THE NILLSON ECHO-SOUNDER

COMPAGNIE FRANÇAISE DE RADIO-NAVIGATION (*)

The NILLSON Echo-Sounding machine comprises :

(i) the pulse transmitter ;
(ii) the Echo receiver ;
(iii) the depth indicator ;
(iv) the feeding arrangement.

Two variants of sounders, differing only in the indicator apparatus, have been developed and improved :

— the first with oscillographic valve indicator the advantages and disadvantages of which are mentioned hereafter. It is a two-range universal sounder (0-50, 0-500 metres) ; it can be placed only in the hands of a specialised radio staff, familiar with radar technics. It is mounted in a tank $670 \times 540 \times 390$ mm. in size, fed from an independent small-size box ($270 \times 270 \times 420$ mm.) which contains the alternator switch and its accessory parts ;

— the second with mechanical indicator and strobotron valve, single-range (0-500 metres), or, on request, a reduced range (0-200 metres) for coastal sounding. This sounding-machine should form part of the equipment of all fishing smacks. It consists of two boxes, one $520 \times 420 \times 250$ mm. in size, containing the transmitter and the general feed outfit, the other, of similar dimensions, holding the depth indicator and the receiver ; the latter box shoud be fixed within reach of the pilot. The whole is equally fed by an alternator switch of the same dimensions.

I. — THE TRANSMITTER

This part includes :

The transmitter properly so-called and (2) the transmitting base.

The transmitting base is formed by a seriate group of three similar magnetostrictive elements. Each element consists of a packet of nickel plates of the mushroom type, 5 cm. in width, piled up to 12 cm. thickness ; the three elements are placed parallelwise at about 0.5 cm. one from the other, so as to improve the directivity of the whole. The mechanical vibration frequency of the base is 24 kH. Figure 13 shows the directive diagram of this base.

The base makes contact with the water by means of a watertight, cylindrical pedestal fixed to the ship's hull ; the nickel elements are mounted by elastic suspension on a cylindrical cover which closes the pedestal at its upper end.

The pedestal contains water under pressure so as to equalise this pressure on one side and the other of the metallic partition which assures the watertightness of the vessel, this being for the purpose of avoiding partial refraction of the ultrasonic wave.

The pressure is maintained by means of a sheet-iron reservoir which, through the medium of a system of pipes in copper, raises the level of the ballast water to sea-level.

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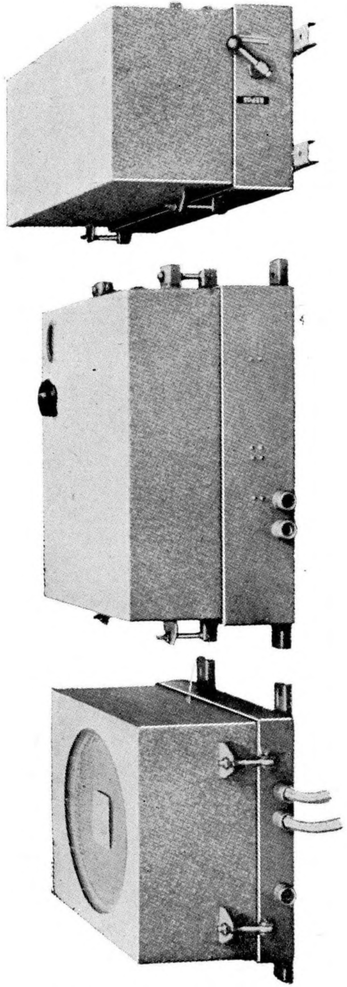
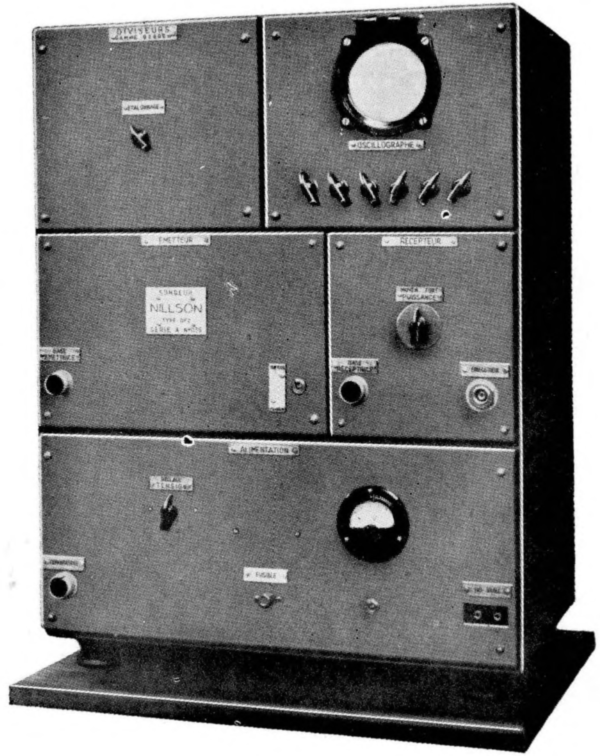


Stroboscopic Echo-Sounder
U. M. S. type.



Oscillographic Echo-Sounder
U. M. O. type.

The NILLSON Echo-Sounders.

The base has therefore inside fixings to the pedestal; stuffing-boxes allow the issue of the connecting wires ; the elements are entirely water-covered ; this arrangement allows airbubbles or steam that might form, to be dissipated on the lateral walls of the base without interfering in any way with the transmission of the vibrations through water. In this way it has been possible to carry the transmitting power to the extreme limit of the "cavitation", the consequence of which is improvement in the useful range of the sounder and greater trustworthiness in service.

The mounting of the pedestal can be effected on steel hulls by direct autogenic soldering, which makes it unnecessary to put the ship in dry-dock when being fitted up. With wooden hulls, the procedure is to bore a hole corresponding to the exterior diameter of the pedestal, between two frames ; in the case of the transmitter pedestal, this hole is only 30 centimetres. Under the lower part of the pedestal a protecting iron plate of from 5 to 10 mm. thickness is soldered, which assures the watertightness of the vessel and prevents the passage into the pedestal of foreign bodies harmful to the preservation of the magnetostrictive elements. Only the mounting of the pedestal is carried out in dry-dock and immobilises the vessel for a few hours.

The Pulse Transmitter

This part consists of (See fig. 1) :

— a monitor oscillator which is tuned on the vibration frequency of the magnetostrictive elements (24kH) ; this oscillator functions permanently and its stability in frequency is excellent (mounting is of the E.C.O.type), the frequency being set once for all in the laboratory ;

— a phasing-amplifier stage comprising two cathode-type phase-displacement penthodes ;

— this stage is freed during the pulses by a triode the cathode of which is common ; this triode is attacked by an unblocking steep frontals signal supplied by a stage known as "flip-flop" which determines the duration of the pulse, rendered variable by a two-position inverser on the oscillographic sounding-machine. The transmission pulse is governed by the trigger "marks" coming from the indicator : in the case of the mechanical sounder with rotating shaft, these marks are produced by the reluctance variation of a small electromagnet and amplified by a valve which is not shown on the sketch ;

— a power stage which consists of two 4654, or EL 39 class B pure, valves functioning with a rather high tension plate (1,000 v.) which supplies, through the medium of an adaptor transformer, the power necessary for putting in action the transmitting base. The self impedance of the base is tuned by a condenser as well as by the wire capacities, the capacities of the output transformer and the capacity of the connecting cable ; this condenser is of rather high value (10,000 *p*F) which allows a great length of cable (several scores of metres) to be used without prejudice to the working of the final stage. A strong capacity in parallel on the very-high-tension source supplies the necessary energy to the transmitter during the pulse ; the average consumption of the power stage remains feeble (6mA).

The magnetic polarisation of the magnetostrictive elements is assured by a direct current traversing the windings ; this current is supplied by the battery through a resistance and a self-inductive shock which limits its value to 2A and eliminates short-circuiting of the transformer from the alternating point of view.

The transmitter supplies a power of 180 Watts for a duration in the vicinity of 400 μS and 2,000 μS (for the two positions). From the electrical point of view, it presents two interesting particularities introduced with a view to improving the trustworthiness in service and the performance of the sounding-

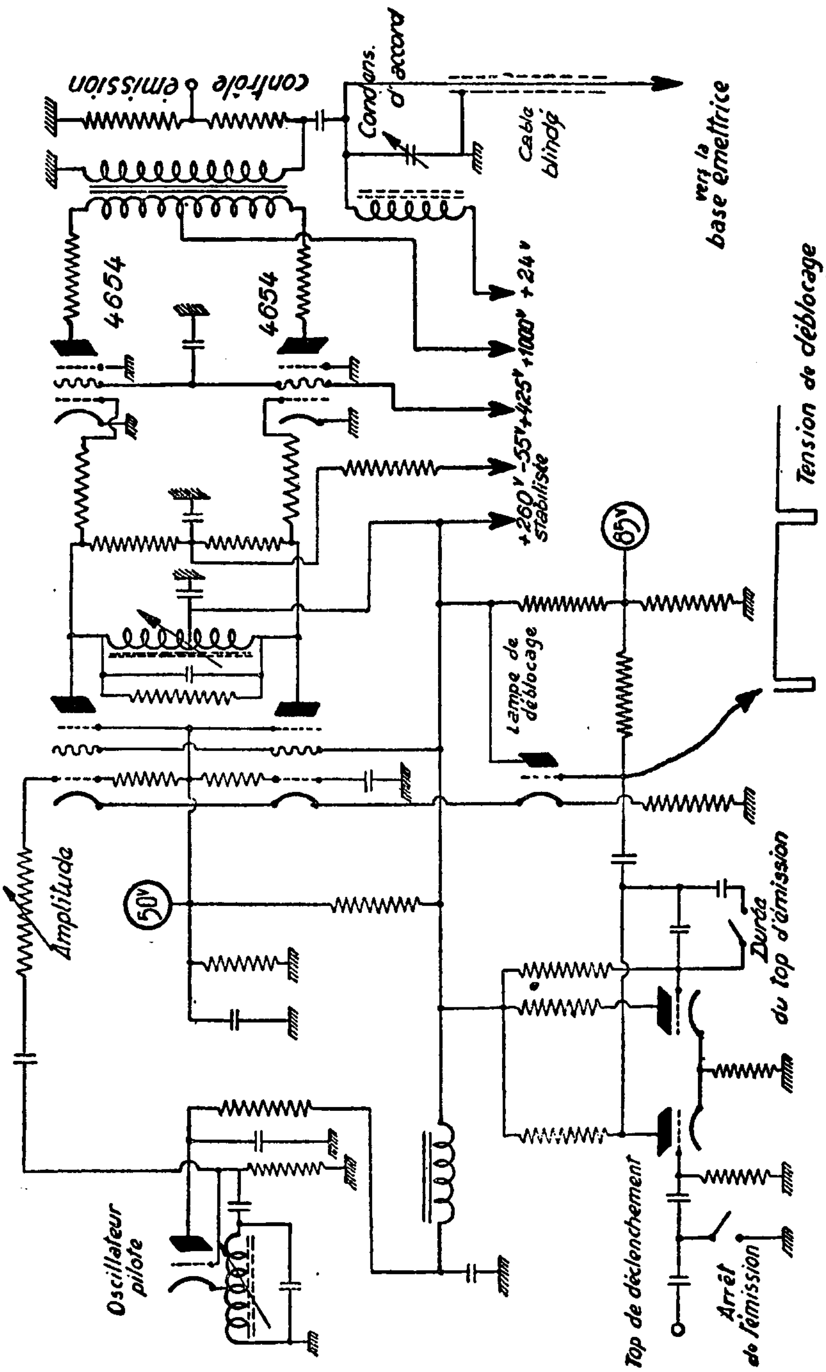


FIG. 1 — Transmitter.

machine. In the first place, the magnetostrictive base is fed by a pure sinusoïdal wave of constant amplitude during the impulse and not by a damped wave produced by an electric shock ; in this way an acoustic power sufficiently near the power for which the cavitation phenomena occur, can be sent into the water. The second special feature is that the duration of the pulse is rendered variable in the oscillographic sounder ; the magnetostrictive base presenting a certain inertia, it requires a fairly long pulse duration for total excitation ; in the case of sounding in shallow waters, the duration of the pulse would be too long to permit a sufficiently accurate reading ; in such a case, however, a diminution of the transmitting power is permissible and therefore a diminution of the width of the pulse also.

The output of the transmitting base being in the neighbourhood of 50%, the power sent into the water during transmission is approximately 90 Watts ; it has been previously noted that the theoretical power limit should be approximately 60 Watts. In practice, since the projector is fixed in a ballast which can be filled with degasified water under pressure a little above normal pressure, a somewhat higher power is admissible.

The working of the transmitter can be interrupted by means of a push-button which short-circuits the arrival of the trigger "pips" coming from the indicator ; as will be seen later on, this allows the uncertainty of 500 metres in the case of deep-sea sounding to be removed.

II. — THE RECEIVER

The Receiver consists of : the receiver properly so-called and (2) the receiving base.

The receiving base is analogous to the transmitting base but of smaller dimensions. It is formed by the seriate group of two similar magnetostrictive elements. Each element consists of a packet of nickel plates of the mushroom type, 5 cm. wide piled up to 8.4 cm. thickness ; the two elements are arranged parallelwise at about 0.5 cm. distance from one another so as to improve the directivity of the whole. Figure 14 represents the directive diagram of this base ; Figures 15 and 16 show the diagram resulting from the transmitter-receiver unit.

The receiving base is not magnetized in permanence ; the signals received are somewhat feeble in magnitude and the remanent magnetization is sufficient for the magnetostriction phenomena. However, with time a progressive demagnetization and loss of sensitivity of the receiving base may be observed. It is necessary to magnetize it from time to time ; this is automatically accomplished by means of a switch on the receiver tank. As will be seen later on, this switch also governs the general H.T. feed of the sounding machine ; on the position "off" a permanent current is sent into the receiving base while the general high tension is cut.

The receiving base is mounted in a small-size ballast in which a certain water-pressure is also maintained. The placing of the pedestal necessitates a hole of 20 cm. diameter in the ship's hull.

The Echo-Receiver

This part consists of (See Fig. 2) :

— An EF 51 amplifying valve of feeble sound resistance and large slope gradient. It has been seen that, at resonance vibration the receiving base is, like the transmitting base, equivalent to the whole formed by the association of self-induction and resistance in series ; it is tuned by a condenser of fairly high value (10,000 pF) ; therefore a considerable length of connecting cable to the receiver may be used. The C. O. equivalent thus formed is branched directly on the grid of the first EF 51 valve ;

— two amplifying stages with fixed slope penthodes. The amplification of the first two stages is controlled by means of an ordinary potentiometer ;

— a detector stage which gives positive pulses to the oscillographic indicator or negative pulses in the case of the sounder fitted with rotating shaft. In

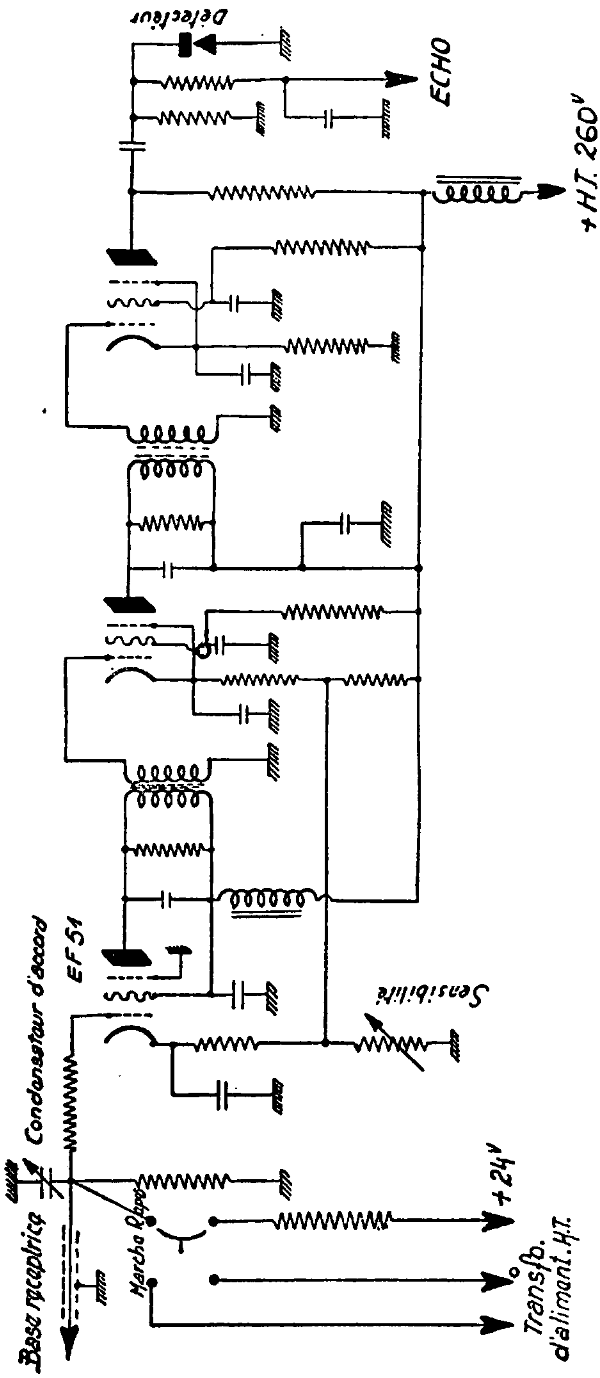


FIG. 2 — Receiver.

the latter case the pulses are smoothed and magnified by means of a triode (not represented on Fig. 2) before being applied on the governing grid (2nd grid) of the 631-P-1 strobotron (Fig. 3). At the same instant the valve lights up in consequence of the ionisation of the neon, energy being supplied to it by the capacity C which must have a fairly high value (several microfarads); the constant of time RC must be sufficiently feeble for the condenser C to have time to recharge between two pulses (for example, transmission and reception).

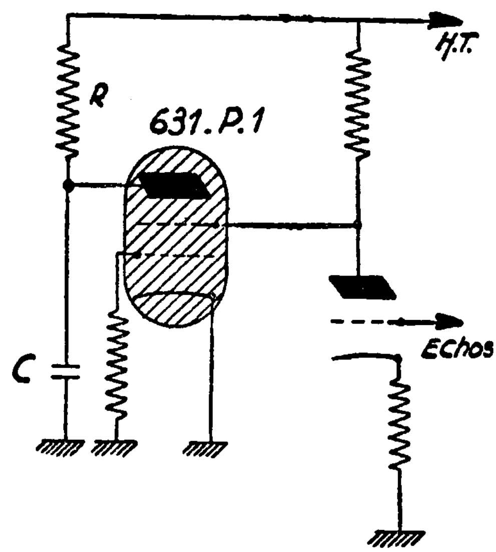


FIG. 3

The utility of the detection might be denied; it is, however, preferable, because it blocks the signals at 24kH, thus eliminating the "hitching-up" tendency of the amplifier. On the other hand, in the case of direct observation of echoes by means of a cathode valve, it gives the envelope of the received pulse and the track obtained remains appreciably constant to each impulse, contrary to that of the sinusoïdal signals that form it.

In the case of shallow-water sounding and in order to increase the accuracy of the reading, there must be a comparatively feeble detection time constant so as to respect as far as possible the steepness of the sides of the received pulses. The connexion between stages is formed by transformer and not by resistance-capacities; in fact, in the latter case, in the presence of powerful signals (superfluous use of sensitivity potentiometer or echoes on nearby parasitical obstacles) there exists a risk of detection of the signals on one of the amplifying stages which shows itself momentarily in a loss of sensitivity of the receiver; the coupling transformers have their primary tuned and damped to have a sufficient pass band and their secondary is aperiodic. The pass band being limited, the ratio signal/sound is thus improved to the maximum of the receiver sensitivity.

The global gain is somewhat high (66db) and has been carried to a limit such that disturbing noise due to the entry circuit (receiver base) is barely perceptible at the oscillograph.

The receiver is sufficiently protected to prevent the energy radiated by the transmitter during the pulse, being received. Only a fraction of this energy is transmitted in the water directly from the transmitting base to the receiving base and the corresponding echo serves to test the satisfactory working of the apparatus.

III. — THE INDICATOR

The Nillson Oscillographic Indicator

The system employed is the use of a cathode valve as reading part according to the principle explained below :

The sensitive surface of the valve is swept by a luminous spot following a certain number of lines (exactly as a pen moves along the lines of a copy-book). The sweeping of each line continues during a given time corresponding to a given sounding depth, for example 100 metres, and on each line, vertical strokes known as "gauging" strokes which correspond to the division desired, say one stroke every twenty metres, are produced electronically. For example, five similar lines may be produced which would mean a normal sounding depth of five hundred metres.

The successive operations of the sounding-machine are as follows : each time that the luminous spot begins to run over the first line of the valve, the transmission of the train of ultrasonic waves is produced. At reception, the echo received produces a small vertical luminous stroke the position of which related to the "gauging" strokes permits an exact determination of the depth, and the form of which permits an interpretation of the nature of sea-bottom.

To reach this result, the point of departure is a reference oscillator the frequency of which corresponds to the highest division desired to be known. From this oscillator and by successive frequency divisions which can be made in an absolutely rigorous way by electronic methods, a group of pulses and of saw-edge curves are produced which serve to form on the one hand the gauge marks and on the other hand, the signals of sweeping of the luminous spot over the valve screen; they also serve to check the transmission of the wave-train at the desired rhythm and the desired instant.

The following (Fig. 4) is an example of the realisation of the procedure : A train of pulses A, the frequency of which (36.75 c/sec.) corresponds to a sounding depth of twenty metres is produced ; after frequency divisions and from these pulses, two pulse trains B and C of 5 and 25 times weaker frequency respectively, are created. The B train serves to synchronise the tensions generator in saw-edge curve D for horizontal sweeping of the cathode valve and the C train serves to synchronise the generator E for the vertical sweep and at the same time to trigger the transmission pulses F. The standardising pulses A and the signals due to the echoes coming from the receiver are mixed with the vertical sweeping signals in the part X. The duration of the total sweeping of the valve screen for a range of 500 metres is of considerable length (0.68 sec.) and corresponds to a sounding rhythm of 88 times per minute ; for this reason it is obligatory to use a lamp with what is known as the remanent layer which possesses the property of remaining luminous for a certain time (several seconds) after the passage of the spot. The aspect of the luminous "mosaic" after the sweeping of the screen is indicated on Fig. 4 ; 1 represents the transmission pulse and 2 the echo that gives the depth (250 metres on the figure).

The exactitude of the measurement depends only on the exactitude of the pilot oscillator frequency and its stability ; on the other hand, the desire to have a sufficiently high reading accuracy has induced the choice in the definite model as frequency of the standardising marks, the frequency 735 c/sec., which corresponds to one standardising mark each metre. This frequency is stabilised by a double-blade ; consequently no getting out of order need be feared. Experience shows that it is difficult to count further than 5 on an electronic scale without division markings ; added to this the consideration of having divisions in ratio 2 and 5 (with a view to sound stability 5 is rarely exceeded), so as to have reading points of easy reference ; on a first range reading 5 lines have been

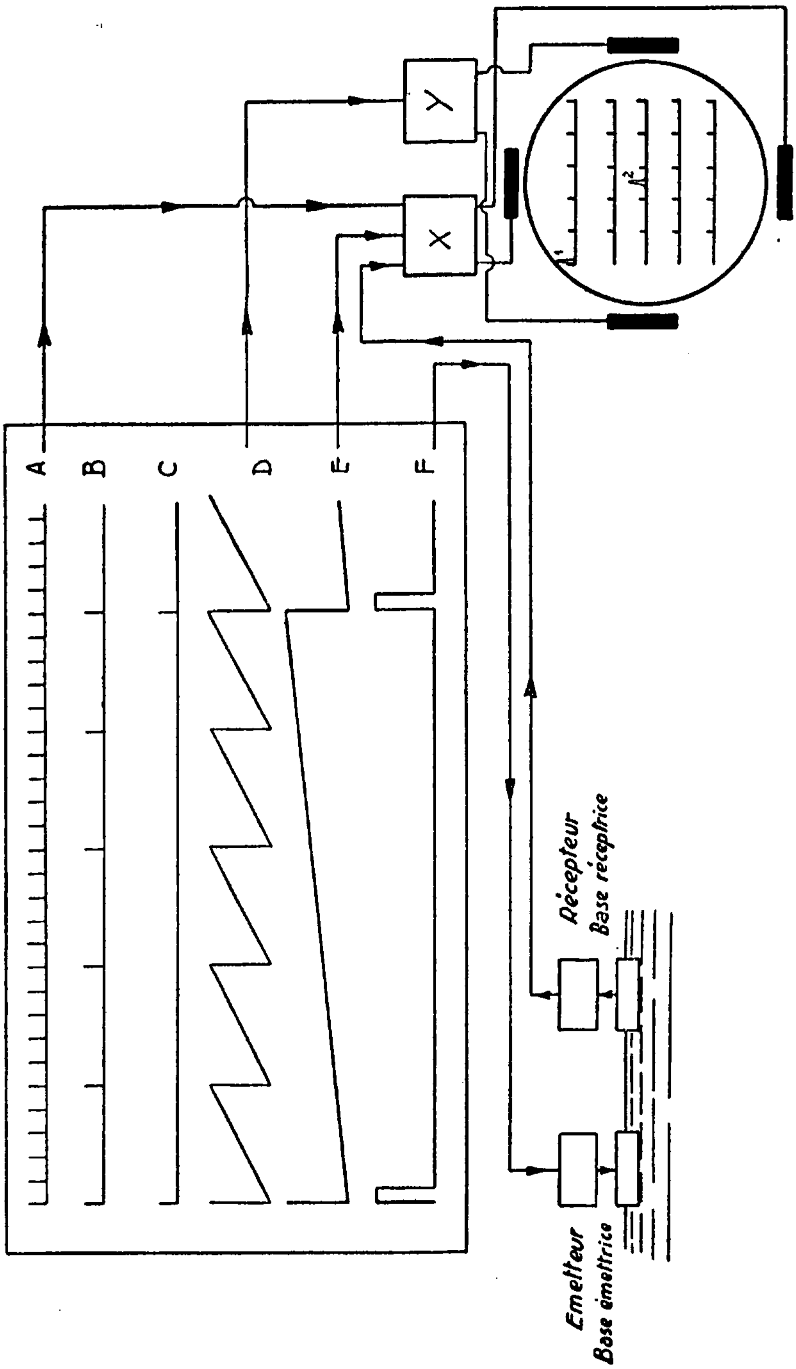


FIG. 4

formed of 10 metres each and on each line, 10 standardising marks among which one larger stroke every five metres (as is generally shown on a divided ruler). The first range being 0-50 metres, the second range has naturelly been chosen 0-500 metres with 5 lines of 100 metres and on each line 10 standardising marks among which one larger every 50 metres. A reading having been made on the 0-500 range, the operator can naturally pass onto the 0-50 range which to within 50 metres acts as vernier and gives an absolute theoretical reading accuracy of the half-metre for all depths; in practice the velocity of sound through water varies with the pressure, the salinity, temperature, etc. The comparative changes of velocity are of about 1% and occasionally even more and a relative higher accuracy of measurement for sounding by the ultra-sonic waves method can hardly be expected.

On the 0-500 range, the rhythm is sufficiently slow to allow the eye to follow the sweeping of the valve screen by the luminous spot. It is therefore easy to sound at depths greater than 500 metres and to solve the uncertainty by a multiple of 500 m. To accomplish this, the transmitter is stopped by means of a push- button; the operator lets go the button during the sweeping which allows the transmitter to start off when the spot resumes sweeping at the top and to left of the valve. It then suffices to count the total number of times the screen is swept before the appearance of the echo to solve the gap of uncertainty in the 500 metres.

To resume, the system of oscillographic reading on two ranges, 0-50 and 0-500, gives an absolutely universal formula of sounding machine permitting measurements from one metre to the greatest depths with absolute accuracy, minimum to 1/2 metre, 1% relative maximum error.

The Rotating Arm Indicator

The arrangement used has been chosen on account of its simplicity and strength in conjunction with the fact that it puts in action the minimum of mechanical parts and consequently requires the minimum of maintenance. As has already been noted, it consists of a full disk with a small radial slit which turns with a uniform motion behind a divided plexiglass dial; the scale is divided in metres or in fathoms as requested. Behind the disk is the strobotron which produces the luminous flash necessary for reading on the dial; a small soft-iron blade is fixed on the periphery of the rotating disk and passes into the air-gap of a small electro-magnet forming part of the instrument; the change of flux resulting from its passage produces a tension pulse; it is this pulse that governs the triggering of the transmitter.

The disk is driven by an asynchronous motor fitted with mechanical speed governor; the adjustment is very good, a change of tension of 10% producing a change of velocity of only 1% approximately which is within the limits of possible changes of velocity of sound in sea water.

IV. — FEEDING ARRANGEMENT

The general feed of the sounding machine is made from the transformers and rectifiers fed by an alternator switch which gives 110 v. alternating. This solution was preferred to that which consists in using a converter because it not allows greater suppleness and consequently greater security, although it is the most economical solution. The alternator switch converts the continuous tension of the ship's batteries (24 v. or any other tension as requested) into the alternating tension necessary for supplying the transformers and the asynchronous motor. An "Off-On" switch is provided on the casing and must be manœuvred by hand; in case of absolute necessity the alternator may be placed near the batteries so as to avoid fall of tension in the lines. The start-off is given by relays by means of a switch placed on the main box (at special request).

The feed of the sounding machine is classic; it consists of a general heating transformer branched directly on line 110 v. and a transformer for the general high tension which is governed by the "off-on" switch of the receiver. By the separation of those two transformers, the sounder may be left under heating when "off" and consumption on the batteries as well as wear on the valves thus limited. On each transformer, by means of the intermediary connections and a contactor and test voltmeter, it is possible to adjust all tensions to their optimum value and thus to palliate any changes of the tension supplied by the battery that may occur.

In the oscillographic sounding machine, high tension is stabilised by means of a very satisfactory arrangement of valves.

On the sounding machine with rotating arm, a special connection is provided on the high tension transformer to feed the asynchronous motor; this solution was chosen in preference to the use of a D.C. motor to avoid commutators which are invariably a frequent source of break-down.

Numerous fuses are provided for the general protection of the sounder. Consumption on the batteries is 15 A. for the oscillographic machine and 7 A. for the machine with rotating arm (24 volts).

CONCLUSION

The two instruments here described were constructed in a careful effort to satisfy the most varied requirements. The first is interesting because of the ideas underlying its conception and its unequalled performance, the second because of its solidity and simplicity of working. Quite different in their realisation, they complete each other perfectly to meet the various aspects of ultrasonic sounding technics.

V. — HISTORICAL NOTES

Birth of the Ultra-sonic Sounding Machine

The first experiments in the detection of obstacles by ultra-sounds were undertaken by the Englishman Lewis Richardson after the catastrophe of the *Titanic* (White Star Line) which in 1912 sank after having struck an iceberg. Richardson's idea was to transmit ultra-sounds through water by means of ultra-sonic submarine whistles ; but in spite of efforts made to concentrate the sonic energy by means of parabolic reflectors, this was too feeble to permit any hope of being able to detect an echo on an obstacle. During the 1914-1918 war, the British Admiralty instructed Sir Charles Parsons to carry out research work along this path ; it led nowhere.

In 1915, having observed the analogy between the ultra-sonic frequencies and the radio frequencies currently used at that time (20Kc/sec.), the Russian engineer Chilowsky suggested that researches be made with a view to finding an instrument capable of transforming electric oscillations which it is known how to produce with sufficient power, into mechanical oscillations ; Professor Langevin, attached to the *Centre d'Etudes*, Toulon, supplied the solution of the problem and realised on this principle the first ultra-sonic sounding-machine.

The first research work on the piezo-electricity reversible properties of quartz was undertaken in 1880 by the brothers Pierre and Jacques Curie and by Lippmann in 1881 ; this work was revised and carried on by Professor Langevin, but the first results were on the whole disappointing ; they demonstrated the necessity of having very high excitation tensions of the quartz to supply sufficient mechanical power (tensions of the order of 100,000 volts) ; the adoption of a mosaïc of quartz blades fixed between two steel plates known as "quartz-steel triplets" marked considerable progress and allowed the use of much weaker (by some thousands of volts) tensions : the first commercial ultra-sonic sounding-machine was an accomplished fact.

The essential elements of this sounding-machine which was based on the echo time measurement of a train of very brief ultra-sonic waves (of the order of one-thousandth second) were :

— a steel-quartz triplet projector ;

— a generator of ultra-sonic frequency electric oscillations constituted by an oscillating circuit shock-excited by means of a *Wien* flasher (spark fractioned flasher);

— a rotating switch with cam liberating about once each second a train of damped waves;

— a receiver amplifying the reflected signals;

— a rotating arm with uniform movement governing the displacement of a luminous indicator, generally a neon valve, in front of a divided scale.

The zero of the division corresponding to the triggering of the transmission by the passage of the rotating cam and the illumination of the neon valve by the reflected signal corresponds to an angular difference proportional to the propagation time of the wave-train; the division read opposite the luminous spot gives a direct reading of the depth-measurement.

The period from 1918 to 1939 saw the evolution of this sounding-machine and also the application of ultra-sounds in numerous industrial branches. Such a realisation was remarkable at that epoch; the only important improvement, made some ten years ago, has been the replacement of the piezo-electric quartz by projectors based on the magnetostriction properties of nickel; the last war definitely consecrated magnetostriction in its application to the production of ultra-sonic frequencies.

Development of Ultra-sonic Projectors

a) At first, sound was transmitted through water by means of a hammer through the intermediary of a stretched membrane; the frequency used was in the vicinity of 2Kc/sec. This method gave and still gives good results and is used by certain instruments fitted on trawlers and for acoustic sweeping. It presents, however, many inconveniences:

— the transmission directivity is null owing to the fact that the relation λ/D of the wave-length through water to the diameter of the vibrating surface is too great (Huyghens principle), which leads to dispersion of the ultra-sonic power and consequently to a diminution of the useful range of the sounder, as well as to the risk of multiple echoes on irregular sea-bottom (fig. 5);

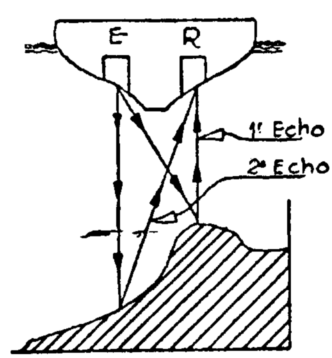


FIG. 5

— manœuvre difficulties owing to the lack of automatic-action in the system;

— unsatisfactory reading accuracy for, by reason of the principle itself, the transmission of ultra-sonic wave-train presents an exponential damped form.

b) The quartz instrument is an improvement on the Marty sounder ; it uses a fairly high transmission frequency with a view to diminishing the relation λ/D ; moreover, the quartz vibrates as piston and not as stretched membrane, which further improves the directivity of the transmission diagram. Offsetting this, the quartz presents other inconveniences :

— it is fragile ; too great a transmission power may cause the quartz to break up or become unfixed ;

— it is a high-resistance system requiring considerable insulation precautions ; in addition, the transmission power stages must be installed rather close to the transmission projector which is a very serious inconvenience both from the point of view of installation of fragile radioelectric materiel in the bottom of the hold and from the point of view of rapid servicing.

c) The magnetostriction projectors offer all the advantages of the preceding types without any of their inconveniences.

VI. — THE MAGNETOSTRICTION OF MAGNETIC MATERIALS

Principle

It has been ascertained that under the action of a magnetic field, certain materials present the property of changing their geometrical dimensions ; inversely, under the effect of exterior mechanical tensions, any change in their geometrical dimensions takes the form of a change in their magnetic state.

The direct effect is known as the *Joule* effect ; the inverse effect as the *Villari* effect.

Elongation magnitudes due to magnetostriction phenomena are very weak ; they are positive for iron (an increase in the magnetic field producing an increase of length of iron), negative for nickel ; as an example, for pure nickel, $\Delta l/l = -25$ to 35×10^{-6} when H varies from O to 100 gauss (See Fig. 6). Two

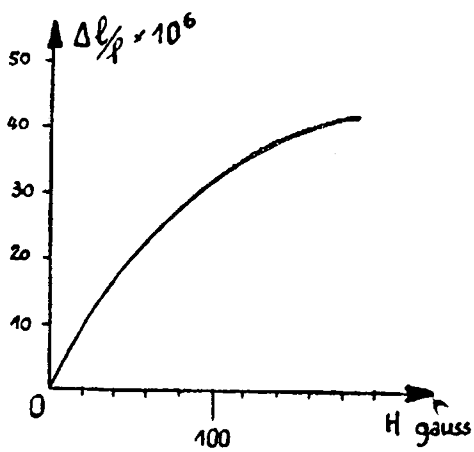


FIG. 6

alloys, iron-cobalt and nickel-cobalt, which present a greater dilatation coefficient ($\Delta l/l = 84 \times 10^{-6}$ for the former), are known ; in practice, because of difficulty in obtaining a perfectly homogenous alloy, pure nickel only is used in the construction of magnetostriction projectors.

Knowledge of magnetostriction phenomena is of long date ; among others the treatises on the magnetostriction of nickel-steel, of the Japanese Honda and Nagaoka in 1904 might be mentioned; Pierce, Black and Mac-Keehan developed the static and dynamic theories of magnetostriction.

It was only towards 1935 that magnetostriction was adopted in practice.

Modern Magnetostriction Bases

A magnetostriction base is constituted by an assemblage of *thin* nickel sheets (to avoid the losses by Foucault currents) of suitable shape; the magnetic field is produced by an appropriate winding. The sheets are generally cut in such a way as to allow free action of the efforts due to magnetostrictive effects and at the same time so as to form a closed circuit for the magnetic field.

There are two distinct types of magnetostriction bases:

a) *Radial-radiation base* formed by a pile of circular sheets (Fig. 7); holes are distributed regularly over a large diameter to give passage to the wire; radiation is concentrated by means of a conical projector which assures the directivity of the beam. (Fig. 8).

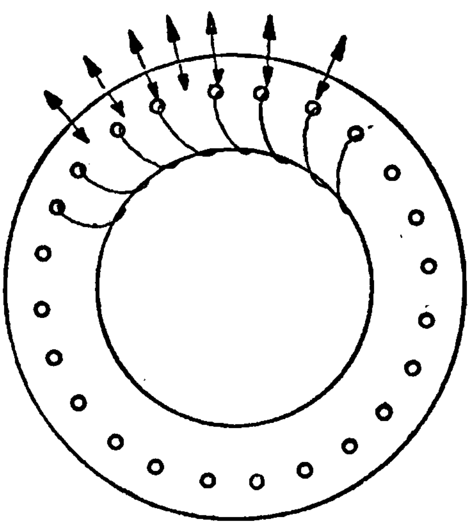


FIG. 7

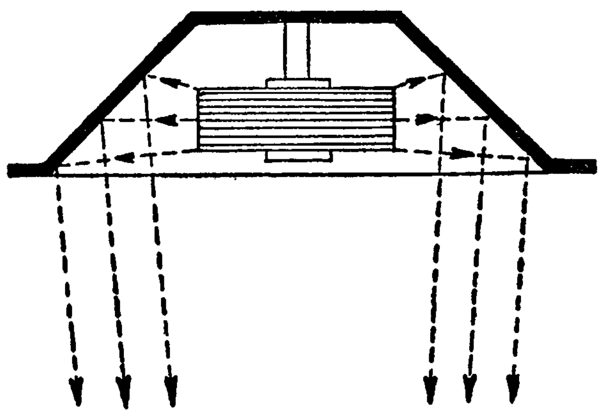


FIG. 8

From the electrical point of view, this type of base is certainly the most interesting; in practice it involves the use of a projector of rather delicate construction and considerable dimensions. It is the only type at present used in the United Kingdom.

b) *The longitudinal-radiation base* which is almost universally adopted. It is formed by an assemblage of sheets in which one particular dimension is greatly favoured and the magnetostrictive effect is produced longitudinally, parrallel-wise to this dimension; the sheets are cut so as to permit the introduction of a winding.

The following is an example of realisation (sheet of the type known as *mushroom*) : each sheet is cut to represent two elastic "legs" or rods surmounted by two horizontal bars (See Figures 9 & 10); a pile of these sheets is built up to the desired thickness. On each rod is a winding and the two coils are branched in a sense giving them a tendency to reinforce mutually their flux. The vibrations developed on each rod act upon the two bars which transmit the flux of one rod to another thus forming a closed magnetic circuit for the magnetic field; four holes are provided for fixing and maintaining the sheets.

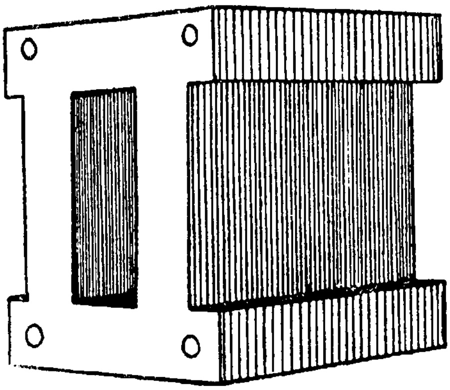


FIG. 9

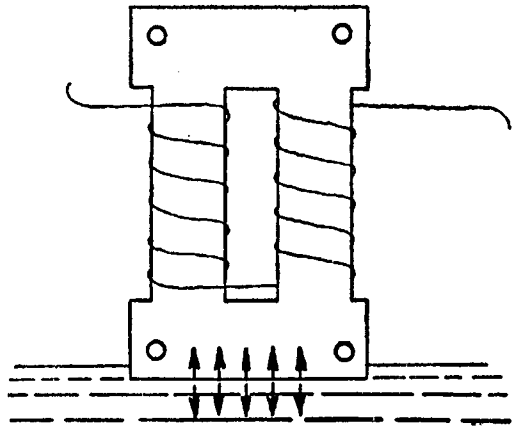


FIG. 10

In such a system, directivity is assured by the fact that the transmission surface is of large dimension as compared with the length of wave of the radiation transmitted through water.

c) *Working of a longitudinal-radiation base* :

When a direct current traverses the winding, under the influence of the magnetic field and as a result of the magnetostriction phenomenon, the two rods contract ; if, to the direct current, an alternative current of less amplitude is superposed, the elastic rods undergo alternative contractions on the frequency of this current ; these vibrations are transmitted to the radiation surface of the elements. As a rule the radiation produced by one only of those two opposite surfaces is useful ; the second is eliminated by means of rubber sheets placed as required or by damping by means of any sort of plastic matter.

The displacement magnitude of the surface of any element, due to the magnetostriction phenomenon, is feeble ; the sinusoïdal effort obtained is approximately 25 kg/cm^2 for an alternative amplitude of field of 50 gauss. By way of comparison : with an electrostatic (quartz) system, a potential difference of about 2,000 v./cm. is necessary to produce an effort of the order of 0.3 kg/cm^2.

On the other hand, when the magnitude of the field is increased, the nickel becomes saturated , and the nickel contraction magnitude tends towards a maximum (See Figure 6) ; to increase this magnitude, the operator sees to it that the mechanical resonance frequency of the system is the same as the alternative current frequency ; the initial displacements are thus multiplied by 10 and even more.

d) *Study of the Resonance* :

Electrically, a magnetostrictive element is equivalent to the group formed by a resistance and a self in series ; the resistance comprises the ohmic resistance and that due to losses by hysteresis and *Foucault* currents. The ohmic resistance is negligible ; the resistance due to losses increases with the frequency but remains sensibly constant over a large range of frequencies if the nickel sheets are sufficiently laminated.

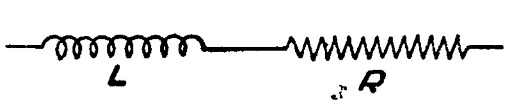


FIG. 11

A measurement with the variable frequency bridge of the quantities $L\omega$ and $R\omega$ shows, when the mechanical resonance of the system is neared, a rapid change in their respective value. This change is observed only when the magnetostrictive element has been previously magnetized (remanent magnetization), or again, when the measurement is made with superposition of direct current (influence of the magnetostriction effect). The theory developed by Pierce is in conformity with experience ; for each frequency there may be defined a resistance R_m and a reactance L_m known as motional which is the difference between the resistance $R\omega$ and the reactance $L\omega$ measured with the bridge with and without magnetization of the element. The locus $L_m \times \omega$ as function of R_m is a circle passing through the origin and tangent to the axis of the ordinates at the origin (Kenelly circle). The mechanical resonance is defined at the maximum of the curve $R_m = f(\omega)$ by their values R_{mo} and L_{mo} (See Figure 12). Theoretically the motional reactance to the resonance is null ; in practice it is otherwise for, resulting from the magnetization, the permeability of the nickel changes during the test, therefore the L value also ; for the same reason a change in the value of R is observed. If the variations of R_m are regarded directly with the frequency, a true resonance curve is seen, different nevertheless from the true-amplitude resonance of a pendular system, in that R_m varies like the square of an amplitude, i. e. like an energy. R_{mo} represents the electric power transformed into mechanical power and the quantity $\frac{R_{mo}}{R + R_{mo}}$ represents the ratio output of the transformation (at transmission).

As previously pointed out, the value R is not accessible ; habitually, that value which is defined by the intersection of the tangent at the curve $R\omega = f(\omega)$ with the pulse ω_0 which corresponds to the mechanical resonance, is adopted. Taking the maximum amplitude R_{mo} of R_m, the resonance pulse ω_0 is found ; taking half amplitudes, we delimit the width of the resonance curve and the pulses ω_1 and ω_2 which Kenelly defined as quadrantal pulses ; on the Kenelly circle they correspond to two points situated on the same vertical diameter. In practice there is no advantage in having a too strong R_{mo} value ; in fact, for reasons of stability of the monitor oscillator, the mechanical resonance curve must not be too sharp. On the other hand, when the magnetostriction system is on reception work a too small or a too high value of R_{mo} (diameter of the Kenelly circle) corresponds to a weak useful electric power. The value $R_{mo} = R$, coresponding to a transmission output of 50%, is generally adopted.

The L value also is not accessible ; it is defined in the same way on the curve $L\omega \times \omega$ as a function of ω. The curves on Figure 12 show that at resonance the motional impedance L_{mo} is slightly capacitive, which is represented by a slight diminution of the self of the group.

e) *Study of the Directivity* :

Transmission and reception of ultra-sonic energy is directed ; to this end, oscillator systems, the transmission or reception surface of which is large as compared with the wave length, are used ; the directional characteristic of these oscillators, which represents the variation of transmission or reception amplitude according to the direction, can, for a base constituted in continuous fashion and having over all the length a uniform output ratio ρ of sound transformation, be expressed by the relation :

$$R = \frac{\sin\left(\frac{\pi d}{\lambda}\sin\gamma\right)}{\frac{\pi \alpha}{\lambda}\sin\gamma}$$

d = length of base ;
λ = wave length in water ;
γ = difference between the considered direction and the direction of the principal maximum (γ = o).

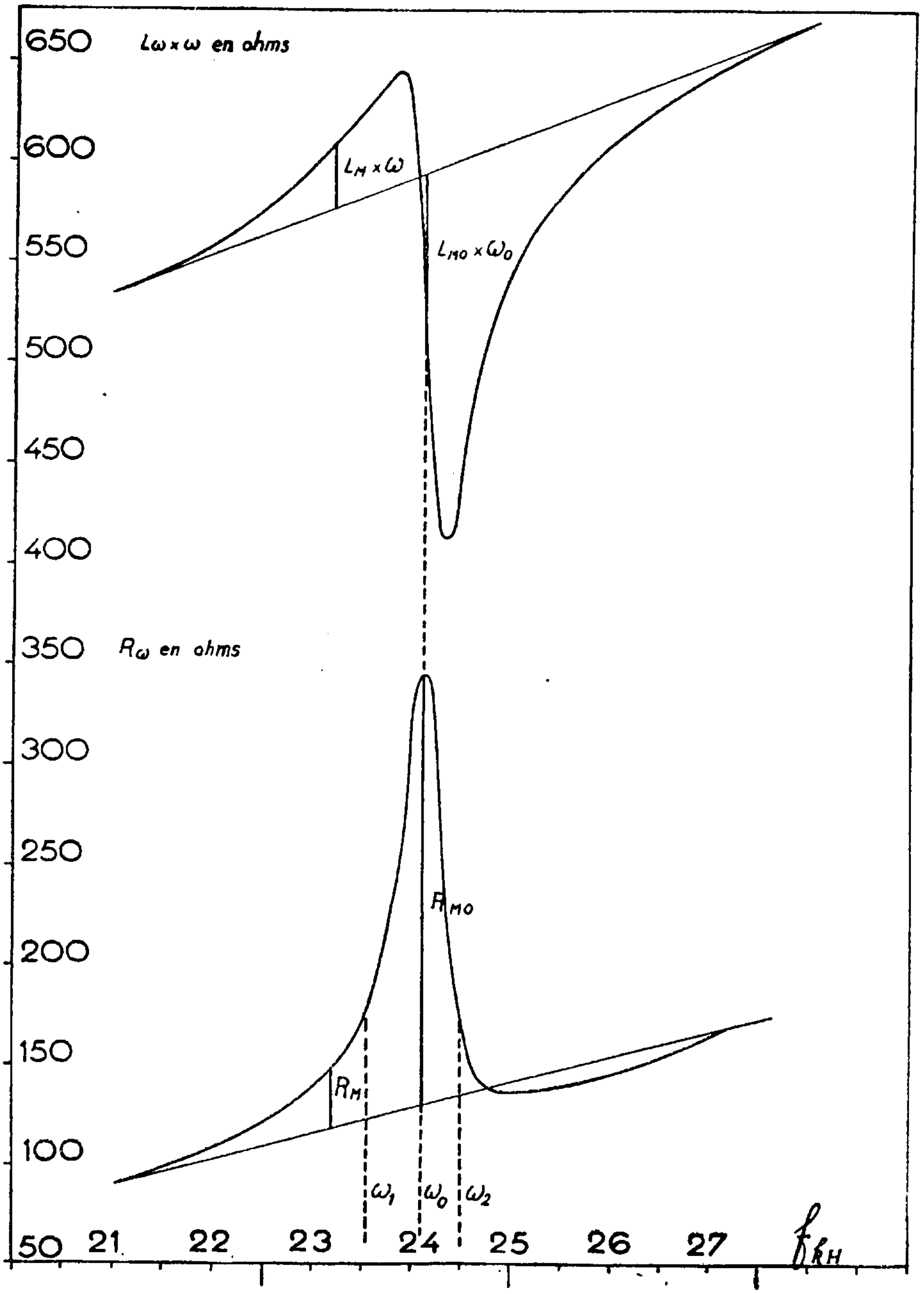


FIG. 12

As may be ascertained by practical application , we note beside the principal maximum, secondary maxima the magnitude of which decreases with an increase in angular difference ; often this makes the bearing much more difficult to obtain ; in particular, the accuracy of direction is affected by the secondary maxima (ASDIC).

Let $\varphi = \dfrac{\pi d \sin \gamma}{\lambda}$: $R = \dfrac{\sin \varphi}{\varphi}$ cancels itself out for $\varphi = \pi, 2\pi, 3\pi$, and the first secondary maximum corresponds to $\varphi_1 = 4.49$ and has value 0,22. Take a

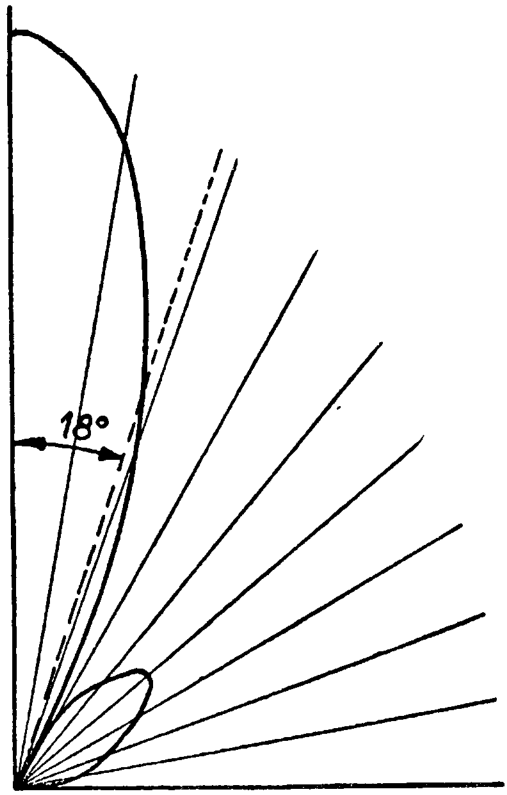


FIG. 13
Radiation characteristic of transmitter base.

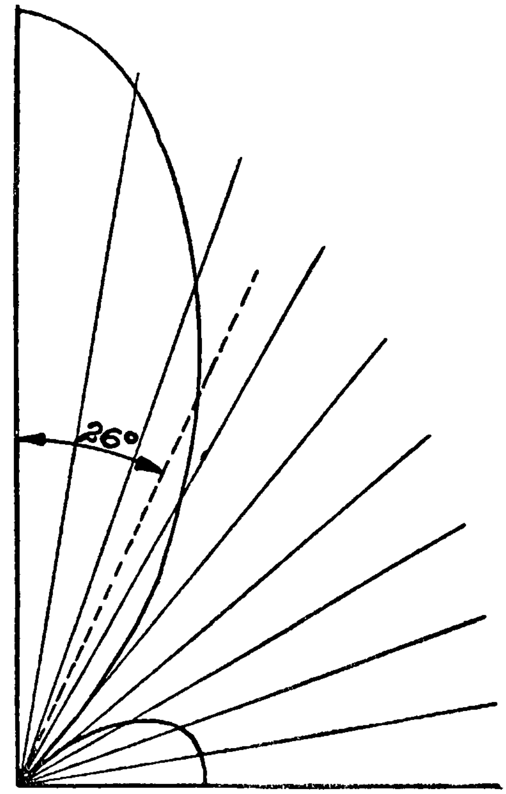


FIG. 14
Radiation characteristic of receiving base.

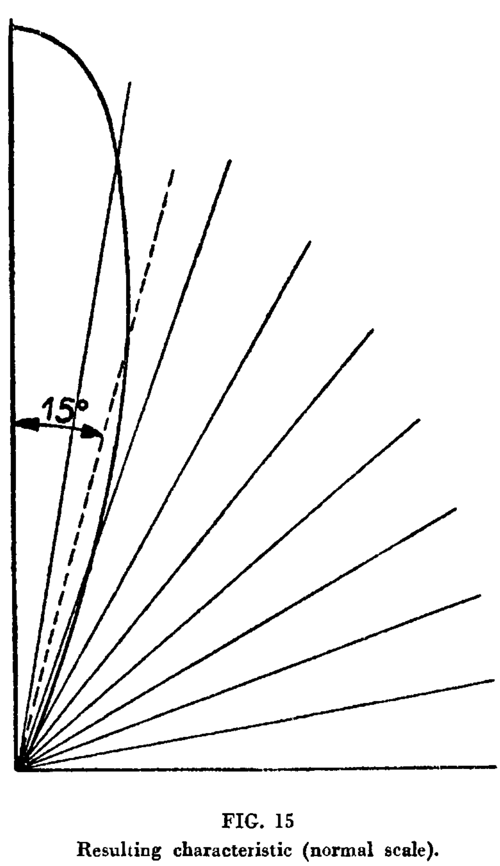


FIG. 15
Resulting characteristic (normal scale).

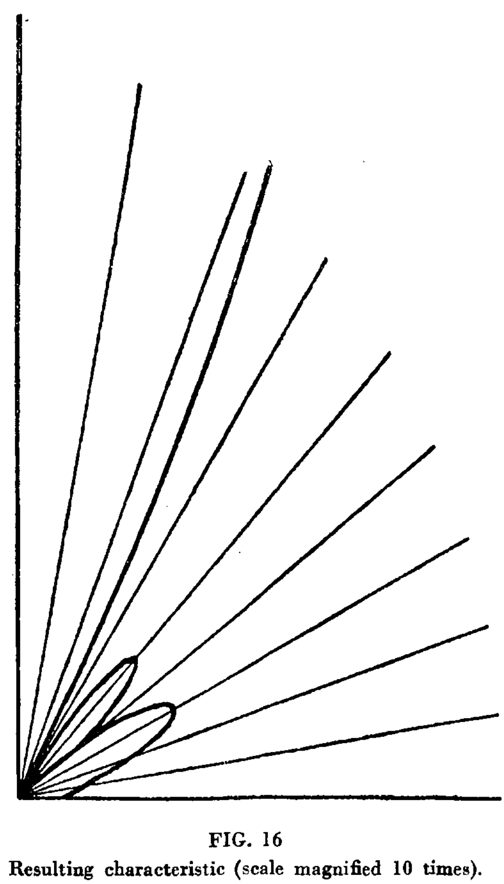


FIG. 16
Resulting characteristic (scale magnified 10 times).

transmission base of dimension d_1 and its characteristic of direction in the perpendicular plane containing this dimension ; for the first secondary maximum $\varphi_1 = 4.494 = \frac{\pi d_1 \sin \gamma}{\lambda}$. Whence the angle γ. The dimension d_2 of the receiving base the directional characteristic of which would cancel itself out for this direction γ, may be determined ; this would give :

$$\varphi_2 = 3.141 = \frac{\pi\, d_2 \sin \gamma}{\lambda}.$$

Dividing member by member we have :

$$\frac{d_1}{d_2} = \frac{4.494}{3.141} = 1.43 \text{ or } \frac{d_2}{d_1} = 0.7.$$

This shows that by a suitable choice of the ratio of dimensions of transmitter and receiver bases, the effects of secondary maxima may to a great extent be eliminated, the maxima of the transmitter base corresponding to the maxima of the receiver base and reciprocally. The resulting characteristic of the whole presents a well-defined maximum.

For example, Figures 13 & 14 show the directional characteristic of a transmitter base of 12 cm. dimension and of a receiver base of 8.4 cm. dimension ; for a transmission frequency of 24 kh, i. e. a wave-length $\lambda = 6.1$ cm., the characteristic of the transmitter base cancels itself out for $\sin \gamma = \frac{\lambda}{d_1} = 0.51$, or $\gamma = 30^\circ 40'$; that of the receiver base cancels itself out for $\sin \gamma = \frac{\lambda}{d_2} = 0.73$, or $\gamma = 46^\circ 40'$.

It may be seen on the resulting characteristic (Figures 15 and 16) that the secondary maxima are greatly attenuated.

f) *Conclusion* :

The advantages of the magnetostriction sounding-machine are numerous :

— low-impedance projectors allowing great length of cable to the radio-electric box ;

— low tensions, therefore less danger of cracking ;

— the magnetostrictive elements are solid and cannot get out of order ;

— simple mounting, good directivity.

Further, on account of its extreme solidity, much greater power than quartz can be brought into play. Also this reserve of power enables the instrument to assure, in spite of damping, transmission of the elastic vibrations through the metallic partitions of steel-built vessels, the piercing of which is avoided thanks to the artifice of an intermediary water tank or ballast.

During recent years the successful application of these processes in France has made a considerable stride forward and has made it possible to place at the disposal of navigators and hydrographers, a measuring instrument that has nothing to envy from foreign competition.

VII. — DIFFERENT ECHO-SOUNDING SYSTEMS

Several echo-sounding systems may be defined.

Sounding by rhythmic impulses which is the system universally adopted as giving the best results, although electrically neither the simplest nor the most economical.

Sounding by pulses triggered by the echo : In this system the transmission pulse is triggered by the echo ; consequently, the depth sounded is in direct relation with the sounding rhythm the measurement of which by means of a simple frequency-meter indicates the depth. This system, extremely attractive *a priori*, has not been applied in practice because of parasite echoes which interfere with reception ; these parasite echoes are of two sorts :

— parasites properly so-called, similar to the atmospheric parasites that exist permanently in the water and interfere with the reception when the receiver is at maximum sensitivity ;

— parasite echoes due to transmission echoes which might be called "intrusive" echoes; these echoes are due to the reflexion or to successive reflexions of the beam of ultra-sounds on reflecting surfaces other than sea-bottom. They occur, for example, after reflexion on the surface separating two layers of water of different temperature and density, after reflexions on the hull of the vessel and on sea-bottom successively (double echo), after reflexions on wrecks, on a school of fish, after double reflexions on sea-bottom constituted by layers of soil of different densities (for example a thick layer of ooze).

Contrary to what might be believed, the first-mentioned are the less troublesome because easily overcome (increase in transmission power), but against the second, which are at the frequency of transmission "marks" there is practically nothing to do (apart from the use of complicated electronic devices of blocking and deblocking in connection with the inertia of the phenomena, devices which are currently used in radar technics).

Continuous sounding at modulated frequency: System analogous to the aircraft sounding system called "Aviasol". The transmission of ultrasonic waves is continuous and modutated in frequency according to a linear law; measurement of the "beat" frequency between the transmission frequency and the reception frequency, gives the measurement of the depth at any moment ; just, as has previously been mentioned, like the action of the frequency-meter. The chief difficulty is to obtain a high output of the acoustic transformer over the whole swept range of frequencies, and for this reason no practical application of this system has been retained.

VIII. — SOUNDING BY RHYTHMIC PULSES

General remarks : The principle of sounding by rhythmic pulses is as follows: a beam of sonic or ultra-sonic waves of short duration is sent through the water ; this wave-train is propagated in the water at a constant mean velocity of 1,470 metres/sec. As soon as the train encounters an obstacle (in this case sea-bottom) a phenomenon of reflexion and diffraction similar to that of a luminous ray on unpolished glass, occurs, and a fraction of the energy transmitted returns to its point of departure at the end of a certain time which is a function of the travel. Measurement of this time gives an exact determination of the distance between the sounding point and the obstacle.

Depth Indicators :

Mechanical Arrangement : The time required for propagation of the ultrasonic wave is sufficiently long for its measurement to be made by means of a mechanical device; habitually a neon valve which moves along in front of a divided scale is used ; each time that the neon valve is in front of the zero division of the scale, it liberates through an appropriate relay system the group of which forms the "transmitter", the transmission of the wave-train ; the echo is received and magnified by a part known as the "receiver" and triggers the neon valve ; consequently, the position of the valve at the moment of lighting-up permits valuation of the depth.

On the same principle there is very close relation between the displacement velocity of the neon and the division ; the slightest change of velocity represents an error in reading and it is therefore necessary to have an arrangement stabilising the rotation velocity of the neon valve.

This is certainly the most practical measurement system ; it has been altered in modern sounding-machines ; the neon valve is a fixed part and its flash is thrown on the scale by, for example, a revolving arm fitted with two total reflexion prisms which eliminates a two-contact collector, always a source of spitting. Another important improvement is the replacement of the ordinary neon valve by a strongly - flashing valve called the strobotron; this tube which is of American origin is a 4-electrode cold cathode valve ; it comprises a special transmission cathode of great transmitting power, two grids used indifferently as governing grid and an anode ; it is also filled with neon under low pressure. During ionisation it allows by the nature of its construction the passage of very strong currents of the order of several score amperes and gives a clear red very vivid and very brief flash (of the order of a few microseconds). By means of a white opaque projector the flash is thrown on a revolving disk in which there is a small slit ; this slit moves behind a plexiglass dial carrying the divisions ; the position of the slit at the moment of lighting-up allows a reading of the depth to be made.

Such a reading part is solid, of unlimited usage ; it is the ideal part for all vessels (trawlers, fishing-vessels) which have no radio staff on board ; by its use easy readings may be made in all weathers and even when the instrument is mounted in a place where there is rather a glare of light (say in the pilot's cabin).

b) *Electric Group* :

Almost all present-day commercial sounding-machines are modelled on Langevin's first instrument with a rotating arm behind a divided dial ; yet the analogy of the principle of submarine sounding technics with that employed in distance radars, turned the mind towards the use of the cathode oscillograph as reading part.

A radar group consists of a transmitter with directed centimetric wave pulses and an echo receiver permitting the measurement of the distance of the reflecting obstacle. The first radars constructed in France towards 1938 and mounted on the ocean-liners "Ile-de-France" and "Normandie" as well as on several navy vessels, included a galvanometer distance indicator. This last part was speedily abandoned because of the inaccuracy of galvanometric readings and their absence of interpretation elements, and the oscillograph was adopted.

The physics department of the National Laboratory of Radio-Electricity also used the oscillograph to measure by means of pulse transmitters the thickness and elevation of the *Heaviside* layer.

The cathode oscillograph is much more than a precision instrument ; it adds to its numerical data very valuable qualitative data, thus permitting visual interpretation.

The oscillographic sounding-machine represents the final stage in the evolution of ultra-sonic sounding technics ; compared with the revolving arm, the oscillograph offers the advantage of much more efficacious interpretation of the form of the received echoes so that the nature of the detected obstacles may be deduced ; further, the range of an oscillographic sounding-machine, transmitting power and diameter of projectors being equal to those of an instrument with revolving arm, is much greater, due to the fact that the ratio signal/sea-bottom sound may be reduced to a value in the vicinity of the unit.

However, the oscillographic sounder is a much more fragile instrument requiring more delicate handling ; it can be used by an experienced staff only.

It is also a much more costly instrument demanding constant maintenance. On account of its qualities it may be of great use for hydrographers, for the Navy or the Merchant Navy Services.

IX. — MAXIMUM RANGE OF A SOUNDING EQUIPMENT

So that it may be detected, the power received must be at least equal to the power developed in the entrance circuit resistance by the sound tension, this supposing that the sound impedance of this circuit be superior to the sound impedance of the first valve ; this may always be arranged for, either by providing a sufficient number of turns on the magnetostrictive elements or by coupling those elements to the first valve by means of a transformer in suitable proportion. To avoid losses due to this transformer, it is preferable to choose the first solution.

We have seen that at resonance, the magnetostrictive element is equivalent to the group formed by a self $L_0 = L + L_{mo}$ in series with a resistance $R_0 = R + R_{mo}$; the self L_0 is tuned with a condenser C at the terminals of which the tension to be applied directly to the grid of the first valve (Figure 17) is collected. It is easily demonstrated that the useful power received is maximum when the output ratio of the element at resonance is 25% ; this is arranged for by trying-out the dimensions of the element, the quality of the nickel, the thickness and thermic treatment of the sheets, the mounting of the instrument, etc.

R_0 being known, the equivalent parallel resistance : $R_{ar} = L_0/CR_0$ (See Figure 18), is deduced from it. It is this fictive resistance that determines the noise level of the circuit ; so that the puff due to the first valve may not interfere, the sound resistance of this valve must be inferior to R_{ar}.

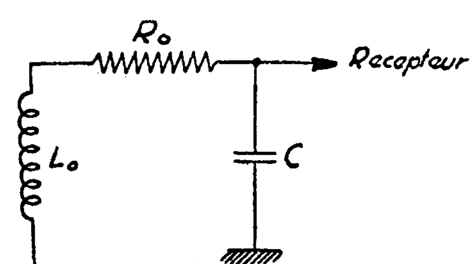


FIG. 17

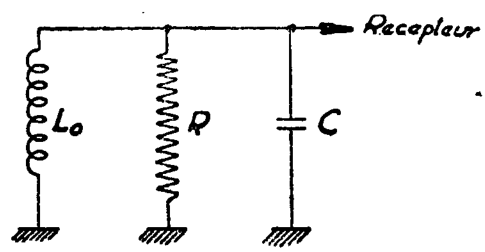


FIG. 18

At first sight it might seem that it would be preferable that R_{ar} be small (always supposing that an entrance valve may be chosen such that its sound impedance be markedly inferior to R_{ar}) ; in fact, the sound tension, given by $\Delta V_g^2 = 4\ kR_{ar}T \times \Delta F$ is proportional to $\sqrt{R_{ar}}$. We shall show that this is not so ; in fact, the power corresponding to the sound tension is $\Delta V_g^2/R_{ar} = 4\,kT \times \Delta F$; if P_r is the power received by the magnetostrictive elements, the output at reception being 25%, the useful power transmitted to the entrance circuit is $P_r/4$. So that it may be detected, the only condition is that

$$\frac{P_r}{4} \geqslant \frac{\Delta V_g^2}{R_{ar}} = 4\,k\,T \times \Delta F. \text{ Therefore } P_r \geqslant 16\,k\,T \times \Delta F$$

This formula is very important and gives in the optima reception conditions (free from parasites), the sensitivity limit of the sounding-machine.

The problem of determination of maximum range consists therefore in computing the distance to which the received power P_r fulfils the above condition. In a certain sense the receiver pass band can be governed; however, to receive correctly very brief pulses (shallow-water sounding), a sufficiently large pass band must be had, the necessary pass band depending solely on the duration of the pulses. In practice a pass band of 5 kc is sufficient ; that already necessitates a rather high carrier frequency during the pulses (10 kh at least) ; if as temperature, the absolute normal temperature $T = 290^o$ be chosen, the result is (k = Boltzmann constant = 1.37×10^{-23}).

$$P_r = 16 \times 1.37 \times 10^{-23} \times 290 \times 5.000 = 32 \times 10^{-17} \text{ Watts.}$$

That is the theoretical minimum power that can be detected.

Let P_e be the transmitted power and G_e the gain furnished by the transmission projector ; this gain is due to the fact that the power P_e is not uniformly transmitted around the projector but is "directed", i.e. concentrated in a principal lobe which is considered ; a somewhat complicated calculation shows that this gain G_e is given by the formula :

$$G_e = K \ S_e / \lambda^2$$

where S_e is the surface of the transmitter base and λ the wave-length through water. It is seen that to have a high gain, one is led to choose a high vibration frequency, consequently a feeble wave-length.

The power transmitted for each surface unit in water at a point distant by R from the transmitter base supposed to be an isotrop radiator (i.e. radiating equally in all directions) would be $P_e/4\pi R^2$, and for our real base of gain G_e this power is : $\dfrac{P_e \ G_e}{4\pi R^2}$.

Take a transmitter E and an object O situated at a distance R (Fig. 19),

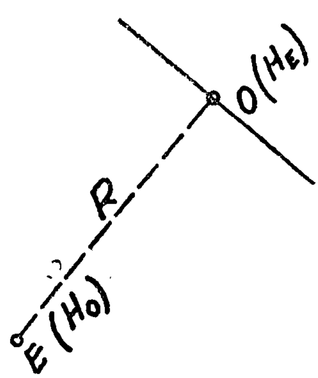


FIG. 19

the transmitter E creates a field H_e in O ; the object O also acts as a transmitter and creates in E a field H_o. Appleton defines the dispersion coefficient L of the object O by the relation

$$\frac{H_o}{H_e} = \frac{L}{R}$$

Note that L has the dimensions of a length.

If we assume that O is a perfectly reflecting surface, plane, infinite and perpendicular to EO, the field reflected by such a surface in O would be $H_e/2$; the output ratio of the object considered in relation to this ideal reflecting surface is therefore

$$\frac{H_o}{0.5\ H_e} = \frac{2\ L}{R}$$

This output is sometimes called the reflexion coefficient k of the considered object. k is the output in field ; the power output is therefore : $k^2 = 4L^2/R^2$.

The power by surface unit on the object is $\frac{P_e \times G_e}{4\ \pi R^2}$; consequently the power reflected in E by O will be :

$$\frac{P_e \times G_e}{4\ \pi R^2} \times \frac{L^2}{R^2}$$

the receiver base is situated in E and has a surface S_r, consequently the received power is written ;

$$P_r = \frac{P_e \times G_e \times L^2 \times S_r}{4 \times \pi \times R^4}$$

It is known that the gain of the receiver base is of the form $G_r = K \frac{S_r}{\lambda^2}$, the preceding equation might be put under the form :

$$P_r = \frac{P_e \times G_e \times \lambda^2 \times G}{R^4} \times \frac{L^2}{4 \pi K}$$

this equation is again met with in the theory of the distance radar.

The preceding equation enables the range limit of a sounding equipment to be determined :

$$h = R = \sqrt[4]{\frac{P_e \times G_e \times S_r \times L^2}{4 \times \pi \times P_r}}$$

This formula admits of a few remarks :

First, it is unnecessary to increase to any considerable extent the transmission power since the variable *h* varies as the fourth root of this power.

For the same reason it is unnecessary to increase the surface S_r ; this partly justifies the choice of a receiver base of less diameter.

On the other hand it is of greater interest to endeavour to increase the directivity at transmission, either by increasing the total transmission surface or by dividing this surface into fractions so as to have smaller elementary surfaces, uniformly distributed in a suitable way.

For a given equipment, it would seem according to this formula that the only means whereby the maximum range might be increased is to increase the transmission power.

Although magnetostriction allows a considerable increase in transmission power, the cavitation phenomena intervene to limit this method : the formation of vapour from water under the influence of too great pressure of the molecules. Theoretically, the maximum power value admissible by unit of surface for water in normal conditions is 0.33 Watt ; in practice, when the ultra-sonic projector is mounted in a ballast the water may be put under pressure and the value in question considerably increased.

Practical Application

Let us consider an equipment constituted by the following elements :

— the transmitter comprises 3 lots of sheets 5 centimetres wide piled up to a thickness of 12 cm.;

— the receiver base comprises 2 lots of sheets 5 cm. wide piled up to a thickness of 8.4 cm. ;

— the pulse frequency is 24 kh.

It is proposed to find out the maximum sounding depth ; the power P_r has been previously calculated : $P_r = 32 \times 10^{-17}$ Watt ; L is very variable according to the nature of sea-bottom (rock, sand, ooze, etc...), mean value might be adopted as $L = 1$ metre.

The transmission surface is $S_e = 12 \times 5 \times 3 = 180 cm^2$ whence the maximum transmission power $P_e = 180 \times 0.33 = 60$ Watts. The transmission diagram of such a projector has been previously traced ; it may be seen that the energy is concentrated in a half-angle at the summit of 18^o (weakening by 6db) ; the projector gain is therefore of the order of 5.

Reception surface is $S_r = 8.4 \times 5 \times 2 = 84 cm^2$, whence :

$$h \text{ cm.} = \sqrt[4]{\frac{60 \times 5 \times 84 \times 100 \times 10^{-17}}{4 \times \pi \times 32}} = \sqrt[4]{\frac{2.500}{400}} \times 10^5 = 1{,}58 \times 10^5 \text{ cm.}$$

and h metres = 1,580 metres.

No account has been taken of the medium absorption. Owing to the incompressibility of water, this absorption is almost wholly due to the coefficient of viscosity in water. A coefficient of energy penetration may be defined :

$$\varepsilon = 3 \lambda^2 \rho_0 V_0 / 8 \pi^2 \mu ;$$

it is in term of the viscosity coefficient μ the distance for which the initial amplitude is reduced by $1/e$; for water for example : $\varepsilon = 2.10^{-5} \lambda^2$. It may be seen that waves of 100 kc/sec. are totally damped over a distance of a few kilometres while waves of 25 kc/sec. are damped only after a travel of about 100 km.

This formula shows that from the point of view of damping in water, it is preferable to operate with a fairly low frequency ; it is this that explains the great ranges of the hammer sounding-machine and the reason why it remained in favour until the appearence of the magnetostriction which alone has made infinitely greater transmission power possible.

Neither, in the preceding computation, has account been taken of water parasites. The sound level of the parasites is often more important than that due to fluctuations of the electronic circuits. Consequently this factor intervenes also on the maximum range of a sounding equipment. Parasites become less troublesome as the transmission frequency increases.

Selection of Frequency

With regard to the selection of frequency of transmission "marks", one is faced with several factors the conditions of which are contradictory :

— in favour of high transmission frequency :

greater power radiated, term of directivity ;

protection from low-frequency vessel noises ;

fairly wide pass band of receiver for shallow-water sounding ;

— in favour of low transmission frequency :

damping through water ;

losses by hysteresis and *Foucault* currents in the nickel sheets, losses in the impedance adaptor transformer.

At present the best results are obtained with a frequency set between 15 and 30 kc/sec. ; to avoid encumbering the base (the height of the magnetostrictive elements is in the vicinity of half a wave length), for ease in winding, for exactitude in cutting and for economising the nickel, the frequency 24 kH has been adopted.