Echo Sounding.

THE extent of the interest which has been excited in foreign navies by the proved rapidity and accuracy of soundings obtained by the method of echo depth sounding is indicated by contributions to the latest number of the *Hydrographic Review*.[1] "Sonic" echo methods, in which the compressional waves sent out from the underwater transmitter are of audible frequencies, are dealt with in part of an article which contains a summary of the results obtained by previous writers in this field, and in an article by Dr. H. C. Hayes, Research Physicist of the U.S. Navy, in which is set forth the theory of three different methods of obtaining depths by sonic echoes. These methods have been described elsewhere and the principles are now well known. Apart from what is known as the "angle method," which is most appropriate to shallow depths, all sonic echo methods reduce to artifices for indicating in a simple and trustworthy manner the interval of time which elapses between making an underwater signal and the return of the echo from the bottom, and methods of avoiding disturbances in the receiving apparatus due to the original signal. A simple device, produced by the Scientific Research Department of the British Admiralty, achieves these objects and has already been described in these columns.[2]

In principle the device is similar to, but differs in an important practical detail from, the Fessenden apparatus described in the *Hydrographic Review*. It is noted that no reference is made in the summary of recent work on depth sounding to the British Admiralty type of sonic sounder or to the simple "Fathometer" of the Submarine Signal Corporation of Boston, Mass., which also resembles the Admiralty apparatus. The writer in the *Hydrographic Review* is in error when he states (on p. 66) that the sonic method can be used only for "rather considerable depths, *e.g.* 50 fms." According to the above-quoted article in NATURE, the British Admiralty sonic sounder has been used with success in water so shallow that the vessel was only just afloat.

A range of possibilities which will be entirely new to many of those who have studied sonic echo methods is suggested in that part of the article which deals with the use of "ultra-sonic" waves in echo sounding. As the name indicates, ultra-sonic waves are compressional waves of frequency so high as to be inaudible to the human ear. The writer of this section of the report describes apparatus patented by Prof. Langevin and M. Chilowsky for producing these high frequency vibrations, and gives information concerning their properties, which are of great scientific interest.

If we assume that the direction of an object which causes an echo can be estimated with as much accuracy as that of a source of sound, we might imagine that rocks and other navigational dangers could be detected by echoes of sounds produced by submarine bells or Fessenden oscillators, and that indications of their direction might be obtained by the use of hydrophones having directional properties, or by the use of some underwater receiving system like the multiple rotating trumpets used for detecting and locating aircraft at a distance by the binaural effect. Theoretically neither idea is impossible, but there are great practical difficulties to be overcome. Since the velocity of sound in sea water is much greater than in air, our underwater "trumpet" system must be about five times as large as a system of similar accuracy in air. Any one who has seen photographs of the air trumpets used in anti-aircraft work will appreciate the impossibility of fitting such a device under water in a vessel. The idea of an effective underwater analogue to the air trumpet must not, however, be dismissed as absurd, for the U.S. Navy M-V Hydrophone described by Dr. Hayes does for underwater signals what the trumpets do for sounds in air.

Again, for physiological and psychological reasons, it is extremely difficult to obtain the direction of a source of sound (and hence of an echo) with a directional hydrophone unless the sound is continuous, or nearly so, and this introduces the question of effectively screening the receiver against the shocks due to the outgoing signals, in order that the listener may not be so deafened that he cannot hear the comparatively faint echo. It would be very difficult, if not impossible, to devise a method of screening which would be satisfactory under these conditions, and in any case accurate direction cannot yet be obtained with a simple directional hydrophone. There is a further serious objection to the use of sonic echo methods for determining the direction of objects under water. Owing to the long wave-length of audible sounds, very little energy is reflected by a small object, and a floating wreck might thus easily be undetected.

In spite of all the difficulties which beset those who searched for better navigational methods, an idea which originated with an Englishman, Richardson, soon after the loss of the *Titanic*, has now materialised. Richardson's idea was to project a "beam" of sound from a transmitter fixed in a vessel and to receive the echoes from submerged obstructions. The beauty of the "beam" idea lies in the fact that if an echo is received, then something with acoustic properties different from those of sea-water is known to lie in the direction in which the transmitter is pointing. That is, the source of an acoustic beam acts the part of a searchlight projector, but under water. The difficulty lay in producing a beam of sound, and for a long time the idea remained uninformed.

It is useful here to return to fundamental principles and to remember that the sources of radiation with which we commonly deal are non-directional unless their size is large compared with a wave-length of the radiation emitted, or other steps are taken to concentrate the energy. Mr. Marconi has shown how directional wireless beams can be produced by using what are in effect transmitting surfaces of size comparable with the wave-length used. Light may be concentrated into a beam by mirrors because even a very small mirror is many wave-lengths in diameter. Since the wave-lengths of audible sounds are measured in feet, it is clear that it is necessary to use sound sources of high frequency in order to reduce the size of the necessary focussing arrangements to practical dimensions.

It can be shown theoretically that a flat circular plate of diameter about 8·7 inches, vibrating in a direction perpendicular to its plane with a frequency of 40,000 cycles per second (corresponding to a wave-length in water of about 1½ inches), produces a beam of energy with an angle of divergence of about 10°, and containing nearly all the energy passed into the water by the vibrating plate. Now it is clear that a transmitter very much larger than this is impracticable, while use of a lower frequency would reduce the sharpness of the beam. Hence, the designers of sound beam apparatus were faced with the problem of producing an oscillator having a frequency approaching 40,000 cycles per second.

Prof. Langevin and M. Chilowsky discarded electrical and mechanical generators, the use of the effect

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[1] *Hydrographic Review*, vol. 2, No. 1, Nov. 1924, pp. 51-121.

[2] NATURE, March 29, 1924, pp. 463-65.

of magnetostriction, condenser-transmitters, high frequency sirens, and whistles—after having tested some and having been told the results of the tests of others—and eventually decided to use the piezo-electric property of quartz,[3] discovered by the Curies in 1880. Quartz, like some other crystals, cut in a particular way with respect to the crystallographic axes, expands or contracts when an electrical potential difference is applied to certain faces of the crystal. This effect is very small for practical voltages and sizes of crystal, and there is a corresponding reverse phenomenon. Thus, if alternating potentials, which may be generated by an ordinary oscillating valve circuit, are applied to a crystal, corresponding mechanical vibrations will be set up in it, and thus energy may be passed into water if the crystal is submerged in the sea. Similarly, the crystal will be strained by any vibrations in the water and the corresponding electrical effects may be amplified and detected by known means.

Now the energy emitted by per unit area of an oscillator of this kind depends, among other things, upon the frequency and voltage of the applied current. To obtain an energy emission of only 1 watt per square cm., alternating potentials of the order of 50,000 volts would have to be applied at a frequency of 40,000 cycles per second, were it not for the fact that Prof. Langevin chooses the thickness of his quartz so that it is in mechanical resonance with the power supply—that is, the thickness of the quartz is equal to one-half wave-length (in quartz) of an elastic vibration of the frequency considered. It is interesting to note the use by Cady and others of this phenomenon of electro-mechanical resonance in piezo-electric crystals in designing frequency standards for wireless and other purposes. Standard oscillators so constructed are small, robust, easily portable, and little affected by normal changes in temperature.

In practice, the oscillators used by Prof. Langevin and M. Chilowsky are stated to have been built up of a layer of pieces of quartz cemented together with insulating compound between two sheets of steel, the whole being arranged so as to be in mechanical resonance with the frequency of the alternating supply. An increased energy emission was then obtained and it was found that the required output could be obtained with only about 2500 applied volts. The oscillators are, of course, specially constructed to withstand both electrical and hydrostatic pressures without breakdown, and sectional drawings of an oscillator and its mounting are given in the article.

It is pointed out in the article under notice that the optimum frequency of transmission is determined by energy losses in the water as well as by the practical limit of size of the oscillator. Energy losses in water increase with increasing frequency, and a formula is given which shows that the amplitude of the compressional wave diminishes with distance according to an exponential law, similar to those which hold for other vibrations passing through absorbing media.

The method adopted to measure the vibrational energy in the water at the high frequencies used in supersonics is interesting. The principle is the same as that upon which the radiometer depends, namely, the relationship between radiation pressure and the energy per unit volume of the medium. The pressures exerted by the supersonic waves were measured by a torsion pendulum in a manner which recalls the use of the Rayleigh disc for obtaining information about the amplitude of air vibrations in resonators.

There appears to be an error in dealing with this question on pp. 60 and 63, in that energy is proportional to the square of the amplitude of the vibration, and the argument on p. 59 relating to the absorption of electro-magnetic and acoustic energy by sea-water is clearly fallacious. Incidentally, the paper appears to have suffered some loss of clarity at the hands of the translators, especially in the theoretical portions. The statement on p. 63 regarding the reduction in energy due to viscosity is worthy of further notice. The conclusion that supersonic waves, having a frequency of 40,000 cycles per second, should travel some 32,000 yards in sea-water before their energy is reduced to one-third of its initial value, taken in conjunction with the statement on p. 83 that a signalling range of 4·9 nautical miles was obtained, suggests that, even with a beam of small divergence, the energy losses over such ranges depend less on viscosity than on the value of some multiplying factor depending on such quantities as the range and beam angle. The value of this factor is not discussed, but some idea of its possible magnitude may be gained from the work of Barkhausen and Lichte reported recently in the *Annalen der Physik*.

The final portion of the paper is devoted to descriptions of the methods which may be used for depth sounding or the location of wrecks, etc., by the ultra-sonic beam. The same oscillator is used for reception and transmission, and can be rotated in its mounting. In one method an oscillograph is used to record the time-interval between the outgoing and incoming signals. In an alternative scheme a fluxmeter is used to integrate a current which flows during the echo interval, and thus a measure of time is obtained. An interesting cross-connected circuit containing two thermionic valves is used to start and stop this current without mechanical relays. It is stated that direct signals have been transmitted with the piezo-electric oscillator over 4·9 nautical miles, soundings taken down to 245 fathoms, and floating bodies located at more than 2000 yards. If the object from which echoes are being received is not the sea bottom but is a floating body, the method gives information both as to its distance and its direction. The latter is as yet unobtainable by sonic methods of depth sounding. But, as direction is generally immaterial in depth sounding, it appears to be doubtful if there is here a large field of utility for what is clearly at present a complicated and expensive piece of apparatus, which would only be safe in skilled hands. Also it may perhaps be permissible to express a doubt as to the results which would be obtained if the supersonic beam were used to detect icebergs. On theoretical grounds it seems improbable that a large proportion of the beam energy would be reflected, because the constants of water and ice which determine the amount of the reflected energy are not notably different.

Whatever may be the limitations of the present device, there is no doubt that, as in many other instances, simplification of design and operation will follow further research, and an aid to navigation of inestimable value will eventually be at the disposal of all who take ships to sea. By the use of the successors of this apparatus the danger of collisions at sea may be greatly reduced, and one is tempted to wonder how many out of the thousands of a future generation of travellers will give a thought to the two scientific workers who, more than forty years ago, discovered the obscure phenomenon on which this method of signalling depends, or to those who have more recently worked out its application. It is a pity that in an age of hurry we are forced to take so many things for granted.

J. B.

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[3] On p. 75, dealing with this point, it is presumed that "Sir E. Rutherford" should be read for "Sir E. Richardson."