A MORE ACCURATE HYDROGRAPHIC SURVEY

BY DIRECT MEASUREMENT OF SOUND VELOCITY IN THE SEA

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INTRODUCTION

The safe navigation of a ship depends primarily on the reliability of the charts used. A chart should, among other things, give a most accurate picture of the sea bed configuration, so that any steep or smooth rising or sloping of the sea bed, i.e., the resulting shoals, can be identified without difficulty. It is the task of hydrographic surveying to conduct the soundings required. The objective of this paper is to discuss the problems of accurate sounding and to report on a new method which permits obtaining accurate values.

There are different methods of determining ocean depths: direct and indirect ones. I include among the direct methods all those in the course of which a weight, a sounding lead, secured to a wire or a line is lowered from the vessel to the bottom of the sea. From the respective marks on these lines or the metering wheels on the drums of the line winches the depth can be established. Hand leads and sounding machines belong to this category. The echo sounder belongs to the category of indirect methods. With the echo sounder, the time required for the sound to travel from the ship to the sea bed and back to the ship is registered and indicated as depth.

Nowadays, the direct method is not likely to be used any longer because it takes too much time and, after all, does not yield accurate values. Let me just mention the term of line angle. So, the echo sounder has for many years now virtually been the only method used. Compared with other methods, its great advantage is that soundings can be taken while the ship is under way.

A modern echo sounder works by means of ultra sound. The sequence of soundings is so fast that continuous lines appear on the echogram thus showing the profile of the sea bed covered by the ship. But even with the most modern echo sounders it is not possible to register the accurate absolute depth for, from the technical point of view, an echo sounder is a short-time probe, a short-time chronometer with plotter.

The mathematic function according to which an echo sounder works can be seen from the following explanation:

The path of the stylus on the paper tape—the echogram—has to be correlated to the path of the sound between the ship and the bottom of the sea. For better understanding let me add that all echo sounders work by means of short sound pulses.

THE ECHO SOUNDER

The method of measuring depths by means of the echo sounder comprises two processes: the process on the paper tape: Distance zero-line —depth-line according to the formula:

$$l = V \cdot t \qquad (1)$$

where:

l = length between pulse emission (zero-line) and pulse reception (depth-line) on the sounding tape;
V = velocity of the stylus;
t = travel time of the stylus;

and the process in the water:

$$A = \frac{v \cdot t}{2} \qquad (2)$$

where:

A = distance to the bottom of the sea;
v = sound velocity in the water;
t = travel time of the sound (vessel → sea bed → vessel).

Both t are equal, for the distance to the sea bed or the depth under the ship should be a function of the indications of the echo sounder.

By inserting t from (2) $t = 2A/v$ in (1) $l = V \cdot t$, the formula for the echo sounder

$$l = \frac{A \cdot 2V}{v}$$

is obtained in a general form

$$l = \eta f(A) .$$

η includes both the velocity of the stylus and of sound pulses in the water. The sound velocity in sea water is a natural phenomenon and is dependent on the temperature, the salinity, and the density of seawater. It cannot be changed, it can only be measured.

In order to obtain an exact indication of the depth on the sounding tape, the stylus velocity has to be adapted in such a way that the correct depths are registered on the echogram. These echo sounder conditions are shown in fig. 1.

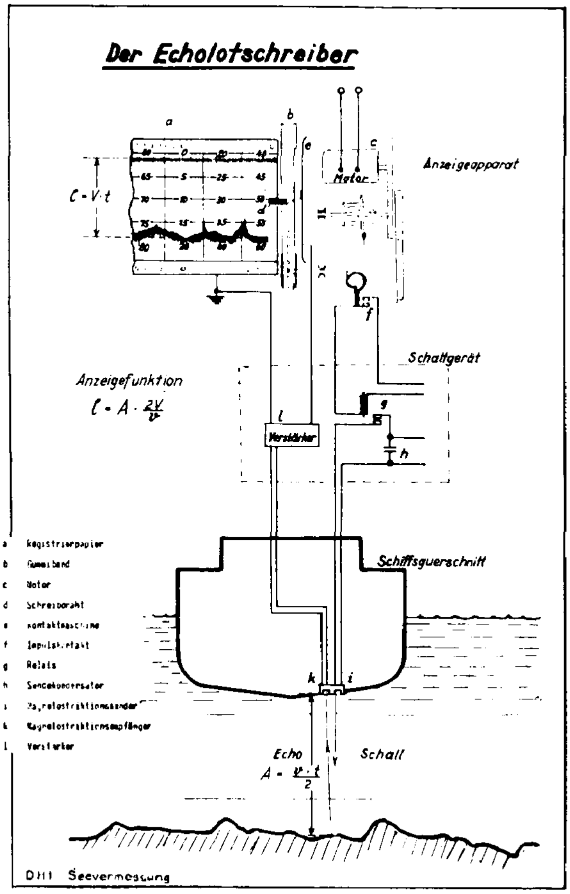

FIG. 1. — Principle of the echo sounder.

THE METHODS OF CORRECTING DEPTH DATA

The evaluation of echograms can be made by various methods: One of these is to adjust the echo sounder to the sound velocity of 1500 m/s, which is internationally known, and to reduce, later on, the measured depths by means of Tables. (Best known are the Tables by D.J. Matthews). Another method would be to reduce, during sounding operations, the echo sounder values to the values of a bathythermograph. Both these methods are very complicated and inexact. The Matthews Tables are only of use under certain conditions, because the areas covered are too large.

Bathythermograph measurements, however, take too much time and do not indicate directly the value of the sound velocity which has first to be calculated from the respective formulae. It is therefore preferable to calibrate the echo sounder during the survey, i.e., by direct adjustment of the exact sound velocity.

A method which is used very often is to lower a plate or an iron bar secured to marked lines. With this method, the calibration-plate (or bar) is left at certain depths under the vessel while at the echo sounder the sound velocity is adjusted so that the sounder registers the correct known depth of the plate, or bar, under the vessel. This is a very simple method which also yields good results. But it has one big drawback: it is not suitable for depths exceeding 15 metres. For, at greater depths, a plate or a bar cannot be kept in a perpendicular position under the vessel as, due to currents in the open sea, it will drift and then be at a different depth than indicated by the line marks; sometimes it might even drift out of the sea area covered by the sounding beam.

The safest method, however, and the simplest at that, is to measure the actual sound velocity in the survey area and to feed the data for sound velocity into the sounder during the survey operations.

Before going into the particulars of this procedure, I want to explain the principle of sound velocity measurement. As I have already given a comprehensive description in my paper read on 7 September 1968 in London, a short recapitulation will now do.

Of all sound velocity meters, the simplest, and economically the most appropriate are those which work according to the feedback method or "sing-around".

THE "SING-AROUND" SOUND VELOCITY METER

Let us look at fig. 2. The transmitter-transducer receives an electric pulse from the generator and converts it in its crystal lattice into a sound pulse. This sound pulse travels through an exactly defined path length (base) within the water and, after a certain time, reaches the receiver-transducer, in the crystal lattice of which the sound pulse is reconverted into an electric pulse. After amplification, the generator will be "triggered" by this electric pulse and thus caused to give a new electric pulse to the transmitter-transducer.

Thus a frequency is created, the height of which—with constant conditions (base length and electronics are constant)—then only depends upon the travel time of sound between the transducers.

Electrical and mechanical pulses are being interchanged within a ring at a frequency which is a direct measure for the travel time of sound. The loss of energy thus arising is compensated in the "semi-circle" of

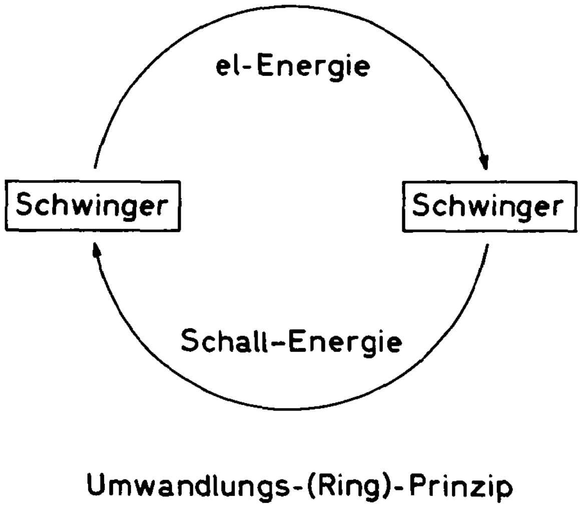

FIG. 2. — The "sing-around" velocimeter principle.

electrical energy. The frequency corresponding to the sound velocity can be measured with any frequency meter.

These "sing-around" probes are very exact and indicate the sound velocities with an accuracy of a few dm/s. With a base of exactly 10 cm, the correct numerical value of the sound velocity is obtained in dm/s. From the technical point of view, however, it is very difficult to establish such an exact base length. With the appropriate time-presetting, the correct numerical value of sound velocity can be obtained by means of a preset counter.

PRINCIPLES OF USE OF SOUND VELOCITY METERS IN SEA AREAS

For survey work it is essential to find the mean sound velocity within each particular area of the survey, and to adjust the echo sounder accordingly, so that the correct depths are registered on the echogram.

In order to obtain the mean sound velocity it is necessary to measure the sound velocity profile from the surface of the water down to the bottom of the sea. For this purpose, the base sound velocity meter mentioned above is lowered from the surface of the water to the sea bottom by winch. The values of sound velocity are then read and registered at constant intervals. From these values, the mean sound velocity has to be calculated.

The mean sound velocity is obtained by adding all measured sound velocities and dividing the resulting value by the number of measurements. The mean sound velocity thus obtained is, theoretically, not quite exact. The difference from the exact actual mean value is so small that an adjustment of the sounder would not be possible. In most cases, echo sounders have tuned reed frequency meters (calibrated according to sound velocity); the distance between the single tuned reeds is 10 m/s. If two tuned reeds are oscillating simultaneously, differences of 5 m/s can still be read.

During the last three years, the research and survey vessel *Gauss* operated according to this method. The figures 3-7 show extracts of the *Gauss* log.

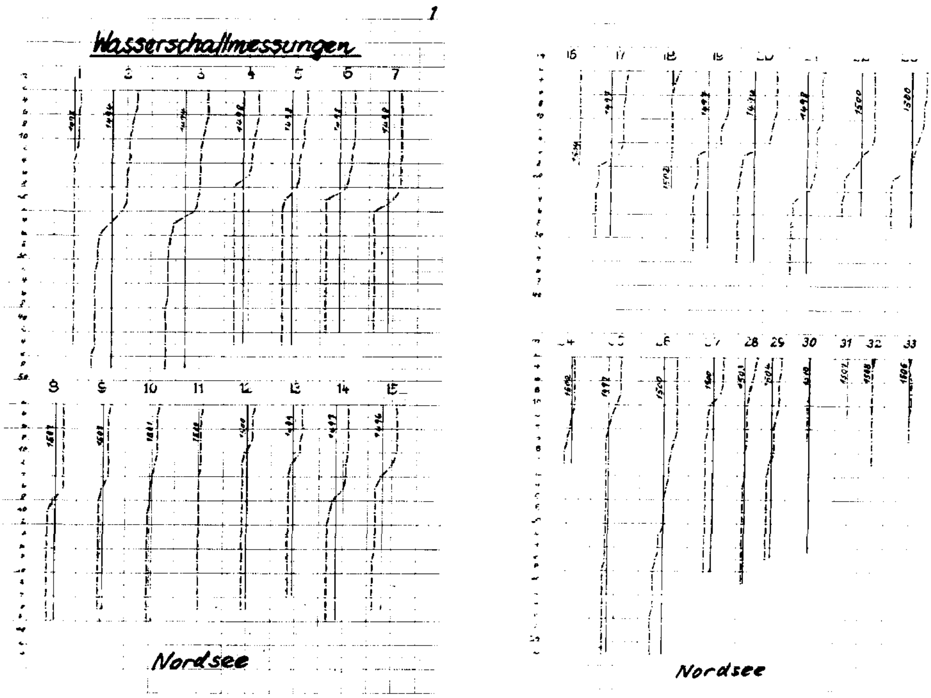

FIG. 3 and 4. — North Sea sound velocity profiles.

I said that from the single sound velocity measurements the mean sound velocity is obtained by adding the single velocities and dividing the sum by the number of measurements, i.e., to calculate the arithmetical mean. This way of averaging the velocities is not quite correct from the physical point of view; it might even be wrong. Let me give you an example: the car. With a velocity of 150 km/h suppose that a car is driving a distance of 150 km. On the way back its speed is 50 km/h. The arithmetical mean would then be 100 km. In fact, the mean velocity is 75 km/h, for the car needs one hour for the way out, and three hours for the way back. In four hours, it covers a distance of 300 km; so, the actual mean velocity is 75 km/h. Exactly the same applies to sound velocities in water. It is therefore correct to divide the total of distances by the total of time. The high differences between arithmetical mean values and correct mean values occuronly if the single velocities are in a multiple ratio to each other. The closer the single values are to each other, then the smaller are the differences between the two methods of averaging.

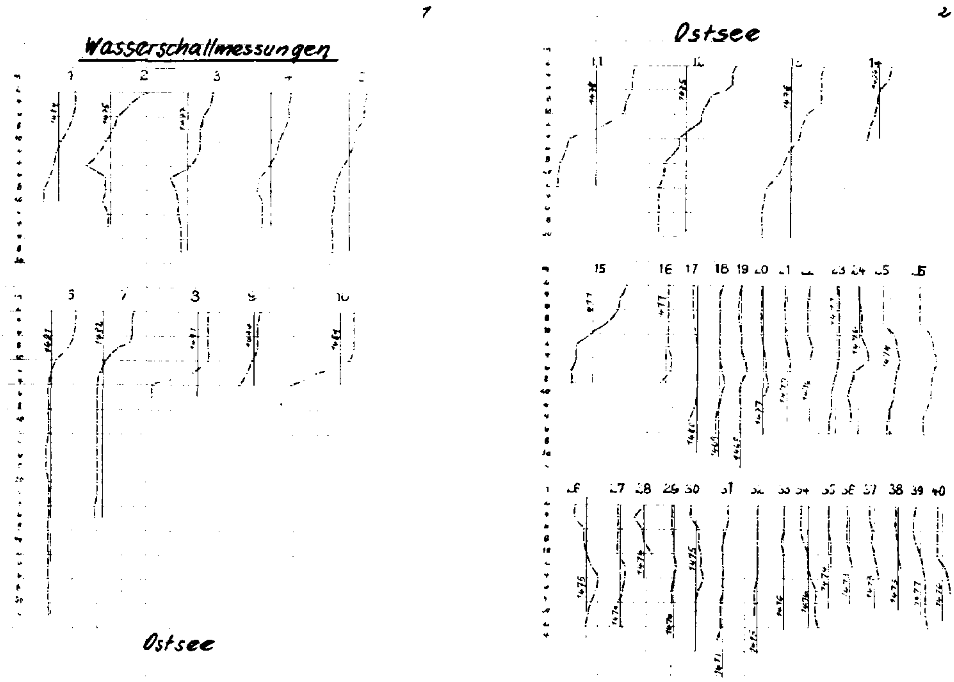

FIG. 5 and 6. Baltic sound velocity profiles.

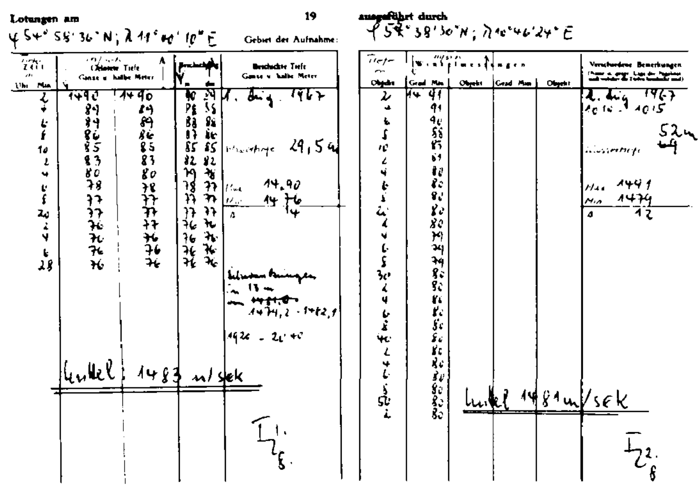

FIG. 7. — Log entries.

The formulae for the calculation of the mean velocities are:

Formula 1 $$V_{m_{arith}} = \frac{\Sigma V_n}{n}$$

$V_{m_{arith}}$ = arithmetical mean

V_n = single values of the velocities

n = number of measurements

and

$$\text{Formula 2} \qquad V_{m_{corr}} = \frac{\Sigma S_n}{\Sigma \frac{S_n}{V_n}} = \frac{\Sigma S_n}{\Sigma t_n} = \frac{S_g}{t_g}$$

$V_{m_{corr}}$ = correct mean
S_n = single paths of the sound
V_n = single values of velocities
t_n = single travel times
S_g = total distance (depth down to which soundings are made)
t_g = total time.

By means of concrete examples given by the figures shown I want to prove that for the calculation of the mean sound velocity arithmetical averaging will be entirely sufficient.

Curve 7 North Sea:

Water depth 42 m, 21 measurements
Sum of the 21 measurements = ΣV_n = 31444

$$V_{m_{arith}} = \frac{\Sigma V_n}{n} = \frac{31444}{21} = 1497.33$$

$$V_{m_{corr}} = \frac{\Sigma S_n}{\Sigma \frac{S_n}{V_n}} = \frac{S_g}{t_g} = \frac{2 + 2 + \cdots\cdots + 2}{\frac{2}{1503} + \frac{2}{1503} + \cdots\cdots + \frac{2}{1492}} =$$

$$= \frac{42}{0.0280497733} = 1497.33$$

In both cases the same value of 1497.3 m/s is obtained for the mean sound velocity.

Curve 6 Baltic Sea:

Water depth 52 m, 26 measurements
Sum of the 26 measurements = 38521

$$V_{m_{arith}} = \frac{38521}{26} = 1481.57 \text{ (m/s)}$$

$$V_{m_{corr}} = \frac{52}{0.03509785} = 1481.57 \text{ (m/s)}$$

Curve 10 Baltic Sea:

Water depth 14 m, 7 measurements
Sum of the 7 measurements = 10421

$$V_{m_{arith}} = \frac{10421}{7} = 1488.71 \text{ (m/s)}$$

$$V_{m_{corr}} = \frac{14}{0.00940447} = 1488.65 \text{ (m/s)}$$

These three examples were taken from coastal surveys, i.e., at depths of less than 100 metres. I want to give a further example of a sound velocity profile, similar to fig. 8, from the deep sea.

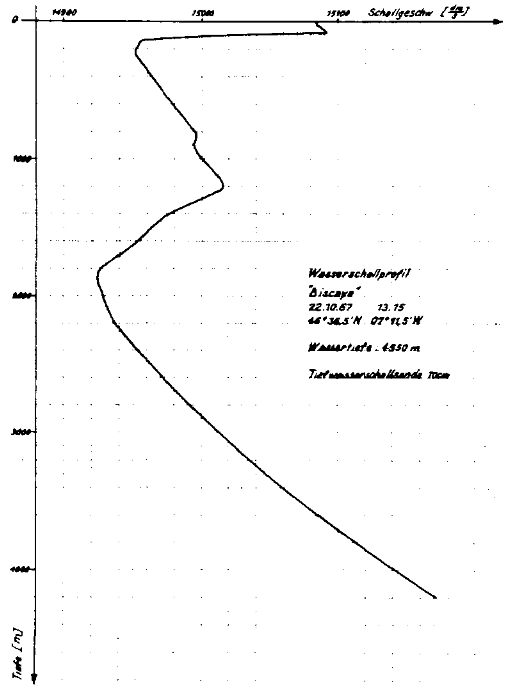

FIG. 8. — Deep sea sound velocity profile from the Bay of Biscay (1967, R/V *Meteor*).

Water depth 4 500 m, 46 measurements (every 100 metres).

Sum of the 46 measurements = 69048.

$$V_{m_{arith}} = \frac{69048}{46} = 1501.04 \text{ (m/s)}$$

$$V_{m_{corr}} = \frac{4500}{2.9983298} = 1500.83 \text{ (m/s)}$$

In this case, too, the difference is not essential.

From these examples it can be seen that in some cases there is no difference, or only a difference which is so small that it can be neglected for surveying. For, as I stated in one of the previous paragraphs, sound velocity differences of less than 5 (m/s) cannot be compensated by adjusting the echo sounders. Nor do evaluations of other curves yield better results. The mean sound velocity obtained by the simple method will always differ only so slightly from the mean sound velocity obtained by the correct method that it is beyond the possibility of compensation [of the 5(m/s)] by adjustment of the echo sounders.

If the echo sounder is coupled electronically to the sound velocity meter, one will have to adjust the electronics so that the computer can calculate the value $V_{m_{corr}}$, as such an automatic calculation does not cause any difficulties.

I wanted to prove in this paper also that by means of the simple method the mean sound velocities can in practice be obtained with sufficient exactitude, in order to get exact depth data on the echogram.

REFERENCE

Arno ULONSKA and Joachim JARKE : Ein Gerät zur in situ-Messung der Schallgeschwindigkeit in marinen Sedimenten. (An instrument for in situ measurements of the velocity of sound in marine sediments). *Deutsche Hydrographische Zeitschrift*, **19**, 1966, No. 3.