USE OF HORIZONTAL SOUNDING FOR WRECK DETECTION

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

I. — GENERAL

Horizontal sounding, which, like radar, was previously used for military purposes only, has been developed considerably and has been adapted in recent years for fishing; it is now mainly used in the detection of fish shoals and whales (1).

It enables fishing craft to investigate much larger areas than with the vertical sounding machine, which can only operate in a perpendicular direction towards the bottom and enables no previous detection. The targets encountered by horizontal detection are not exclusively fish shoals : all reflecting objects within the zone of horizontal operation can of course be detected, as well as such surface targets as ships and buoys, or bottom targets such as irregularities of the sea-bed, tips of rocks, coral reefs, etc. Horizontal sounding offers particular advantages in the detection of wrecks, which constitute a special type of target resting on the sea-bottom, and an account will be given here of various experiments carried out and results so far obtained.

One of the main characteristics of wreck detection is that discovery becomes doubly important in the case of relatively shallow water, i.e. down to a depth of 40 m. In the first place, the wreck may be an important danger to navigation if it lies in shallow water, and should thus be shown on the charts ; secondly, if the wreck is a valuable one, an attempt will be made to salvage it under optimum conditions. Salvage will be possible, meaning that the expense involved will be acceptable, only in relatively shallow depths. Thus it will be seen that in practice wreck research is preferably carried out in shallow water.

The horizontal propagation of sound waves is even more dependent than vertical propagation on special conditions, i.e. on the geometry and shape of the mass of water as well as on the particular properties of the water. It may be entirely different under water and on the surface, and may also largely depend on temperature changes within the water mass. The geometry of the water mass is determined by the length and depth of the water and by the shape of the bottom. At a range of 2,000 m from the sounding device and a depth of 20 to 30 m, as in the case of vast areas in the Baltic, the vertical dimension of the water mass represents a mere 1 to 1.5 % of the horizontal dimension, with the result that wave propagation occurs in an extremely flat area, bounded above by the water surface and below by the sea bottom, as shown in Figure 1. The horizontal angle of the beam (Fig. 1) has an aperture of 18°. The three targets illustrated in the figure, including a ship, a shoal of fish and a wreck, appear to be very small. They are nevertheless represented more or less according to scale, and they also appear to be relatively small with regard to the beam of sound waves which must detect them at that distance. It will readily be seen from the figure that it is difficult at first to

(1) E. AHRENS, Horizontallotung im Fischfang, *Archiv für Fischereiwissenschaft* 6, 1955, Heft 3/4 S. 230.

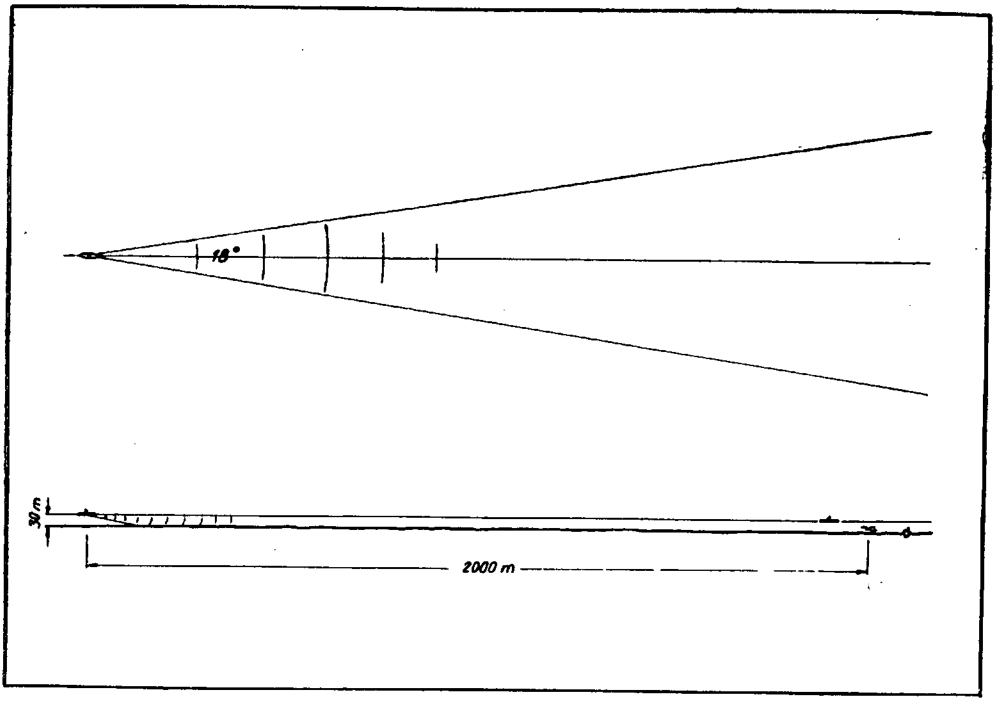

Fig. 1.
Horizontal detection in shallow water 2,000 m/30m.

determine from the point of transmission of the sound waves whether a surface target (ship), intermediate target (fish), or bottom target (wreck) is involved, since the angular difference between a bottom target and surface target at a depth of 30 m at 2,000 m range is less than 1°. We shall see later on how they may be distinguished.

The precise delimiting of the water mass is an advantage. The energy of the sound waves is concentrated, so that, apart from attenuation, the strength of the sound waves does not decrease according to the square of the distance, but linearly according to the distance only. Moreover, since the delimiting surfaces, i.e. the bottom and surface, are neither absolutely even nor perfectly reflective, losses occur due to scatter and reflection, which give rise to a greater decrease in strength according to distance than that prescribed by the law of direct proportion. Under conditions of ideal reflection and absolute homogeneity of water, it may be assumed that upon issuing from the transmitter, the waves would be uniformly propagated through the homogeneous mass and would reach all surface, intermediate, and bottom targets, causing them to appear. This scarcely ever occurs, however, as, regardless of the roughness and absorption of both delimiting surfaces, the water is rarely homogenous. This lack of homogeneity is mainly due to differences in temperature according to the depth, which results in variation of the speed of sound. The speed of sound, c (m/s) is dependent on the temperature t (°C), salinity s (percentage in relation to weight) and depth d (m), whence the following formula :

$$c = 1410 + 4.21\, t - 0.037\, t^2 + 11\, s + 0.018\, d$$

The speed of sound varies with depth, resulting in curvature of the sound-wave beam. Even though there may be no abrupt change in the temperature of a layer, the constant varying of temperature with depth is enough to cause deviation of the beam. If we take the simplest case — to which we may also reduce the more complex cases — where the speed of sound c increases or decreases in the same ratio as depth d, $c = c_0 + ad$, we may compute the path followed by the beam. The result of this computation is simple and is shown in Figure 2. We assume that the path of the beam is a circle whose radius is dependent on the speed of sound c_0 at the starting-point $d = 0$, on the variation a of the speed of sound per metre, on the depth d_0 of the transmitter, and on the angle formed with the horizontal, along the axis of which the beam is radiated.

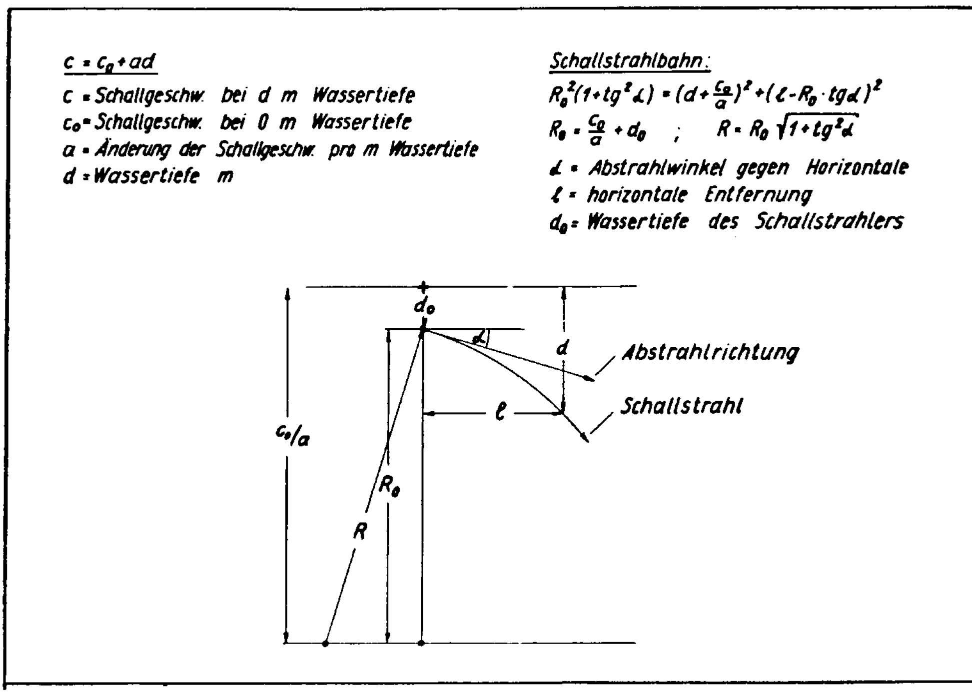

Fig. 2.

Bending of sound waves for a constant gradient of speed of sound

c : Speed of sound for depth of d m.
c_0 : Speed of sound for depth of 0 m.
a : Variation in speed of sound per m of depth.
d : Depth of water.

Sound wave path

α : Angle of incidence with horizontal.
l : Horizontal distance.
d_0 : Depth of transmitter.

Figure 2 shows both the equation of this curve and a simple construction method for obtaining the path of the beam: at distance $\frac{c_0}{a}$ we plot a parallel line on the water surface, and obtain the radius and centre of the path travelled at the point of intersection of this line with the line perpendicular to the direction of the incident beam from the transmitter located at depth d . According to the sign of a, the surface parallel is located either below or above this line, so that in one of the cases the beam curves downwards, and in the other upwards. If the beam is rotated through angle $\alpha = 0$, the radius will be reduced to $R = \frac{c_o}{a} + d_o$ and the centre of the circle will be located perpendicularly above or below the transmitter. If, as often occurs in practice, the relationship between the speed of sound and the depth of the water is a complex one, we may divide the line into approximate fractions, and compute the beam in the manner indicated for each section, ending by ascertaining the entire path of the waves. The variation of the speed of sound with depth, which is especially marked in the vicinity of the surface down to about 50m, may be positive or negative. The highest values of this variation, discovered during summer in the Baltic, amount to about 1 metre per mile.

An interesting case arises in the event of a gradient which changes sign or when unfavourable conditions of propagation occur, as during bad weather. As an illustration, sound waves measured in the Baltic are shown in Figure 3. In the upper

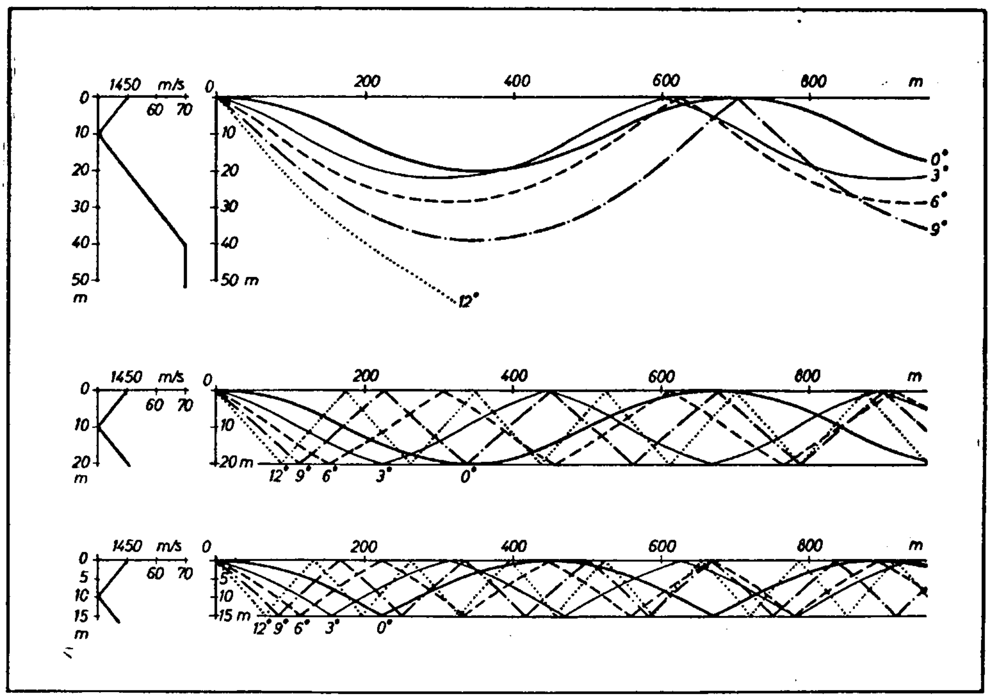

Fig. 3.
Propagation of waves in shallow water for a change in sign of gradient of speed of sound.

diagram, the waves bend in a downward direction ($d = 0$ to 10 m, gradient $a = -1 \frac{\text{m/s}}{\text{m}}$); in the centre diagram they bend upwards ($d = 10$ to 40 m., $a = +1 \frac{\text{m/s}}{\text{m}}$); in the lower one they are propagated in a straight line ($d > 40$ m, $a = 0$), until they reach this zone. The waves appear to bend periodically upwards and downwards, with the result that shadow areas are formed within which the sound waves are incapable of detecting and consequently reflecting surface targets. If the diffused reflection of the surface is observed in a horizontal sounding recorder, which normally results in a uniform gray blur on the chart-paper upon sufficient amplification, it will be seen that the gray cast is interrupted periodically, with consequent loss of the targets near the surface.

In the centre diagram of Figure 3, the same gradients have been taken, but for a depth of 20 m, and in the lower diagram, for 15 m. We know that in the case of this amount of beam curvature due to constant reflection of the bottom and the surface, we may expect the waves to follow a more uniform path through the water mass than in greater depths. Reflection, particularly from the bottom, however, results in considerable loss of strength as the reflection coefficient amounts to only 0.1-0.01, so that even over a short horizontal distance, we must expect considerable attenuation and therefore a shorter range.

In addition to the phenomena due to thermal effects, a band is occasionally observed, during shallow-water horizontal sounding, like the one shown in the diagram of Figure 4. The transducer is placed in an approximately horizontal direction. If amplification is sufficient, the diffuse echoes of the bottom appear on the paper as a gray blur. Owing to certain weather conditions, the grayness may occasionally be interrupted over short distances by white zones, resulting in the diagram's being composed of various bands. Our initial assumption that the bands correspond to the bending of the beam according to the temperature is no longer valid here.

The explanation for the event must be sought in an effect of interference. The sound waves propagated by the transducer obliquely towards the bottom interfere at certain defined distances with the waves reflected by the water surface, so that the resultant strength is destroyed at this point and no echo is received. This may be explained by the fact that the difference in the path of the direct waves and of the reflected waves is a multiple of λ. Phase slipping due to reflection must hence be accounted for, and the following relationship as regards the calculation of the distance of zones of interference is obtained :

$$L_0 = \frac{2\,D\,.\,d_0}{n\,\lambda}$$

L_0 = Distance of interference zones.

D = Depth of water.

d_0 = Depth of transducer beneath water surface.

$n\,\lambda$ = Multiple of λ.

Using the data of the centre section of Figure 4 as a basis, we get a depth of water $D = 14$ m, a depth above the transducer $d_0 = 1$ m, and a wavelength of 0.05 m (30 kHz) in conformity with the values shown on the echogram. The values obtained for $n = 2$ to 7 are marked on the centre section of the figure by dashes. The closely approximate measured values show that the bands may be interpreted as due to interference.

Following these remarks of a general nature concerning certain special conditions that may arise in shallow-water horizontal sounding, we shall now describe the technical characteristics of the horizontal sounding devices used during our experiments, and discuss some of the practical results of wreck location.

II. — The Lodar Device

The horizontal sounding instrument used during wreck-locating experiments was an Elac-Lodar device, which combines horizontal with vertical sounding. The equipment includes a hoist for the horizontal transducer, a high-frequency generator (Fig. 5), a control panel, a recorder (Fig. 6), and an accessory instrument for the sonic recording of the echo. The horizontal transducer, used both as a transmitter and receiver, is fixed below the hoist, placed on the ship's bottom. During experiments, the two oscillators were of identical size and characteristics, and were powered by generators at the same high frequency.

The width of the beam (gradient of 3 db of receiving voltage with reference to the beam axis) is only about 18° × 24° upon reception, and for transmission and reception combined about 12° × 18°. Absolute calibration based on the reciprocity method supplies a receiver sensitivity of $60 \frac{\mu V}{\mu b}$ and a transmission constant of $6.0 \times 10^4 \frac{\mu b . m}{A}$. Used vertically, the instrument enables depths of the order of 4,000 m to be sounded, as shown by tests in the Bay of Biscay. The hoist is remote-controlled by an electric device which starts and stops the hoist and rotates the oscillator. All the controls for starting up the unit, rotating the oscillator, operation and stopping, as well as for change of range, are located on the control panel and the recorder, which are both on the bridge. Starting and stopping, as well as the angle of rotation, are signalled on the control panel by means of lights.

Bottom or fish echoes are recorded on paper 200 mm wide in the recorder. The speed of the paper can be adjusted by hand and is marked from time to time on the paper itself. When proceeding from vertical to horizontal sounding, the length of the pulses is increased automatically. The echoes may simultaneously be amplified by a loud-speaker, which enables the sonic receiving frequency to be reduced to about 1 kHz.

The echograms reproduced in the following figures were recorded for ranges between :

0 — 200 m.
0 — 500 m.
500 — 1,000 m.
0 — 1,000 m.
1,000 — 2,000 m.

The oscillator may be rotated automatically according to a predetermined pattern, in which the beam shifts from starboard to port, thus sweeping the entire area of horizontal exploration. In following a shoal of fish, the beam should be directed by hand.

III. — Results

An attempt was made with this equipment to locate a series of wrecks in the Channel, Œresund and Kattegat. An account of these operations will be given below. Danish waters are well suited for this type of experiment, as they contain a large number of wrecks.

The left-hand side of Figure 7 shows a typical instance of horizontal sounding : the echo obtained from two cutters, i.e. two surface targets, detected at a distance of 1,500 or 2,000 m. Ranges extend from 1,000 to 2,000 m, and from 0 to 1,000 m. Both cutters were followed as soon as they were detected. The

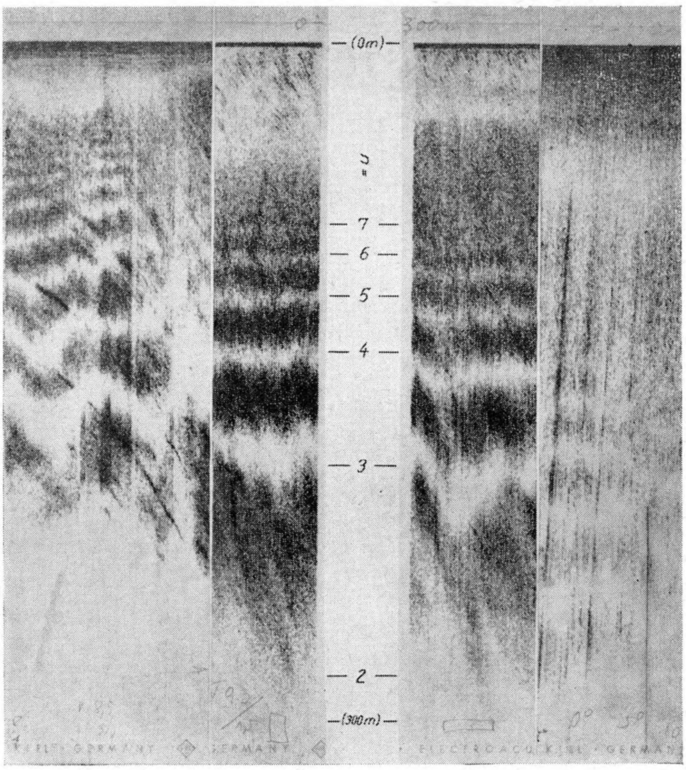

Fig. 4.

Effect of interference on wave propagation in shallow water. Range : 0-300 m.

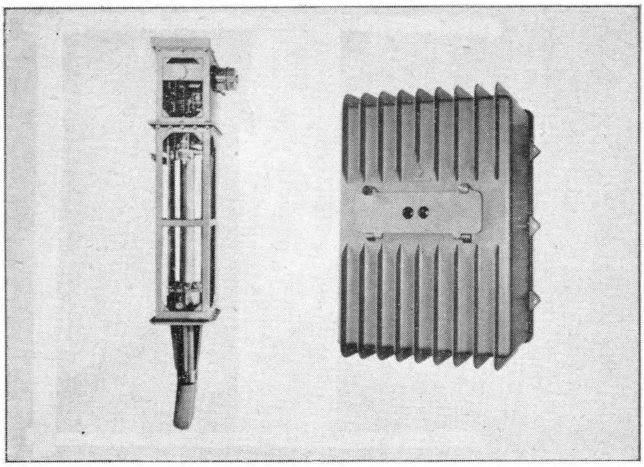

Fig. 5.
Hoist and high-frequency generator of Lodar equipment.

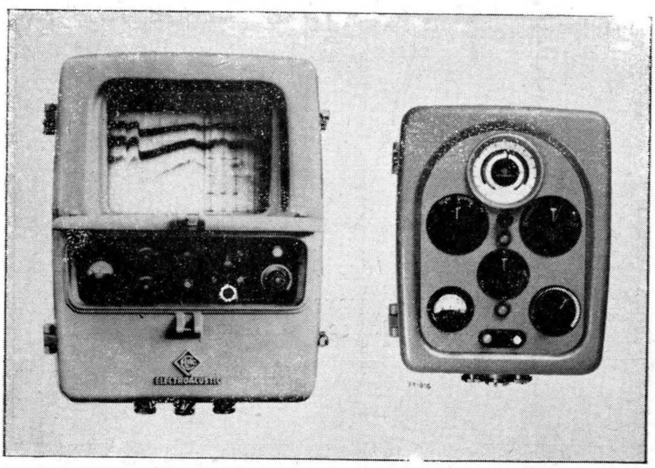

Fig. 6.
Recorder and control panel of Lodar equipment.

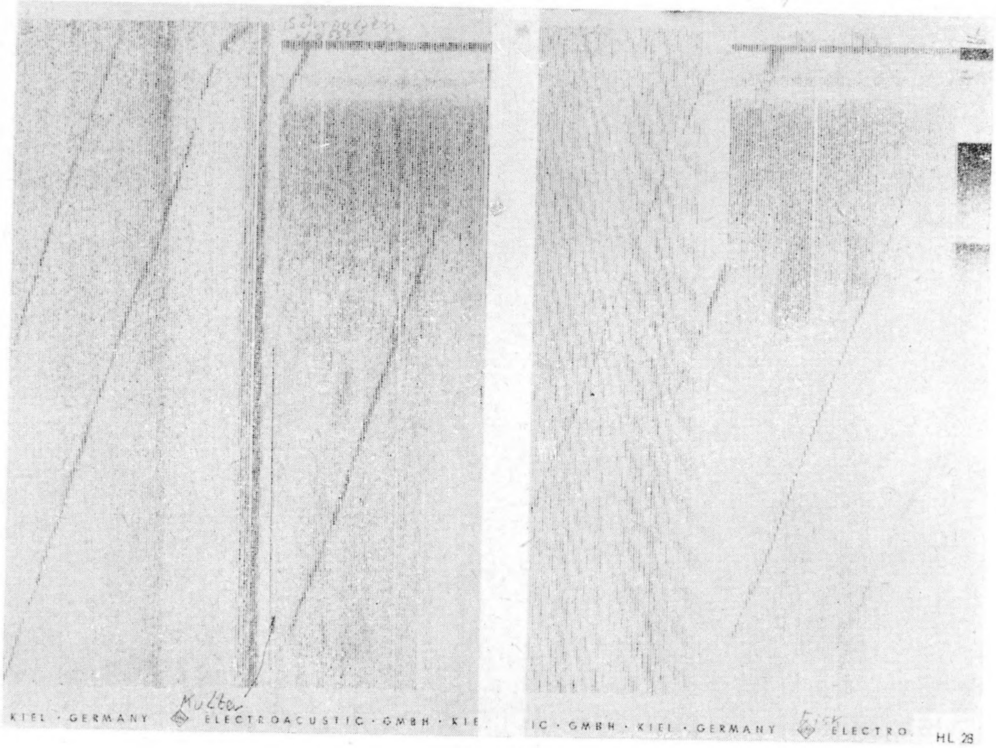

Fig. 7.
Horizontal detection of surface targets : 2 cutters at 2,000 and 1,700 m.

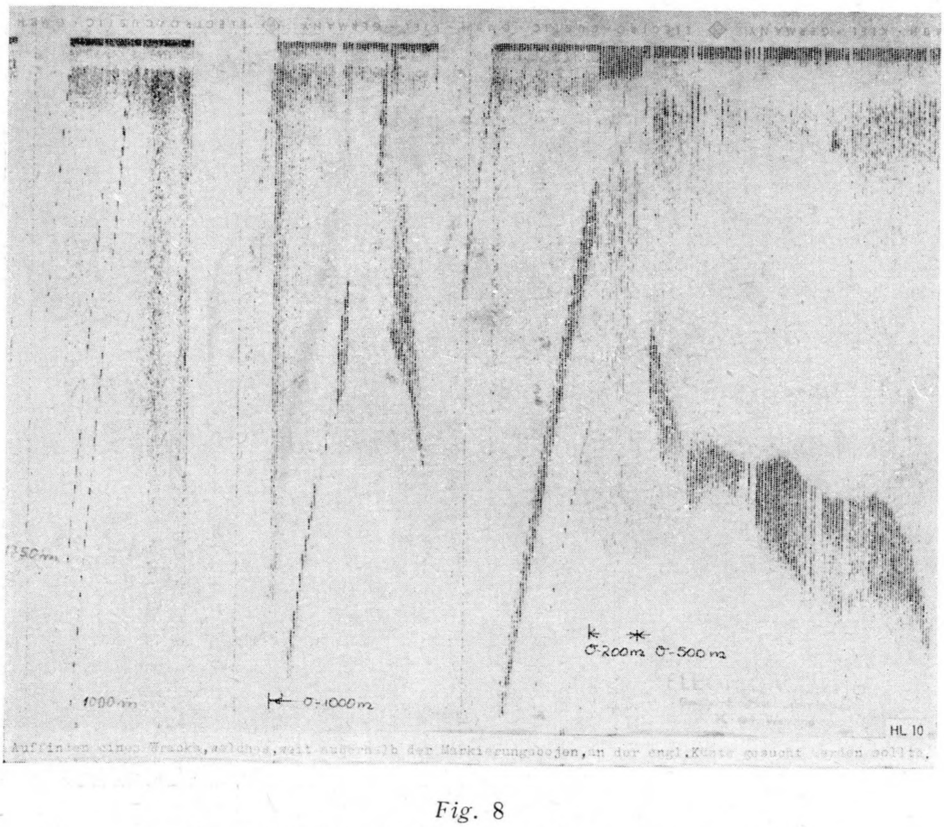

Fig. 8
Location in English Channel of wreck near two buoys out of position 1,000/500 m.

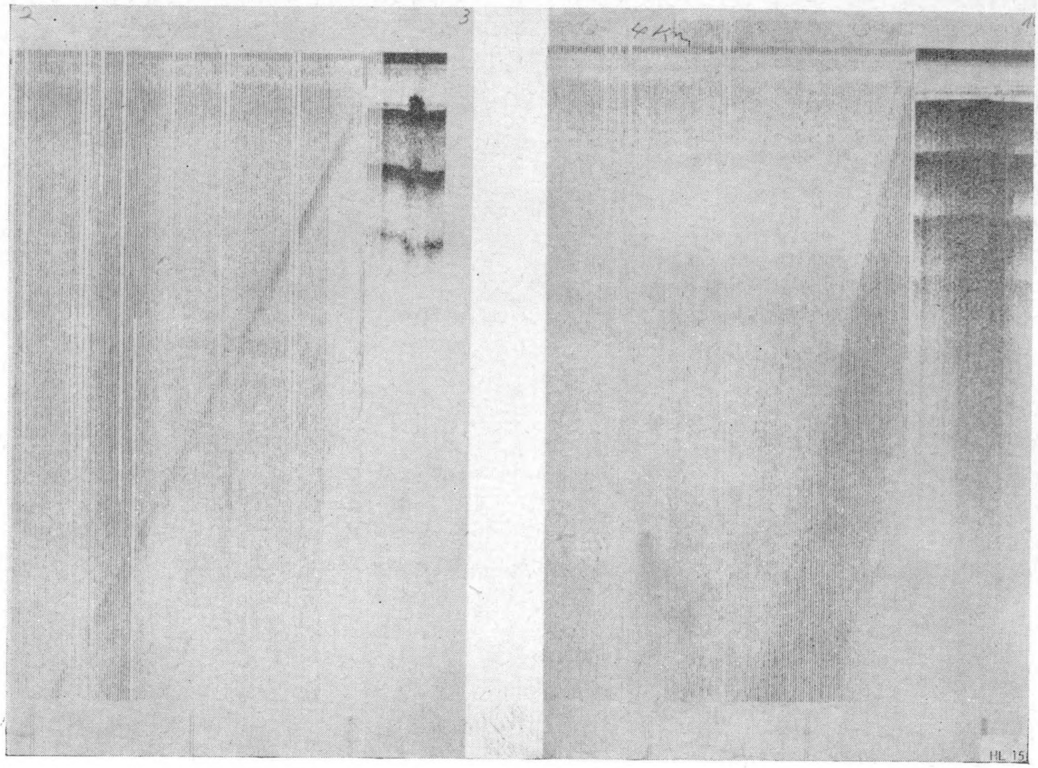

Fig. 9.
Horizontal sounding recording of wreck (left) and bottom swell (right) in Sund
H : 0-1,000 m. V : 0-200 m.

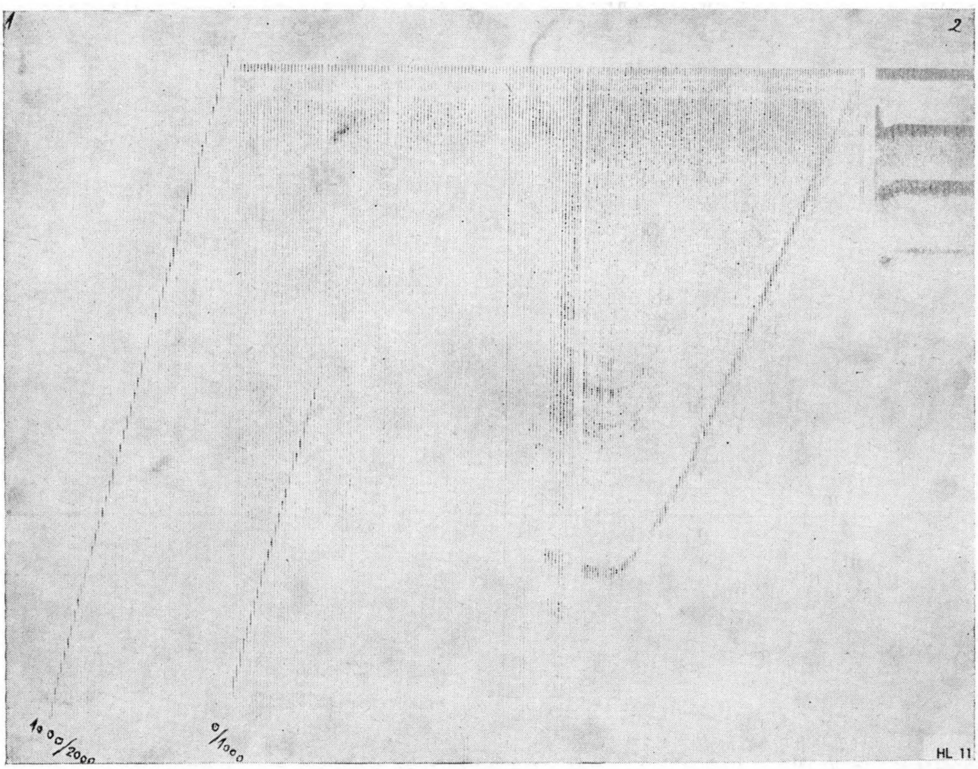

Fig. 10.
Location of wreck of old sailing ship 2,000/1,000/200 m.
Sonic detection at 4,000 m.

horizontal distance corresponds at a 0-1,000-m range to the distance measured perpendicularly on the echogram from the zero shown at the top of the figure. For the 1,000-2,000-m range, the zero of the initial pulse is of course lacking. If the target is approached at a constant speed, the echo trace obtained is a straight line, since the distance from the target during a certain fixed period invariably decreases by the same amount. The inclination of the line depends on the speed of the ship, the range, and the paper speed.

A similar figure is obtained in the recording of another cutter (Fig. 7, right-hand side), which was detected at 1,700 m. In order to ensure that a cutter, and not some other target such as a shoal of fish, was involved, the range was changed (0 to 200 m) so that the target could be reached by vertical sounding. As expected, there were no other intermediate targets, as shown on the right in Figure 7. The spots appearing on the left of the right-hand figure result from the direct reception of noise from the propeller of one of the cutters, which in the present case is nearly synchronized with the recording mechanism.

The echogram in Figure 8 was obtained during the spring of 1956 while locating a wreck in the Channel, which normally should have lain near two marker buoys, but which had shifted considerably in relation to the latter. Detection of the buoys resulted initially in a relatively weak echo at a distance of 1,750 m (left-hand side of Fig. 8, range 1,000 to 2,000 m). After switching to the 0 — 1,000 m range, both buoys were clearly received 250 m apart, but no echo was detected from the wreck itself.

Search for the wreck then proceeded by operating the hoist. A weak echo was first received in the 1,000-2,000- m range, at about 1,200 m, followed by a stronger echo in the 0-1,000-m range at about 1,000 m (Fig. 8, centre), the distance decreasing at first, then increasing according to the turns made by the ship. At the next run, the wreck was accurately located at 1,350 m (right-hand side of the figure) on the extreme right in the 0-500-m range, with the ship drifting slowly. The operations took about 30 minutes.

The left side of Figure 9 shows the outline of a wreck in the Sund, about 50 km south of Copenhagen, located at 1,000-m range, and which, following the use of vertical sounding (0-200-m range), was identified as a typical wreck bottom target. The right-hand side of the figure, however, is the echo trace of a rise and fall of the bottom, which shows a marked difference from that of a fish or ship target. The rise is bounded by a small crest, followed by a fall, after which the horizontal echo ceases.

After further research in the Sund (Fig. 10), a strong echo was received at 4,000 m, in a place where no fish shoals were expected and no wreck appeared on the chart. This unknown target was recorded at 2,000 m and approached. Following a maneuver of the ship, the echo disappeared at 500 m. It was detected again at 700 m, and a new run was made towards it. Use of vertical sounding, which unfortunately occurred rather too late, showed that a wreck was definitely involved. Although the captain doubted the existence of a wreck at this particular spot, a diver was sent down who eventually returned with a ship's bell as trophy; he had found a wooden ship over 200 years old, covered with shells and still carrying its rigging.

Figure 11 shows an echogram of the wreck of the « Hamm », a ship of around 1,000 tons, sunk in the Kattegat during World War I, and shown on the chart. The relatively wide echo trace, corresponding to a target size of about

100 m, indicates that the wreck was detected lengthwise. The echogram was recorded from 2,000 m away until the ship passed over it, when recourse was had to vertical sounding. During the second run (Fig. 11, right), a vertical picture was obtained of the typical appearance of a wreck, with fish swimming over and near the wreck, a frequent occurrence, as fishing confirms. It is clear that eddies around the wreck attract the fish. This may also be observed in the figures following.

Figure 12 shows the difference between the echo from a shoal of fish and that from a wreck; both targets were recorded in the Kattegat at a 2,000-m range. In such cases sonic detection occurs much sooner. The fish shoal is extremely concentrated and gives a sharply defined echo, whereas the echo from the wreck is broader. Only a run overhead enables an accurate identification to be obtained. This wreck is also surrounded by fish. The hake caught were 60 cm long. Vertical sounding of the wreck supplies a double echo, another characteristic feature. The wreck always lies in a hollow of the sea-bed, which is evidently shaped by currents through the years.

No general rules can be established with regard to the echo width obtained from wrecks and fish when horizontal sounding is used, with the result that at long range the targets cannot be clearly distinguished on the basis of echo shape. Only by running overhead and taking vertical soundings can the type of echo be determined. In this case, the echo from the wreck is of course made broader by the fish shoal. The shape of the horizontal echo of the fish shoal can vary according to the extent and form of the shoal, as shown in subsequent figures. The echo from the wreck may likewise be more or less sharp, according to whether it is detected lengthwise or breadthwise.

Figures 13 and 14 show a few instances of echoes received from fish shoals in Danish waters. The range of detection is between 1,000 and 2,000 metres. The echo for this type of shoal is always relatively well-defined. The depth of water is about 15 m. The shoals usually remain near the surface. On the left-hand side of Figure 14, the sharp horizontal echo of a buoy recorded at 800 m can be seen.

Figure 15 shows another wreck echo, detected sonically from 2,500 m away, and recorded at 2,000 m. This wreck is likewise surrounded by fish. During the first overhead run, one side of the wreck was missed; during the second run, only the fish were detected; and during the third, directly overhead, a vertical recording of both the wreck and fish shoal were obtained. The irregularities of the bottom echo between the two vertical echoes are due to a breakdown in the current and are actually non-existent.

Figure 16 shows another vertical echo-sounding diagram of a charted wreck of medium size in the Sund, where the target was not entirely detected during the run overhead. A single irregularity of the bottom echo may be seen in the vertical diagram, originating from the wreck lying nearby.

Figure 17 is an echogram of the *Oranienburg* (3,000 tons), which was sunk in the Kattegat during the First World War. Sonic detection occurred at 5,000 m, and the diagram was recorded at 2,000 m. The various overhead runs show the typical bottom depression and the surrounding shoal of fish. The right-hand section of the diagram clearly shows the disturbance caused among the fish by the noise of the ship, with their consequent movement upwards.

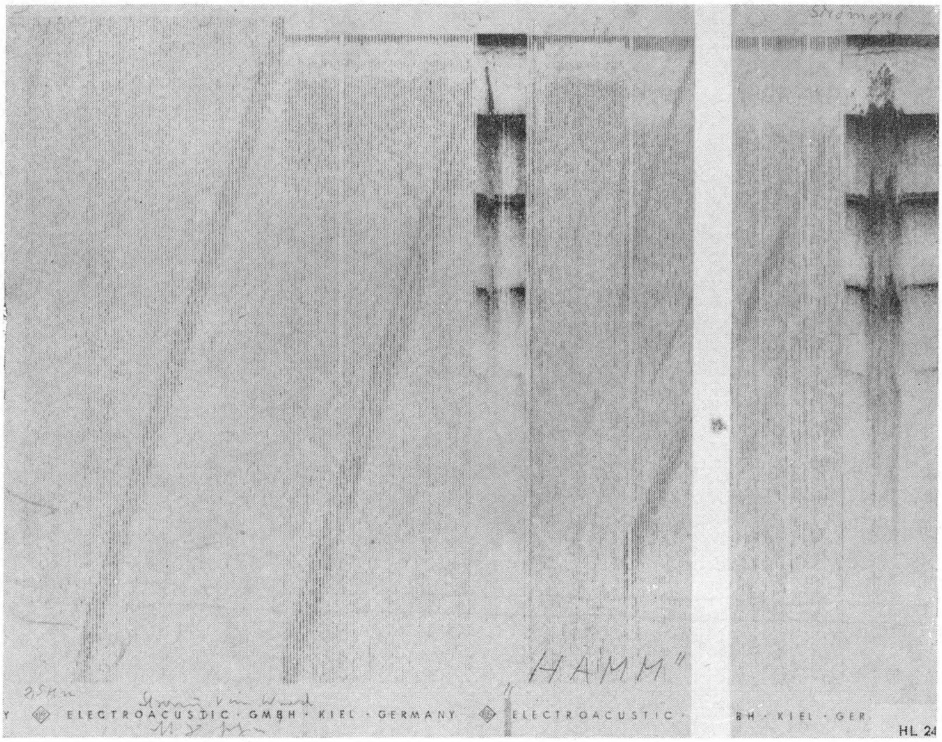

Fig. 11.
Wreck of *Hamm* (World War I), 1,000 t, with fish shoal

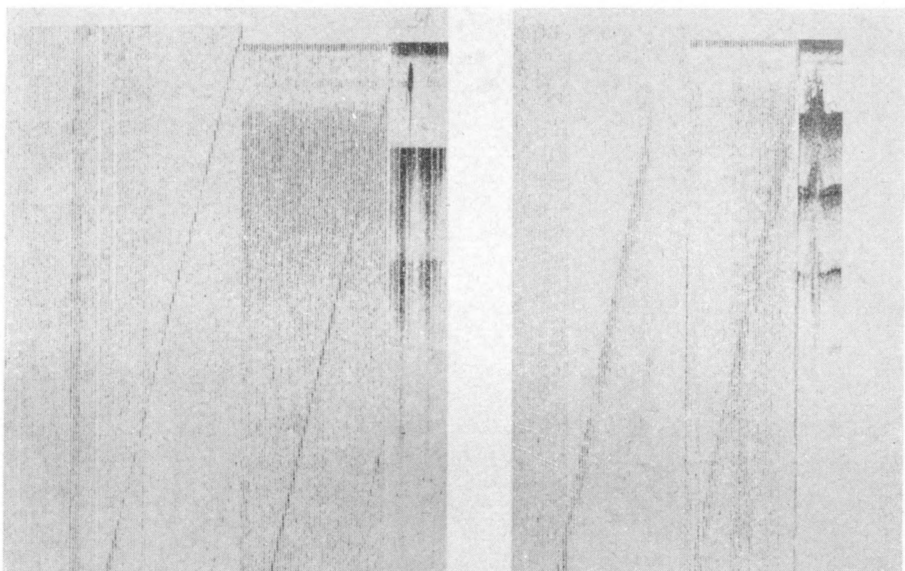

Fig. 12.
Location of fish and wreck in Kattegat
H : 1,000-2,000/0-1,000 m. V : 0-200 m.

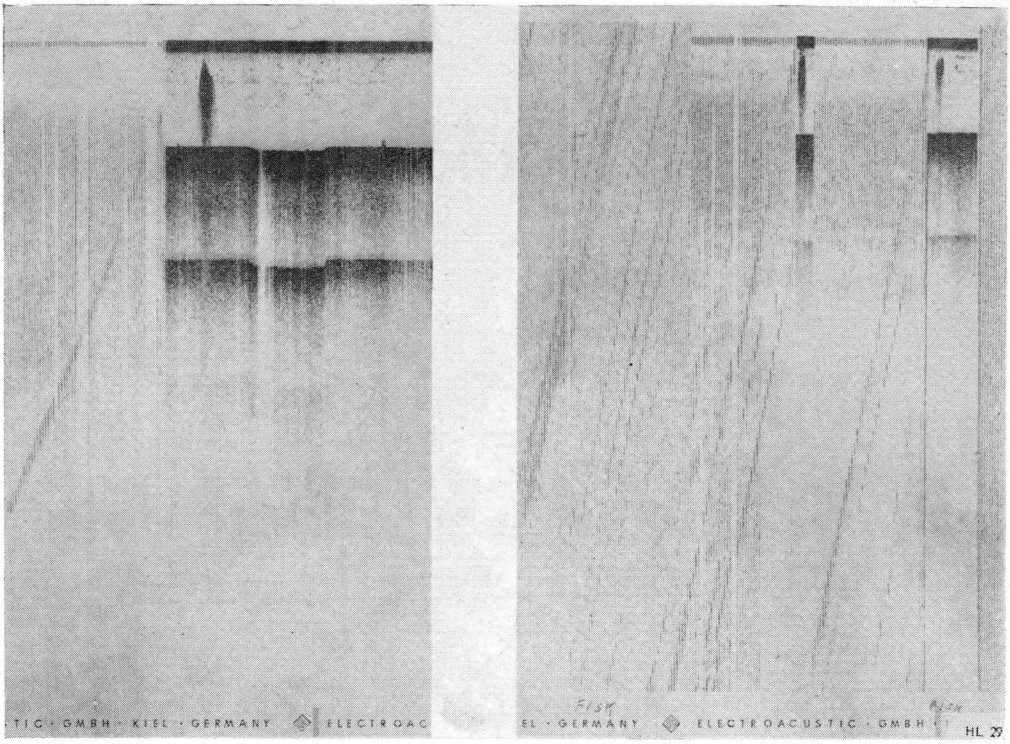

Fig. 13.
Fish shoals near Skagen.

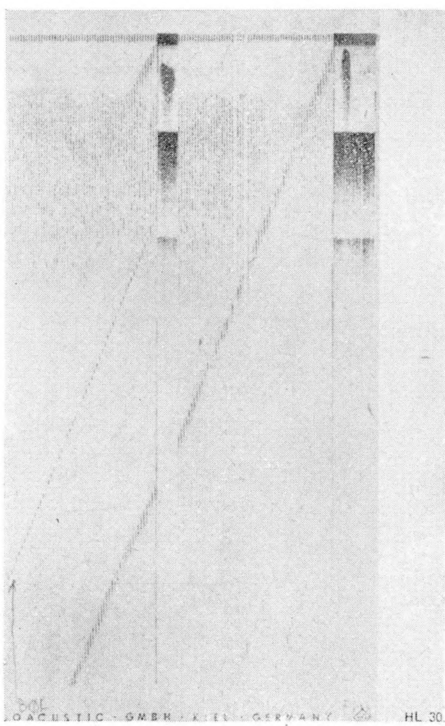

Fig. 14
Fish shoals and buoys 1,000 m.

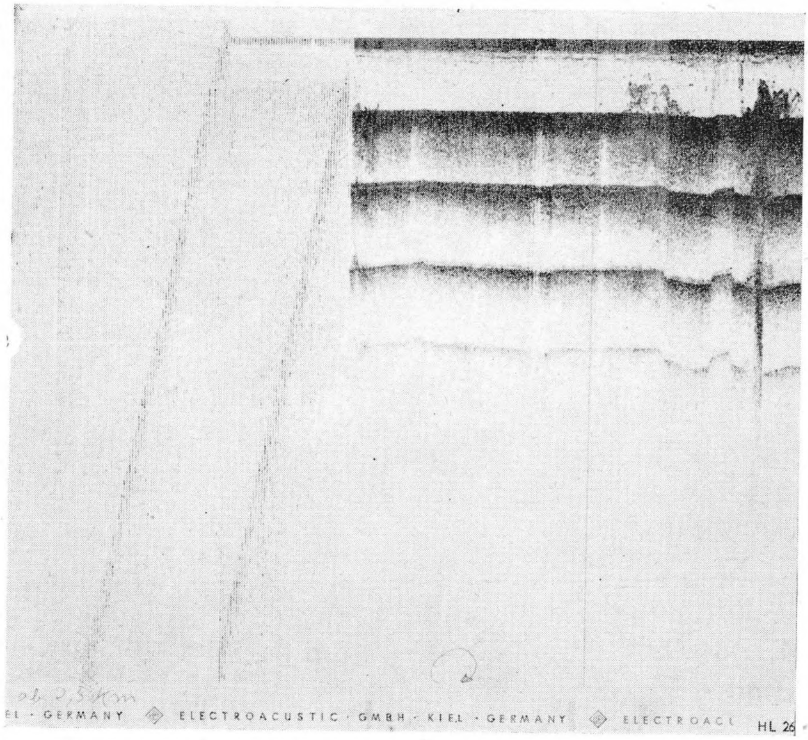

Fig. 15.
Wreck with fish shoal in Kattegat
2,000/1,000/200 m.

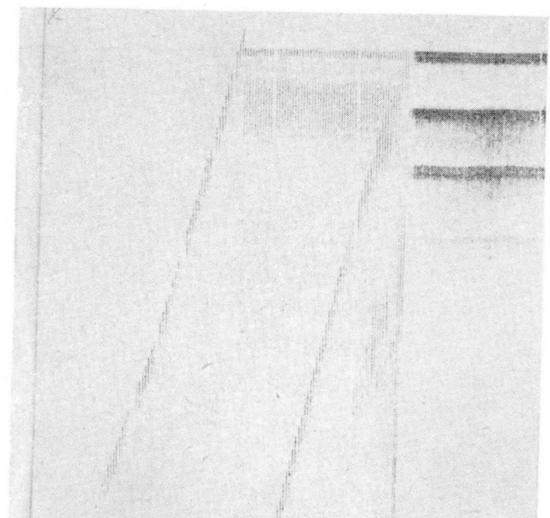

Fig. 16.
Horizontal location of wreck in Sund
H : 2,000/1,000 m.   V : 200 m.

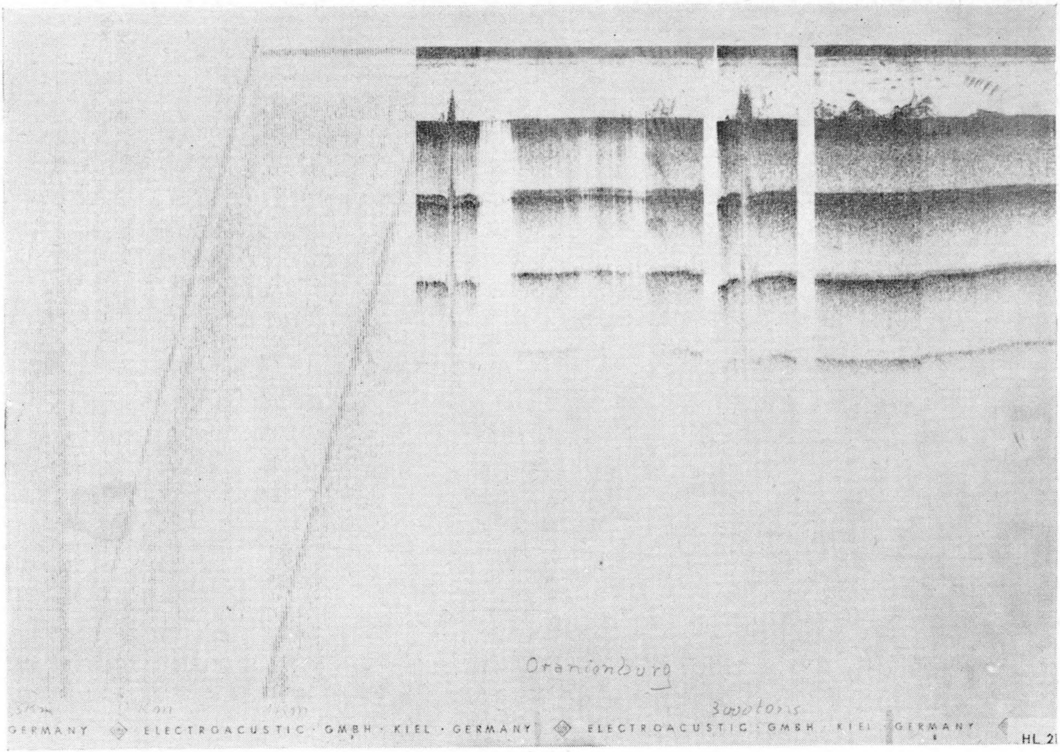
Oranienburg
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Fig. 17.

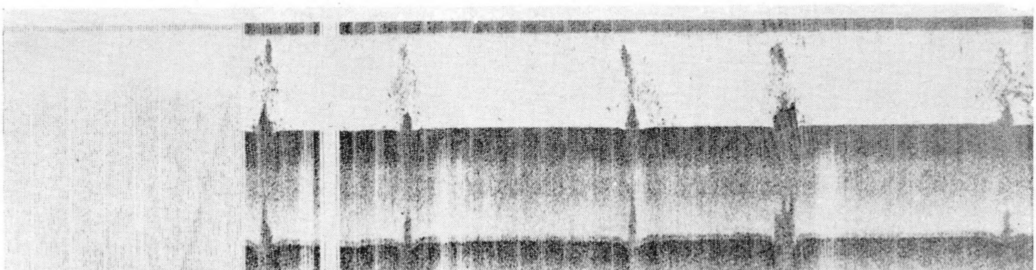
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Fig. 18.

The same characteristic picture occurs in Figure 18, which represents a record of the horizontal detection of an additional charted wreck in the Kattegat. Five direct runs overhead were made during vertical sounding operations. The usual fish shoal is particularly striking here, in which even the loose formation of the fish can be seen. The hollow in which the wreck is located, especially in the third echo, can also clearly be seen.

IV. — Summary

Special conditions encountered in wreck detection by means of horizontal sounding have been discussed. Such conditions are mainly characterized by the fact that the detection of wrecks is best effected in shallow water. A horizontal sounding device, the Lodar apparatus of Elac manufacture, has been described, and data have been given regarding wreck detection by means of this equipment. Results show that it is possible to use horizontal sounding with success in wreck detection.