GENERAL ASPECTS OF APPLICATION OF HORIZONTAL ECHO SOUNDING METHOD TO SHIPPING

by Dr. W. Kunze

Lecture delivered at the International Meeting on Radiolocation, Hamburg, October, 1956.

During the meeting which took place in Bremen 2 years ago echo sounding in a vertical direction i.e. down to the seabed, was especially discussed. This meeting emphasized the application and the importance of vertical echo sounding for measurement of the depth of water, for hydrographic purposes, for navigation and especially also for fishing. This year's meeting will emphasize the echo sounding method in a horizontal direction or, generally speaking, in all directions around the vessel, with the exception of the waters directly below the ship's keel.

It is the task of the horizontal echo sounding method to detect and locate objects which are between the surface of the sea and the seabed in the vicinity of the vessel. The methods and devices developed by the navies of various countries before and during the last war, especially as regards the detection and location of submarines and mines, were aimed at the solution of this problem. In the German navy devices of this type were designated as « S-Geräte » (Search-equipment) whereas the Allied Forces called them Asdic or Sonar equipment. To-day merchant shipping profits from this work of development originally carried out for military purposes. I shall now briefly discuss and explain the problems involved in the horizontal echo sounding method and the equipment available. Moreover, I shall give general aspects of their application in merchant shipping.

At first, let me make some remaks on the history of the problem of the horizontal echo sounding method.

Both as regards wireless telegraphy and sound location, the disaster of the *Titanic*, which collided with an iceberg on April 15, 1912, and sank taking 1500 people with her, was a milestone in history. At that time physicists and technicians all over the world proposed to install devices aboard vessels, which would enable icebergs to be detected by observing the echoes of sound signals emitted from the ship and reflected by the iceberg. Thus, at that time the idea of the horizontal echo sounding method was born. In this connection proposals and tests were made in 1912 and 1913, e.g. by Fessenden, Richardson and Behm. In his patent application which he filed in England on May 10, 1912, thus shortly after the *Titanic* disaster, Richardson made the proposal to radiate an ultrasonic beam from the ship in a horizontal direction and to observe the returning echoes. This British patent of Richardson's (Fig. 1) is approximately of the same importance for the history of the horizontal sound location as Hülsmeyer's German patent for radiolocation. It already indicated the main essentials of the horizontal echo sounding method in water, but no suitable ultrasonic transducers were available at that time in order to put Richardson's ideas efficiently into practice. Not before

Langevin invented the well-known piezoelectric transducer at the end of World War I for the generation and reception of ultrasonic waves in water was the practical application of the horizontal echo sounding method made possible. In the twenties, the magnetostrictive oscillators for the generation of ultrasonic waves in water were added to the piezoelectric oscillators, mainly as a result of research work carried out by Pierce. Nowadays these two principles are in use for horizontal echo sounding equipment.

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Date of Application, 10th May, 1912

Complete Specification Left, 10th Dec., 1912 — Accepted, 27th Mar., 1913

PROVISIONAL SPECIFICATION.

Apparatus for Warning a Ship at Sea of its Nearness to Large Objects Wholly or Partly under Water.

I, LEWIS FRY RICHARDSON, of 120, Rye Hill, Newcastle on Tyne, Physicist, do hereby declare the nature of this invention to be as follows:—

In British Specification No. 9423 of 1912 an apparatus has been described for detecting the echo from a large object when the sound travels through the air. The present invention is an adaptation of this method so as to make it work under water.

Advantages of working under water are as follows:

(1) The absorbtion of sound by water is less than that by air. That is to say, a higher frequency (desirable on account of freedom from diffraction) can be

Fig. 1.

Richardson patent of 1912 on horizontal echo sounding.

From the historical point of view, it will be of special interest to note that the work begun in connection with the *Titanic* disaster in the field of horizontal echo sounding also resulted in the solution of the less complicated problem of depth measurement by means of sound waves, which had been worked on for some time. The measurement of the depth of water by means of sound waves was thereupon rapidly introduced into merchant shipping, whereas the horizontal echo sounding method at first remained in the domain of naval forces, and the research work done and the results obtained were kept secret. Not until the last war ended did the developed methods and equipment gradually become known and were they introduced into merchant shipping for various purposes.

In principle, the essential difference between the application of the echo sounding method for the measurement of depths, and the detection and ranging of objects in water in a more or less horizontal direction, is that the propagation conditions of sound in a vertical direction are more favourable than in a horizontal direction. When taking horizontal soundings, one cannot expect to obtain the same ranges of transmission as when the vertical depth of water is sounded. With regard to sound propagation, the water between the surface and the seabed represents no homogeneous body of constant sound velocity but consists of more or less horizontally arranged layers of different temperature, salinity and pressure. These three factors affect the sound velocity, and with increasing values all three factors result in an increase of this velocity. Temperature has a high influence, whereas salinity and pressure have less.

An average value of 1500 m/sec. can be assumed as the velocity of sound in the open sea. At low temperatures and low salinity, as for instance in winter in the Baltic Sea, sound velocities down to 1435 m/sec. can be expected, whereas in waters of higher temperature and of high salinity sound velocities of 1520 m/sec. may occur. In general, layers of different temperatures are arranged one above the other in seawater. Consequently a sound beam when radiated in a horizontal direction will be gradually deviated from its rectilinear path during propagation. This beam will be deviated from the layer with inherent higher velocity, i.e. of higher temperature, salinity or pressure, into layers having a lower temperature, lower salinity or lower pressure, so that curved sound beams will be originated. In vertical sound propagation, as in measurement of the depth of water, such curved beams will not develop.

These conditions of sound propagation in sea water, hitherto based on theoretical reflections, are illustrated by means of 2 figures.

In a lecture given by Prof. Thorade, of the German Naval Observatory, in 1943 in Rankenheim, three types of stratification of sea water are systematically distinguished as regards velocity of sound (Fig. 2):

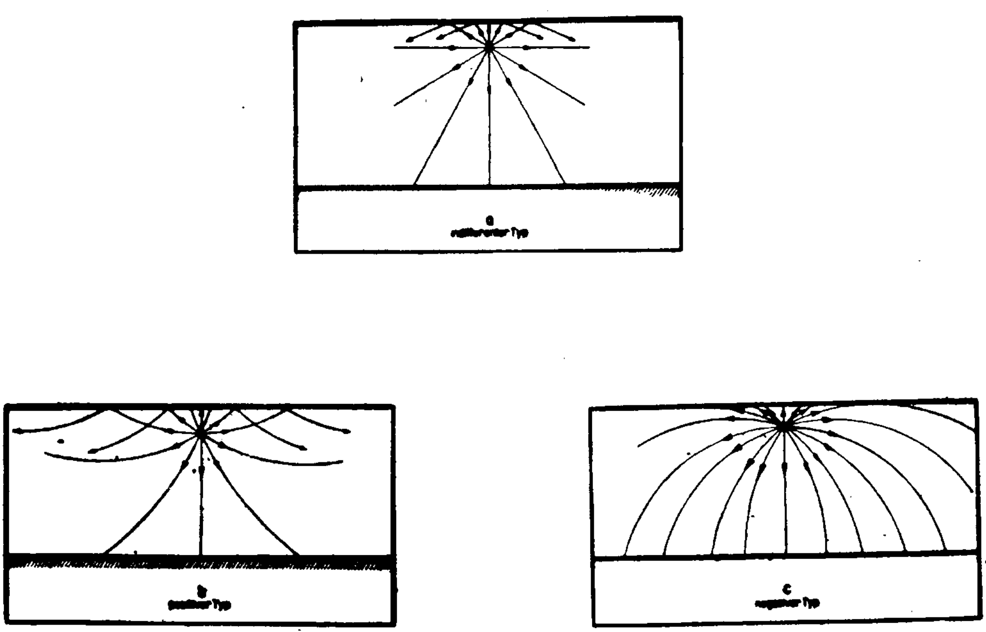

Fig. 2.

Propagation of sound in sea water.

a) Indifferent type.
b) Positive type.
c) Negative type.

(a) *Indifferent type:*

Between the surface and the seabed or within a greater depth range the sound velocity is constant. In this case the sound waves radiated by the oscillator are propagated in a straight line.

(b) *Positive type:*

The sound velocity increases in a downward direction; the gradient is positive. In this case the sound waves will be curved in an upward direction.

(c) *Negative type:*

The sound velocity decreases in a downward direction; the gradient is negative. In this case the sound waves are curved in a downward direction.

Unfortunately, the ideal case of the indifferent type will rarely occur in practice. Even when the temperature of the water and the salinity are constant from the surface down to greater depths, the pressure will increase with the depth and thus we have the case of the positive type. The positive type will occur occasionally, especially in winter, when the water is of increasing or constant temperature from the surface down to a definite depth. In this case the sound beams will be curved in an upward direction. The negative type, thus a negative gradient, will occur more frequently, especially as the temperature normally decreases with depth. Hence the sound beams will be curved in a downward direction.

In most cases the conditions will be such that a combination of the positive and negative types will occur. The temperature will be uniform down to a definite depth below the surface, and as a consequence thereof, the sound beams will be curved upwards in this layer owing to increasing pressure. Then a jump of temperature may suddenly appear, the temperature will decrease and the sound beams will be curved in a downward direction.

In case the sound beams radiated in an upward direction (or, as in the positive type, curved in an upward direction) meet the surface of the sea, they will be reflected in a downward direction. On the other hand, as in the negative type, the sound beams curved downwards to the seabed will be reflected by the seabed in an upward direction. Owing to these reflections the sound waves radiated by a transmitting oscillator can penetrate into areas which they could not reach directly, as the sound beams are curved in most cases.

Moreover, it should be observed that the position and the form of the shadow areas, into which no sound can enter according to the theory of rays, is dependent on the depth of water in which the sound oscillator is placed. If, for instance, in the case of the negative type, the oscillator could be lowered to greater depths instead of being fixed on the ship's bottom, the distance in which the shadow zone will occur could be considerably increased.

In the next figure, which my colleague Dr. Howey displayed at a lecture on sound propagation in sea water, held at a meeting of the Deutsche Physikalische Gesellschaft, these conditions are again clearly represented (Fig. 3).

At the beginning of this account I dealt with these problems of sound propagation as they essentially influence the transmission ranges obtainable by the horizontal echo sounding method. Besides the transmission loss of the ultrasonic waves in sea water due to absorption of the sonic energy, which is approximately

5-10 decibels per km at frequencies of 20-30 kilocycles, 30-40 decibels per km at a frequency of 100 kilocycles, the stratification of temperature is the factor which is decisive for the transmission range. Unfortunately, this factor is not as stable as the transmission loss but will change depending on local, seasonal and even daily conditions. For this reason it is likewise impossible for the transmission range of horizontal echo sounding equipment, even when the radiated sound energy is very high, to supply a reliable figure as in the case of the transmission range of aerial sonic signals, the high dependance of which on meteorological conditions is well known in shipping circles.

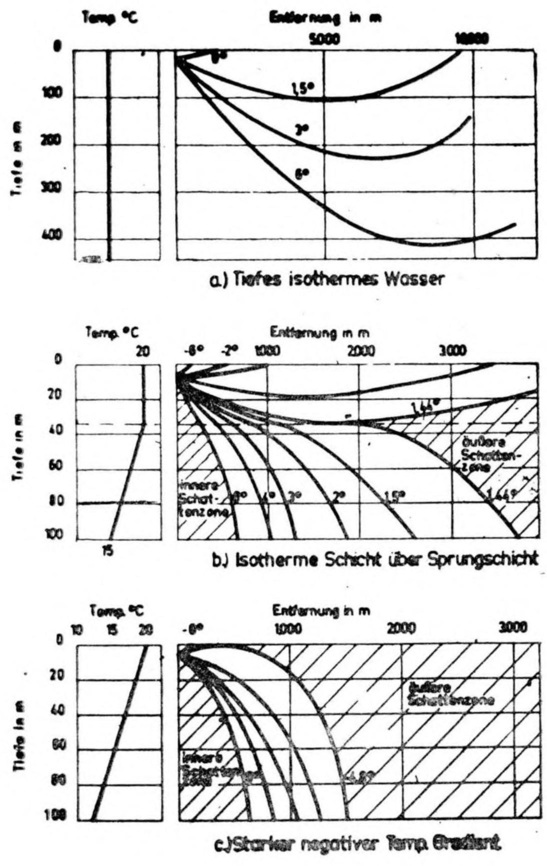

Fig. 3.

Diffraction of sound rays in sea water by temperature gradient.

a) Deep isothermal water.

b) Isothermal water above thermocline (35 m), negative gradient at greater depth.

c) Strong negative gradient from surface towards bottom.

In order to give an idea of transmission ranges which can be obtained for horizontal sound propagation in water, I shall mention a few results acquired through actual experience.

Statistic evaluations which I made in the years after the First World War on the basis of approximately 1100 reports of merchant vessels on the transmission range of underwater sound fog signals, i.e. the direct transmission of sound from one oscillator installed on a light-ship to a receiver installed in a vessel, resulted in average ranges from 10 to 20 km for the waters of the North and Baltic Seas; in individual cases considerably shorter or longer transmission ranges appeared. When taking into consideration that in this case low frequencies of approximately 1000 cycles were involved (for which the transmission loss is considerably lower than for ultrasonic frequencies), that for horizontal echo sounding the sound has to travel twice the distance, and that in case of reflection only a fraction of the energy striking the object will be returned to the oscillator, it is evident that in horizontal echo sounding considerably lower average ranges of transmission must be expected than those mentioned above. During the last World War, it was possible to locate submarines by applying the horizontal echo sounding method, at ranges of 2 to 3 km, and mines floating between the surface of the sea and the seabed at distances of several hundred meters, up to a maximum distance of 500 m. Ranges of transmission similar to those obtained for submarines can be expected in the case of whales, whereas the sound location of schools of fish in the neighbourhood of the surface will be possible at average ranges of 500 m to 1000 m.

I shall now give additional details regarding methods and equipment used in horizontal echo sounding.

In principle, such methods and devices are identical with those used for acoustic depth sounding. Piezo-electric or magnetostrictive oscillators are employed for the generation of the sound pulses. In order to obtain a sufficiently sharp directional effect, the dimensions of the radiating surfaces of the oscillators must be a multiple of the wave length employed. Since very high frequencies, i.e. short waves, cannot be expected to result in sufficiently long transmission ranges due to high transmission losses, and since lower ultrasonic frequencies with their comparatively long wave lengths would require, with regard to the desired directional effect, very large radiation surfaces and thus would cause difficulties when installing the oscillators in the ship's bottom, a compromise has to be made. For this reason, when using the horizontal echo sounding method in merchant shipping, ultrasonic frequencies between 15 to 50 kilocycles, i.e. wave lengths between 10 and 3 cm, are utilized. Owing to the advantages resulting from the smaller dimensions, the devices designed for operation on higher frequencies intentionally forsake the possibility of longer transmission ranges.

In order to enable scanning the horizon for reflecting objects, the oscillators are fitted to a rotatable, retractable shaft, so that the sound waves radiated by the oscillator as by a search light will sweep all directions of the horizon when the shaft is rotated. In case the equipment is used when the ship is proceeding at speeds exceeding 10 knots, the shaft with the oscillator at the lower end must be surrounded by a streamlined dome in order to avoid eddying. For the excitation of the oscillator the discharge of a condenser or the pulse of a tube-generator must be used.

The oscillator radiating the sonic signal simultaneously serves as a receiver for the reception of the returning echoes. Each direction in which the signals return to the oscillator in form of an echo is indicated on a scale at the operator's position by a repeater showing the angular position of the rotatable shaft. Similar indicators, with corresponding amplifiers as used for depth sounding, including a recorder or a cathode-ray tube, serve to indicate the distance of the reflecting object.

To sum up, a sounder for horizontal echo sounding therefore consists of an oscillator rotating around a vertical axis and retracted from the ship's hull; of a unit indicating the momentary angular position of the oscillator; of a device for the electric excitation of the oscillator; of an amplifier provided for the amplification of the echo signal received by the receiver; and of the optical indicator indicating the distance. It would be suitable to provide an acoustic indicating device in addition to the optical indicator as the ear is well adapted for distinguishing fine differences in the individual echo signals.

Should one confine oneself to observing only one definite sector from a ship, such as the sector in the ship's heading, the fixed installation of several separate oscillators in the ship's bow can be arranged in place of a rotatable oscillator scanning the entire horizon. These individual oscillators will radiate sound waves in different directions within the sector in the ship's heading and will be energized one after the other.

According to another scheme, two oscillators radiating sharply focussed beams in a horizontal direction can be installed in the ship's bottom; one of these oscillators will radiate signals off starboard and the other one off port. If the ship is proceeding straight ahead, the entire area along the two sides of the ship will be gradually observed and a true picture of the reflecting objects at either side of the course will be recorded on the recording paper.

Moreover, group arrangements of fixed oscillators installed in the ship have been proposed for the horizontal echo sounding method. With these arrangements the rotation of the beam around the horizon is effected not mechanically, but by electric circuit arrangements.

The most important difficulty to be overcome in the horizontal echo sounding method, in case the entire area surrounding a ship must be observed for objects which are present, is that, if a sound signal has been radiated in a definite direction, one has to wait until the echo has returned from a definite distance which has been assumed as range limit of transmission. At a distance of 1.5 km the sound requires a period of 2 seconds for travelling through the water. If the direction of the objects would have to be determined with an accuracy of only 10 degrees at least a period of 36 seconds is required for the entire horizon if only one sounding is taken in each sector of 10 degrees. Normally, it will be impossible to restrict oneself to the transmission of only one signal in a definite direction, and several signals will have to be emitted one after the other, thus multiplying the time required. If higher accuracies should have to be obtained as regards the direction, the time would further increase. The ideal procedure, as attained in radar practice for objects in the air due to the extremely high velocity of propagation of the electric waves, cannot be applied to the acoustic procedure in the water without difficulty. Fortunately, the objects floating in the water cannot change their position with the same speed as an airplane in the air. Consequently, for the problem concerned here, there will be more time available. Moreover, in the field of application involved, we need not continuously observe the entire horizon, but generally only the sector in the ship's heading. This limitation of the problem offers the possibility of likewise considering the development of radar-like devices for horizontal echo sounding purposes. Devices of this kind have already been built for short distances.

Two figures illustrate equipment at present available to merchant shipping. The most simple devices (Fig. 4) consist of a shaft with a relatively small oscillator with a radiating surface of approximately 10×20 cm, and with a frequency of approximately 30 kilocycles, which can be lowered from the ship's hull and withdrawn into it by hand. An Echograph used for the measurement of depth serves as an indicator unit (Fig. 5).

Figure 6 shows a larger model: the oscillator is larger and is installed in a streamlined casing. Lowering and withdrawal operations, as well as the rotation of the shaft, are effected by remote control. An echograph or a cathode-ray tube likewise serve as an indicator unit. Regarding further devices, I should like to refer to the lecture which Dr. Ahrens gave during the Bremen Meeting 2 years ago on the horizontal echo sounding method as used in fishing, and which has been published by the Library of Radio Location, Volume 4, 1954.

What is the present situation regarding the application of these methods and use of these devices? Above all they may be used for fishing, whale-catching, wreck detection, and underwater hydrographic purposes.

Since the application of the equipment for vertical echo sounding was introduced into fishing with such considerable success and to such a vast extent, *the use of horizontal echo sounding in fishing* would doubtlessly be of high interest.

It must frankly be admitted that according to the present state of technology the use of the horizontal echo sounding method in trawl fishing holds out no prospects. Fish which are close to the seabed can barely be detected by horizontal echo sounding and cannot be clearly distinguished from raised objects on the seabed, unless there are dense schools of fish which when the seabed is flat will rise to a considerable height above it.

There are much more favourable prospects for horizontal echo sounding when catching fish which appear in schools swimming freely between the surface and the seabed. A school of herring or sardines which are more or less close to the surface can be detected up to average distances of 500 m. by means of echo sounders adopted for horizontal echo sounding. The range of transmission largely depends on the conditions of sound propagation as described in the beginning of this lecture. If there is a school of fish which can be visually recognized near the surface, the horizontal echo sounding equipment offers the possibility of evaluating the extent of the school below the water. If a school of fish has been detected by means of the horizontal echo sounder, the device will indicate nothing of the depth at which the fish are located when the oscillator can only be rotated around a vertical axis. It is therefore necessary to proceed to the place in question and to determine the depth of the school of fish by means of the vertical echo sounder. In addition to weather conditions, the fishing method will decide whether a horizontal sounder can be successfully employed or not. If the schools of fish are fairly large, it will suffice for a few vessels which detect and locate the schools of fish to be equipped with this device, while the main body of fishing vessels apply the conventional vertical method of echo sounding. If the fish appear in smaller schools which are distributed over greater areas, each individual fishing vessel should be suitably equipped with a horizontal echo sounder. According to my knowledge the first method is successfully applied in Norwegian herring-fishing whereas favourable results have been obtained with the second method in herring-fishing in the vicinity of Iceland and in sardine-fishing off Portugal and in other countries.

Fig. 7 shows the example of an echogram of shoals of herrings obtained with the « Periphon » according to Fig. 5.

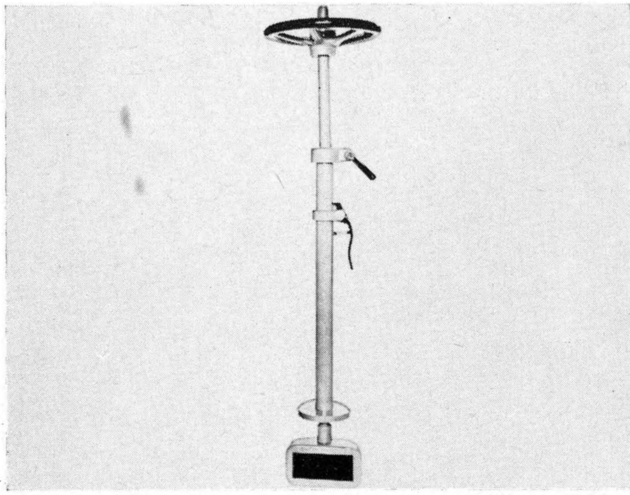

Fig. 4.

Hand-operated magnetostriction transducer for horizontal echo sounding.

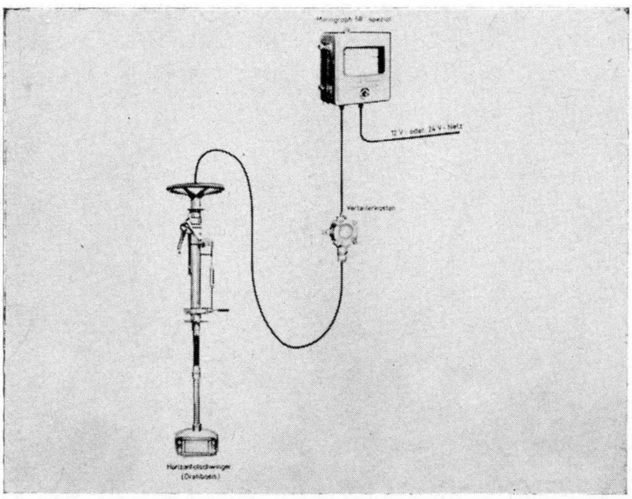

Fig. 5.

Complete hand-operated Periphon equipment.

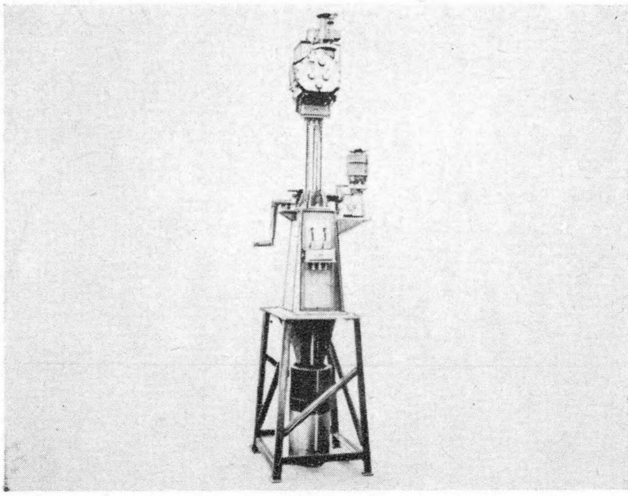

Fig. 6.

Periphon with streamlined casing for whaling ships.
Operation by remote control.

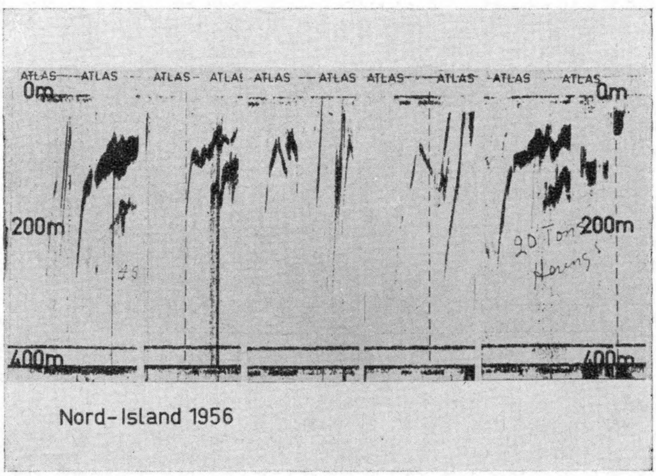

Fig. **7.**

Echogram of shoals of herring obtained by Periphon (Fig. 5).

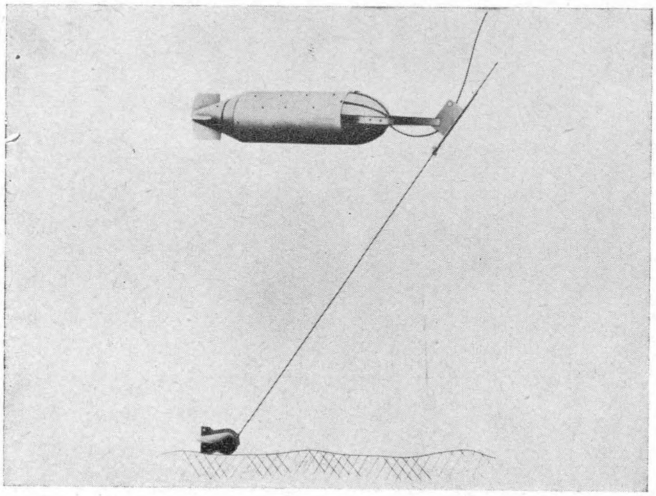

Fig. 8.

Float containing two ultrasonic transducers for wreck location.

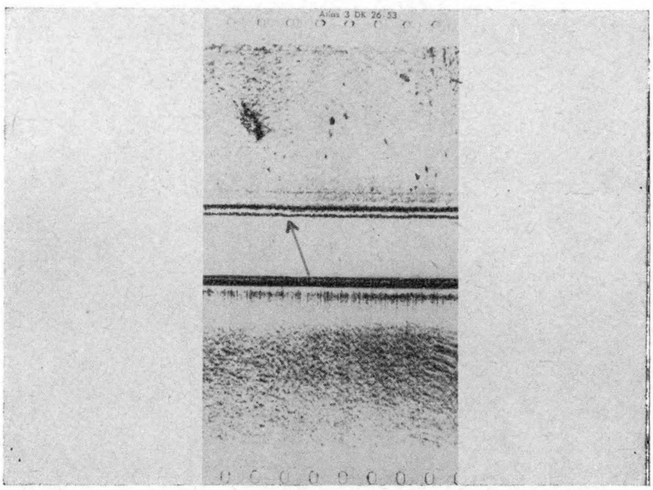

Fig. 9.

Echogram of wreck.

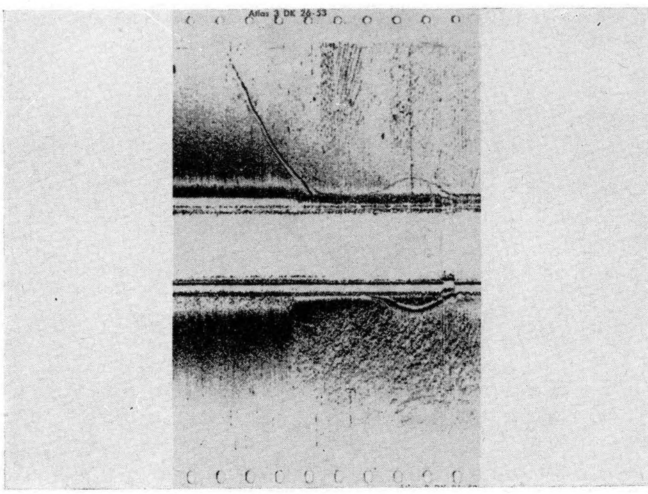

Fig. 10.

Echogram of depression in seabed obtained by device shown in Fig. 8.

There is no doubt that echo sounders for horizontal sounding will be introduced more and more into fishing within the next few years as accessory devices to vertical echo sounding equipment. But as to the range obtainable, optimism should not run too high.

Whaling is a special case of fishing by horizontal sounder. Owing to its dimensions, a whale can be compared with a submarine, and the devices and methods developed by the navies for submarine warfare can be employed in this case. The devices are of course considerably more voluminous and more expensive than the devices suited for ordinary fishing. As a whale after diving can develop considerable speeds during flight, equipment designed for whaling must offer the possibility of recognizing immediately the direction of flight of the whale in order that one may pursue it and be at close range for firing when the whale is about to surface. The Doppler effect considerably facilitates recognition of the whale echo returning from the water or from the surface of the sea. As we know, this is the effect which occurs when the echo, returned from an object with a speed component relative to the ship or the medium, has a frequency other than the echoes which are reflected by objects at rest in the medium. This difference of frequency will considerably facilitate the recognition of whale echoes when listening to the sequence of echoes. On the other hand it should be considered that when chasing whales, the whaler must follow the whale at high speed, and thus a higher noise level will develop. For this reason, only horizontal echo sounders can be used for whaling where the oscillator is surrounded by a stream-lined casing. These devices must be remotely controlled for training, descent and ascent. Moreover, the devices must be designed so that the depth angle can be evaluated and the moment of surfacing of the whale can be recognized. Horizontal echo sounders have proved their efficiency in whaling and are already used by a certain number of whalers.

In locating wrecks, vertical echo sounders have well proved their efficiency. Since only a relatively small area of the seabed below the ship can be covered by vertical echo sounders, much time is required if larger areas must be gradually investigated. In this case there are good prospects for the horizontal echo sounding method, since this method offers the possibility of observing a larger area of the seabed. In order to enable the detection of wrecks, an oscillator with a directional diagram sloping downwards from the ship should be suitably installed. For this purpose one oscillator should point to port and another to starboard, and the bottom echoes should be recorded by means of an echograph. A wreck on the seabed will be represented on the chart paper by a distinct blackening with a white sound-shadow behind it. Objects on the seabed will be most distinctly represented if the sound beams do not strike them from above but pass over the seabed more horizontally, i.e. when the oscillator and the receiver are guided as close as possible above the seabed. A device which was developed by my colleague Dr. Kietz serves this purpose. In a float (Fig. 8), the diving depth of which is adjustable and which is towed behind a ship by means of a cable, two oscillators with sharp horizontal focussing are installed, which take soundings on both sides abaft of the direction of tow. The echoes are recorded by a double recorder. Figures 9 and 10 display two echograms of objects on the seabed which were taken by such a horizontal sounding device.

For hydrographic purposes, horizontal echo sounding can be used in checking guaranteed depths of water in ports, canals, rivers or other waterways. It is for instance possible to install two ultrasonic oscillators at the lower end of a shaft vertically arranged with respect to the hull, aboard a vessel which is proceeding down the middle of the waterway to be surveyed. This shaft will protrude down to the guaranteed depth of water. The oscillators radiate a sharply focussed beam off the ship's heading on either side. In case obstacles extend into the areas which have to be kept free, they will be indicated by the indicator unit and can thus be eliminated.

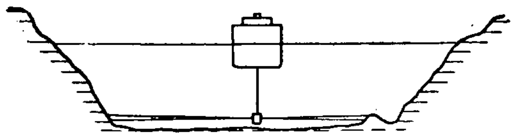

Fig. 11.

Method for checking depth of waterways by horizontal echo sounding.

Such an arrangement may in future enable the recording of level lines of banks if especially sharply focussed sound beams are used in a vertical and horizontal direction and the oscillators are arranged at varying depths along the shaft.

The examples show that the method of horizontal echo sounding offers numerous applications to merchant shipping, fishing, whaling, wreck location and hydrography, and these possibilities may be expected to be used to an ever increasing extent.