into the hull are obviously seriously affected by such clouds whenever they become numerous. In shallow draft vessels in a heavy sea the bubbles actually reach the condition of forming a continuous cloud under the vessel, and this makes impossible all attempts to take soundings by means of appliances let into the hull, unless special precautions are taken. This happens with ultra-sonic sounding appliances which are particularly sensitive to the effects of air bubbles.

It seems that the only certain method of avoiding this bad influence of air bubbles is to fit an acoustic appliance on projections underneath the hull, but though the thickness of the bubble clouds is not great and consequently only a small projection of the appliance (from a half, to one metre) is sufficient to avoid them, such projections are not

favoured owing to their inconvenience (if only from the point of view of the safety of the vessel); consequently a partially effective remedy is usually applied and this consists in fitting the acoustic appliances under those parts of the hull which are close to the keel, as these, even in bad weather, are in solid water at certain times, and this allows the instruments to work, even though only intermittently.

CHAPTER III.

DESCRIPTIONS OF THE INSTRUMENTS AT PRESENT IN EXISTENCE

As stated above, the instruments so far constructed may be classed according to the acoustic phenomena employed, namely:—

a) *Sounding by detonation or by blows*; this uses a powerful but very much damped acoustic wave, *i.e.* a noise of very short duration such as that made by a firearm or the cracking of a whip, or the blow of a hammer on a non-resonant object. In this type of sounding the echo is distinguished from the parasitic noises by its strength alone.

b) *Sounding by waves of audible frequency*; this utilizes ordinary sounds; these sounds can be fully maintained notes, such as those produced by a whistle or siren, or may be slightly damped, such as those produced by a bell or piano. The sinusoidal nature of the vibration is utilized in this method of sounding to accentuate the echo, as compared with the parasitic noises, by means of resonance.

c) *Sounding by waves of inaudible frequency*; these use ultra sounds in exactly the same way as audible sounds are used, ultra sounds being those the frequency of which is so great that the human ear cannot perceive them, and these ultra sounds may be fully continuous or slightly damped; here also the sinusoidal nature of the vibration is used to accentuate the echo by resonance as compared with the parasitic noises.

A. SOUNDING BY DETONATIONS OR BLOWS.

This is the method of sounding which has found the most favour in research; it seems, also, that it is likely to have the better chance of coming into general use. It has been examined simultaneously in France, Germany and England, and latterly in the United States, but in different ways; this work has produced a particular form of instrument in each country.

In France, the *Société Indépendante d'Exploitation Radio-électrique* (S.I.E.R.) has undertaken the development of this process. This Firm produces an instrument for receiving echo and for measuring the echo interval which can be used all at depths; it is put into action by sonic waves of power appropriate to the depth in which the sounding is required.

The appliance for emitting the waves is:

In shallow water (from 10 to 200 metres), a hammer which strikes some part of the steel of the ship or on a steel anvil attached to the hull; the hammer, which is in the hold, is worked from the bridge by mechanical or electrical means.

At medium depths (from 100 to 1,000 metres), a rifle, the bullet from which strikes the surface of the water alongside the ship.

In great depths (*i.e.* those which the preceding appliances cannot reach), *detonating cartridges* which are exploded within the mass of the water; these cartridges are either attached to an appliance which submerges them behind the vessel in spite of its speed and are detonated electrically, or else they are thrown into the sea and are fired by means of a slow match which is lit beforehand, the length of the slow match being adjusted so that the detonation shall occur when the charge has reached a depth of a few metres.

The receiving apparatus which is used, no matter what form of emission is employed, includes:

A *microphone in the hull*, which is enclosed in a small cast-iron tank secured, from the interior, on to the skin of the ship, and which is filled with water; the microphone thus receives the sonic waves from the sea water through the skin of the ship, it is not necessary, therefore, to make holes in the latter. When taking a sounding the microphone receives two waves; the first, which is received directly and is suitably damped

by setting the emitter and the microphone at a suitable distance from each other, gives, with a slight and constant lag, the moment of emission of the acoustic wave; the second is the echo.

A *valve amplifier* of special type, by means of which the noises received by the microphone are graphically recorded.

A *graphic recorder* by means of which the echo interval is determined. In this apparatus, which is started shortly before the sounding is to be taken, the sonic wave is recorded by a pen on a narrow tape, similar to that used by some telegraphic instruments, which is driven by clock-work at a known constant speed. Thus the distance between the *V* made by the pen at the moment of emission of the wave and that produced by the echo gives the echo interval; a transparent graduated rule is applied on to the paper tape with its zero at the beginning of the first *V* and makes it possible for the depth, shown by the beginning of the second *V*, to be read off directly (fig. 4).



FIG. 4.

The S.I.E.R. instrument has the following advantages:—

It is simple and relatively cheap;

It can be fitted in ships without the necessity of dry-docking them, as no holes need be made in the hull;

Finally, the receivers of this instrument allow soundings to be taken at all depths, whether great or small; this property is of very great advantage for vessels carrying out oceanography, cable, *etc.*, work, which have to sound in great depths.

However, the complaint has been made that this instrument requires that the operator shall apply a graduated scale to the recording tape in order to read the depth; this, it is true, constitutes a slight inferiority as compared with the instruments which give direct readings of the depth on a permanent graduation.

In Germany, the *Behmecholotgesellschaft* of Kiel, produces a sounding appliance using detonations, invented by Dr. BEHM.

The instrument comprises:—

A single source of sound consisting of *detonating cartridges*; the charges in these cartridges vary, and they are shot into the sea and their fuses fired at the same moment by a sort of pistol. The fuse contains a slow burning charge which retards the explosion of the cartridge until it is below water.

Two microphones attached to the hull of the ship; one is not very sensitive and is in the vicinity of the position where the cartridges explode; this is used to record the moment of emission of the wave. The other microphone, which is very sensitive, is attached on the other side of the vessel and is used to receive the echo.

A *special apparatus* for measuring the echo interval. In this instrument, which is wound up before taking sounding, the emission of the wave, as recorded by the first microphone, liberates a spring which starts a disc revolving at a constant known speed, the echo received by the second microphone frees a brake which stops the disc, and the echo interval is determined by the position in which the disc is thus held. It remains visible until the spring is wound up again for the next sounding; naturally the instrument is marked off directly in metres of depth.

The *Behmecholotgesellschaft* instrument has the following advantages:—

The use of amplifiers is avoided;

Like the S.I.E.R. instrument it may be installed without dry-docking the ship;

The measuring appliance, which requires but the manipulation of a few buttons, may be used by even untrained operators.

On the other hand the BEHM instrument has the disadvantage that the operator has no means of checking the accuracy of the readings. This is a property of instruments which are entirely automatic, for all direct reading by the operators is avoided (which is certainly an advantage), but they are unable to make a check (which seems to be a

disadvantage, for in the present state of sonic sounding the users of such instruments should take every precaution to avoid serious errors). As a matter of fact it is recommended that repeat soundings be taken with the BEHM instrument as a check.

In England, a hammer blow sounding instrument has been developed by the Admiralty. This instrument is constructed by Messrs. HUGHES & Son, Ltd., and includes:—

An electrically worked *hammer*, which strikes permanently and at relatively rapid rhythm, on a steel disc in contact with the sea.

A *microphone* attached to the skin of the vessel but on the other side.

An *apparatus for measuring* the echo interval which revolves continuously and which ensures rhythmic striking of the hammer by means of an electric contact. It has, in addition, an arrangement which makes it possible to hear noises transmitted from the microphone during a very short interval only after each blow of the hammer. This is at an arbitrary but known interval of time after the stroke of the hammer. To take a sounding, this time interval is varied until the rhythmic noises of the echos are heard in the receiving apparatus, then the time interval (from the hammer blow to the moment when the microphone circuit is closed) is equal to the echo interval, and this gives the depth.

This British instrument has the same advantage as the BEHM instrument in that it avoids the use of amplifiers.

Complaints are made, however, that the measurement of the echo interval must be made by ear; appliances which use reading by eye appear to be preferred by users of sonic sounding machines.

It is not known whether this instrument can be installed on board ships without docking them.

In America, a hammer-blow sounding instrument has been constructed by the *Submarine Signal Company*. This instrument, which gives continuous readings of the depth, includes:—

A *hammer* similar to the British hammer, which is worked electrically and strikes continuously, about one stroke every three seconds, on a steel disc attached to the hull.

A *microphone* attached to the skin of the ship at a certain distance from the hammer

A *selective amplifier* which is sensitive to violent waves only, and thus does not come into action except to receive the echos.

An *appliance for measuring* the echo interval, called the Fathometer, which works continuously (in just the same way as the corresponding British apparatus). It governs the rhythmic working of the hammer by means of an electrical contact, and records continuously, by means of an optical arrangement, the acoustic energy received by the microphone and transmitted to the amplifier. This optical arrangement consists of a line of light which moves regularly and in the same direction after each hammer blow; this luminous effect, produced at the moment of reception of the echo, indicates, by the point where it is produced, the interval between the hammer blow and the echo and, consequently, the depth of water.

The *Submarine Signal Company* instrument has the following advantages:—

That it gives permanent readings of the depth of water, which characteristic is much appreciated by users of this instrument when they navigate in waters in which they are uncertain as to the depths which they are likely to come across.

That, like the S.I.E.R. and the *Behmechotgesellschaft* instruments, it can be installed on board ships without dry-docking them.

B. SOUNDING BY WAVES OF AUDIBLE FREQUENCY.

Sounding by continuous sounds has been closely studied in the United States. The American constructors adopted a powerful oscillator, invented some time ago by FESSENDEN for submarine signals, for sounding in great depths.

It is the *Submarine Signal Company* which markets this process also; the instrument includes:

The *oscillator*, a sort of submarine electric siren, fed by an alternating current of frequency of about 1,000, which is produced by a transformer similar to that which is used in certain wireless telegraphy sets. The oscillator is attached to the hull of the ship and, when electrically connected to the alternator, emits a powerful sound in the sea.

A *microphone*, likewise attached to the hull of the ship at some distance from the oscillator, however, in order that it shall be affected but moderately by the waves which pass through the frame of the ship.

A *selective amplifier* tuned to the frequency of the oscillator, and consequently allowing the echos to be perceived above the parasitic noises when only feeble echos are obtainable as is often the case in deep-sea sounding.

An *appliance for measuring* the echo interval similar to the Fathometer. By means of an electric contact short sounds are emitted by the oscillator rhythmically. In this instrument continuous luminous reading of the depth may be replaced, if the echos are feeble, by a determination "by ear and by eye" which gives the echo interval with sufficient accuracy for deep-sea sounding.

Sounding by slightly damped sounds, such as those given out by bells when they are struck, is not, so far as we know, used in any country. However, as we have tried it, we are sure that it might give some results.

C. SOUNDING BY WAVES OF INAUDIBLE FREQUENCY.

Sounding by means of such waves has been particularly studied in France. The remarkable appliance for emitting and receiving ultra sounds, invented by M. LANGEVIN, can be adapted to taking soundings without any great difficulty.

It is the *Société de Condensation et Applications Mécaniques* (S.C.A.M.) which markets this method of sounding. The instrument includes (*) :—

The *appliance for emitting and receiving ultra sounds*, the working of which is based on the piezo-electric properties of crystals; it is composed of a mosaic of quartz sandwiched between two steel plates. This apparatus, in which the maximum acoustic energy lies within a cone the apex of which includes but a few degrees, and the axis of which is perpendicular to the steel plates, is attached to the hull in such a way that the cone is directed towards the sea bottom.

An *electric emitting apparatus*, the essential part of which is an induction coil. When this is put into action for sounding purposes it sends to the emitting-receiving apparatus a slightly damped alternating tension which the latter transforms into an acoustic vibration, also slightly damped, of the same frequency. The frequency is such that the elastic resonance of the steel plates is brought into play, *i.e.* a frequency generally of the order of fifty thousand vibrations per second.

A *detecting high frequency amplifier*, permanently connected to the above electric emitting appliance. This causes a noise to be heard at the moment when this appliance excites the piezo-electric apparatus (*i.e.* at the moment of emission of the acoustic waves) and again at the moment when the echo returns from the bottom and the piezo-electric appliance acts as a receiver and communicates to the electric appliance a weak alternating tension.

An *appliance for measuring* the time which has elapsed between these two noises. This apparatus may be either a *continuous depth gauge* similar to the Fathometer but known as the "optical analyser", or else a *continuous graphic recorder of depth*, as preferred by the operators. This latter recorder has an electric contact which works the rhythmic acoustic sounding appliance (*e.g.* one sounding every three seconds) and records the event each time on a strip of paper in much the same way as the S.I.E.R. instrument; in this case, however, the record is made across the paper which is, therefore, relatively wide. The band of paper is moved a short distance after each record, and thus the successive soundings are recorded in close vicinity to each other. The emission occurs always at the moment when the recording pen begins to cross the strip of paper, and consequently the *V*'s due to the emission of the wave lie along a straight line close to the edge of the strip, whereas the *V*'s due to the echo lie along another line and are closer or further from the other *V*'s according as the depth is small or great (*see fig. 5*). The strip of paper is graduated in width for depth and hence the instrument automatically draws a diagram showing the outline of the depths over which the ship has passed.

The S.C.A.M. instrument has the following advantages:

Like the Fathometer it gives permanent readings of the depths or, if required, will give a permanent graphic record of the depths passed over by the ship. This latter arrangement is obviously of particular advantage in all hydrographic work and, in navigation, for comparing with the depths recorded on the chart.

It allows a depth to be ascertained with remarkable accuracy; this property leads us to consider it, at the present moment, as the best for hydrographic surveys.

(*) In this connection, see the Memorandum presented by Mr. FLORISSON to the Association Technique Maritime et Aéronautique in 1927.

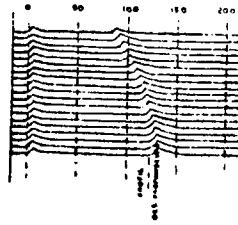


FIG. 5.

It is occasionally asked whether the use of high frequency in acoustic sounding is not likely to be a source of difficulty. Certainly it is necessary that appliances for ultra-sonic sounding should be set up with great care, and it is preferable that they should be operated by expert operators, but numerous cases allow it to be said that, subject to the above reservations, it gives perfectly regular and entirely satisfactory results.

EXTRACTS FROM THE
DISCUSSION ON THE ABOVE NOTE BY M. MARTI
AT THE JUNE 1930 PLENARY SESSION
OF THE ASSOCIATION TECHNIQUE MARITIME ET AÉRONAUTIQUE.

M. FLORISSON. — I would like to say :

I. It may be interesting to give as a parallel to the history given by M. MARTI, a few historical notes as to the researches carried out in connection with the application of ultra sounds to the taking of soundings at sea during the years 1917-1922 :

1917 : Professor LANGEVIN invented the piezo-electric ultra-sonic emitter in practically its final form.

1917-1918 : Practical application at sea of ultra-sonic detecting and intercommunicating appliances.

Beginning of 1919 : First tests with ultra sounds for vertical sounding at sea. A high frequency valve generator was used and measurements of the echo interval were made by ear using a chronograph. The depths measured reached about two thousand metres. No shallow soundings were taken.

September 1919 : M. LANGEVIN suggested the emission of a succession of single damped waves in order to reduce the length of the emission and thus allow soundings in shoal water to be taken. M. LANGEVIN requested me to go into this question.

End of 1919 and beginning of 1920 : Construction of various sounding appliances (use of relays, recording of separate soundings on a paper band).

October 1920 : First line of ultra-sonic soundings taken off Nice.

April 1921 : Experimental initiation of the L. F. (LANGEVIN-FLORISSON) ultra-sonic sounding machine (spark emission, oscillographic analysis of the echos).

February and March 1922 : The first commercial L. F. sounding machine installed on board the scout *Ville d'Ys*. This vessel ran a line of soundings between Norway and Iceland in April 1922.

The development of ultra-sonic sounding, of which the above are the dates of the principal events, was carried out by the French Navy at Toulon.

I believe that it was in April 1921 that M. MARTI succeeded in making, with myself, at Toulon the first records of the echo pulsations of ultra-sonic appliances on his first cylindrical recorder, and that in 1922 he adapted his new continuous recorder to ultra-sonic appliances.

It may be said, therefore, that 1922 is the date of the entry of ultra-sonic sounding appliances into practical navigation, these appliances being provided with an optical analyser or with the MARTI recorder.

II. I agree with M. MARTI (*see note p. 127*) that, *with the present width of the cone of emission*, the initial point of the *V* of the ultra-sonic echo, on sloping bottoms, does not, generally, give the exact vertical depth.

The vibrations which have reached the bottom and are reflected towards the ultrasonic projector are spread over a certain interval of time and this is the greater the higher the power of emission used and the greater the sensitiveness of the receiver (in practice it is of advantage to reduce the power of emission and the sensitiveness of reception to the barest minimum).



FIG. 1.

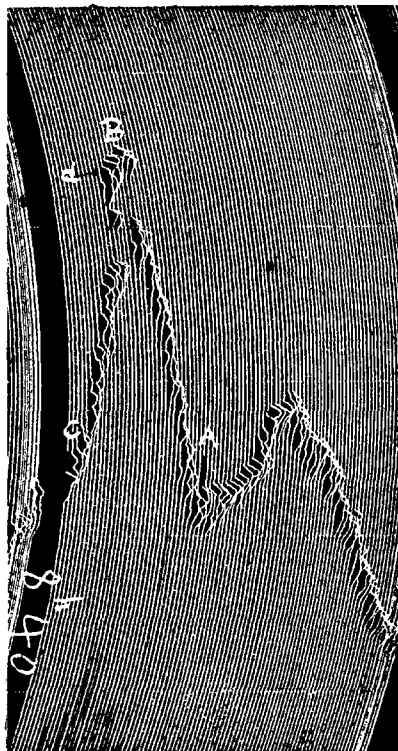


FIG. 2.

I want to say that, in spite of this, valuable information as to the vertical depth as well as the shape of the bottom may be obtained by the form of the *V* of the ultrasonic echo by means of appliances of the oscillographic type, such as the MARTI continuous recorder.

On regularly sloping bottoms, *i.e.* when the echo *V*'s are wide in time, I believe that the echo interval should be measured, not to the beginning of the *V*, but practically to the middle of it. This will give the vertical depth with but slight error.

Further, with a spread out echo *V*, points where changes of slope occur, if there are any, will give the horizontal planes tangent to the various irregularities of the bottom within the zone reached by the ultra sounds.

The carrying out of this rule makes it possible to give an accurate outline of the irregularities of the bottom.

As an example of this I take, from a band record recently made by the L. F. sounding machine in conjunction with M. MARTI's recorder, on board the S.S. *d'Artaignan* in the vicinity of Cape Guardafui, two fairly characteristic irregularities of the bottom (figs. 1 and 2). I give also outlines of the bottom to scale (constructed in accordance with the method which I described); these are shown in figures 3 and 4. The letters marking points on the records and outline sketches are placed in corresponding positions.

Let us examine the part lying between the points *C.* and *D.* of figures 1 and 3 :

The bottom slopes at about 30° from the horizontal (it will be noted *en passant* that even with this comparatively steep slope no echo was missed on the band on which the record was made at the ordinary cruising speed of the vessel). If the widest spread echo *V* be measured (about 32 metres at *d*) it will be found that the beginning of the

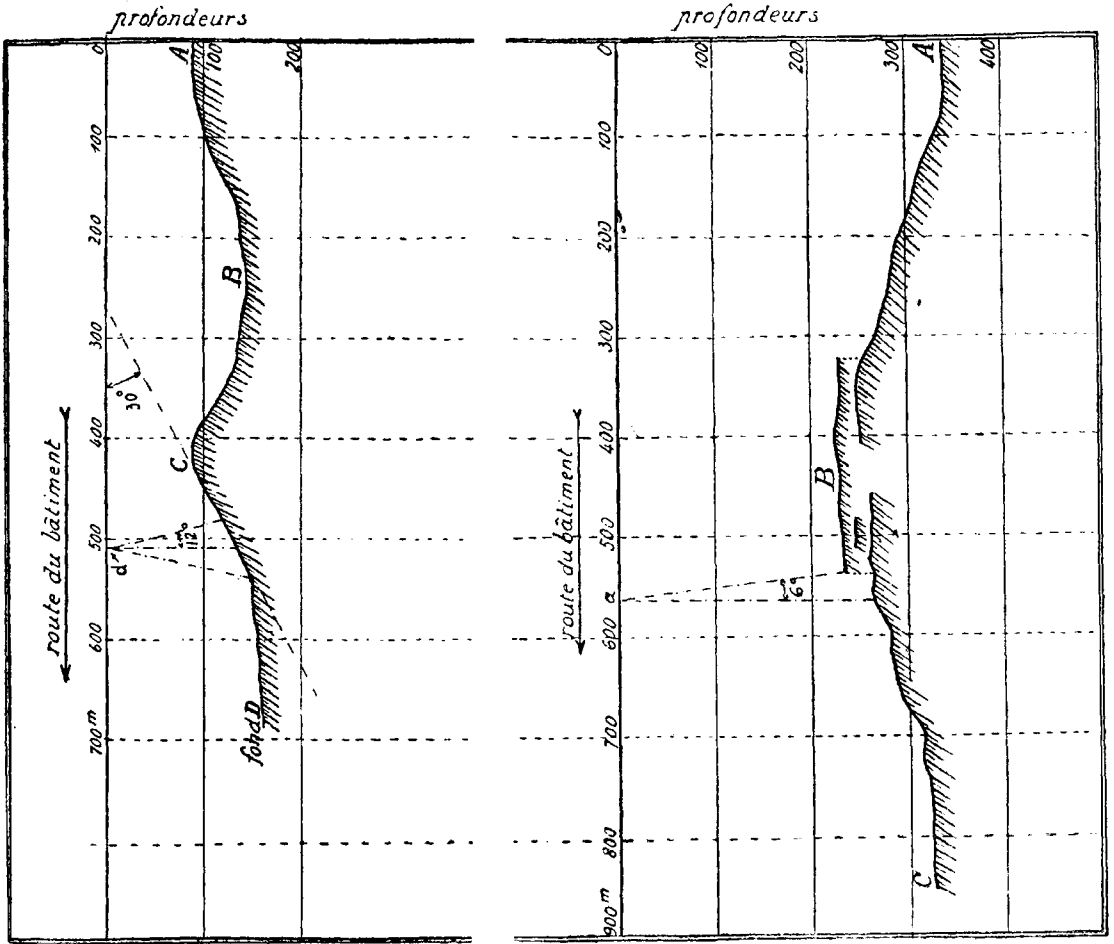


FIG. 3.

FIG. 4.

V gives a spread of about 12° from the vertical for the ultra-sonic rays. The sounding error thus introduced, if the echo interval were not measured to the centre of the V , would be about 14 %.

It should be noted that the record in figure 1 was made in relatively shallow water (100 to 250 metres) and that the amplification and the emission were too powerful. A narrower echo V could have been obtained by reducing the power of the emission and the sensitiveness of the receiver.

The second piece of recording band (figures 1 and 4) shows a fairly curious case of a submarine cliff with steep shelves (certain lines on the record show as much as three successive echos). Owing to the use of the oscillograph the ultra-sonic sounding machine has discovered accurate details of the shape of the bottom during a single line of soundings from the ship. It may be of interest to note that there is no echo of the ultra-sonic rays which lie at 6° from the vertical (e. g. at a) and that this occurred at places where the bottom was practically horizontal, but at depths of about 250 metres.

In concluding this remark II, I think it would be of advantage if Hydrographic Services adopted, as has been suggested, a special type of figures for showing acoustic soundings on charts, that these special figures should be used exclusively for soundings taken with machines which give a spherical and undirected emission. Soundings taken by ultra sounds, if properly interpreted, should logically be represented by the same figures as are used for soundings obtained with lead and line.

III.....

IV. M. MARTI says on page 131 that "certain vessels take soundings by ultra-sonic methods regularly at speeds over 20 knots". I can state definitely that numerous war-ships, e.g. cruisers, sound regularly at 30 knots.

This result is due, I believe, to the following causes which act together to nullify the parasitic noises of the ship :

- a) The use of ultra sonic frequencies, *i.e.* those which are relatively far from the centre of the acoustic range of the noises due to a moving vessel ;
- b) The use of the piezo-electric emitter with its tuned circuit, the whole being sharply resonant ;
- c) The use of a receiver of the oscillograph type and not of the relay receiver.

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M. MARTI, having been informed of the remarks made, sent the following reply to the Association :—

.....

M. FLORISSON states that ultra-sonic sounding machines, though giving wide *V*'s over sloping bottoms, give practically the vertical depth provided that the echo interval be measured to the centre of the wide echo *V*. It seems likely that this is the case when the bottom consists of a succession of steps (like a staircase). But to what extent is this true when the bottom, as is generally the case, is composed of a practically regular slope covered with finely divided material, and even viscous material? I think that experience alone can provide full information on this point.

But this is mainly a question of theoretical interest for sharply sloping bottoms are exceptions at sea, and when they do occur it is usually far from land. Besides, exact knowledge of the depth is not required, when the bottom slopes, except when it is possible to obtain (or it is desired to obtain) the position of the ship with corresponding accuracy, and this is not the case when sloping parts of the bottom are far from land. Even in the Mediterranean, for example, where the submarine slopes drop to great depths comparatively close to the coast, an accurate record of vertical soundings is of but secondary importance for drawing up charts and their use later on. It seems that it is only in the Fjords of Norway, or in similar regions, where there are steep slopes of the bottom in close proximity to the coast, that there would be any great advantage in obtaining vertical soundings. In such cases it is correct to state that the advantage rests with ultra-sonic appliances which, suitably employed, can record vertical soundings whereas all others cannot do so.

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