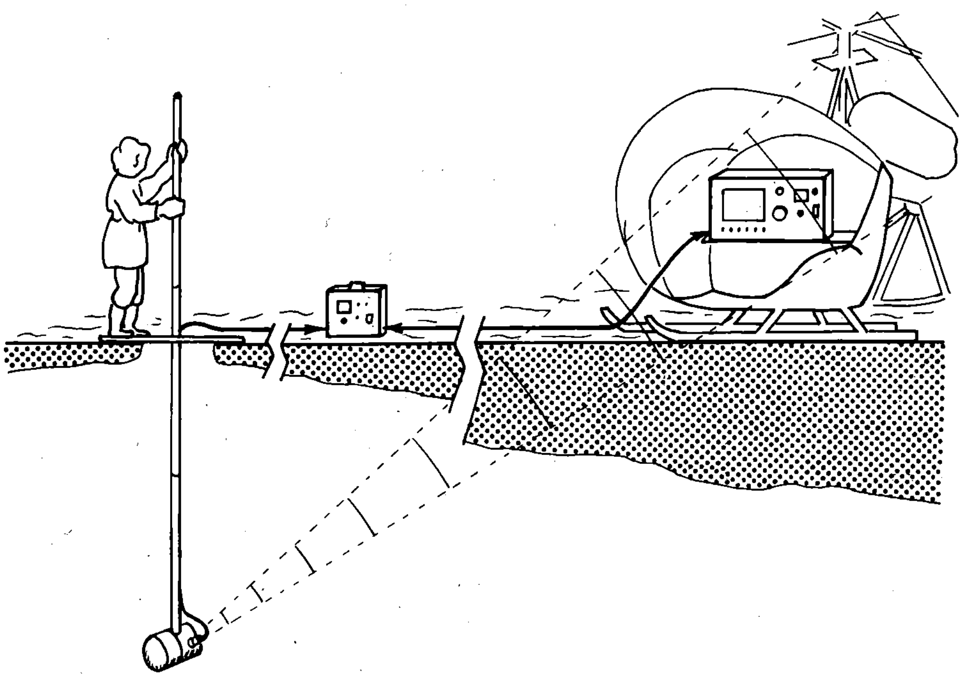
STYRELSEN FÖR

VINTERSJÖFARTSFORSKNING

WINTER NAVIGATION RESEARCH BOARD

Research Report No 14

A NARROW BEAM SONAR TO MEASURE THE SUBMARINE PROFILE OF AN ICE RIDGE



Sjöfartsstyrelsen
Finland

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Preface

The Winter Navigation Research Board presents its report No 14 . This report gives an account of the experiments and investigation carried out for developing a narrow beam sonar suitable for measuring the submarine profile of an ice ridge. The work has been carried out by a team from the Helsinki University led by Professor Erkki Palosuo, the former Head of Ice Department, Institute of Marine Research and Professor Mauri Luukkala, Department of Physics.

The Winter Navigation Research Board expresses its appreciation of the work and its thanks to Professors Palosuo and Luukkala and Mr. Pousi.

Helsinki and Stockholm November 1975

Helge Jääsalo   Lennart Johansson

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Experiments with a narrow beam sonar for studying ice ridges

Erkki Palosuo
University of Helsinki
Department of Geophysics

Pressure ridges have been studied by diving (Kovacs 1971, Palosuo 1975), but this is a rather troublesome procedure. A more practical method is to use a scanning sonar.
These instruments are very often commercial models with a rather broad beam angle. The selectivity of these models is only useful for short distances. Experimets using a narrow beam sonar for studying ice ridges were therefore carried out in Finland in winter 1973.

I found that Edo Western Corp. of Salt Lake City had produced a narrow beam sonar to study e.g. holes made during drilling for oil. This model had two alternatives for the beam angle: one wide to examine larger areas and the second narrow for detailed studies. In the latter the beam angle was 2 degrees in horizontal and 0,7 degrees in vertical direction. The selectivity of the latter was good at a distance of 150 meters, which meets stiff requirements. The sonar scans horizontally and the picture is shown in an oscilloscope.

A Edo Western Corp. scanning sonar was rented for use in Finland for one month and was installed on the side of an icebreaker (Figs 1 to 2). A ten meter long tube lowered the scanning head meter-by-meter using the icebreaker's crane. An extra tube was installed to protect the scanning head when it was driven through the broken ice. Mr. Pinebrook, the chief constructor of Edo Western Corp., helped us to do these experiments.

In the first experiments the scanning sonar functioned very well, and the pictures seen on the oscilloscope were clear. In order to make notes of the pictures seen in the oscilloscope, the out-

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lines were drawned on a transparent sheet (Figs 3 to 5).

The horizontal cuts shown were not, however, suitable for practical purposes. The scanning head was repositioned to scan vertically. By making several scannings in various directions, adjoining profiles gave a full picture of the submarine part of an ice ridge.

It was peculier that the narrow beam sonar gave not only an echo from the surface of an ice cake but also a second echo from the backside of the cake (Fig. 6). Thus the thickness and size of single froes close to the outer side of the ridge were shown in the oscilloscope. In experiments in a deformed ice field, the scanner showed seven single floes, one behind the other (Fig. 6). A skindiver cheched that the result was accurate. It might be mentioned that the level ice on top of the observation site was seen as well, but only for a certain distance. When the beam met the ice from a more skew angle it was deflected.

For practical purposes, however, a recording instrument was more of a handicap, but the impulses from the scanning head were too weak for recording. I therefore asked Mauri Luukkala and Tapio Pousi from the Department of Physics to build a recording scanning sonar with a narrow beam. To solve the problem we had to make a quite new construction. The project was successful and we hope that this kind of scanning instrument can be placed on the bottom of an icebreaker.

References

Kovacs, A. (1971): On Pressured Sea Ice. Int. Sea Ice Conference, Nat. Res. Council of Island, Reykjavik.

Palosuo, Erkki (1975): The Formation and Structure of Ice Ridges in the Baltic. Winter Navigation Research Board, Report 12. Helsinki.

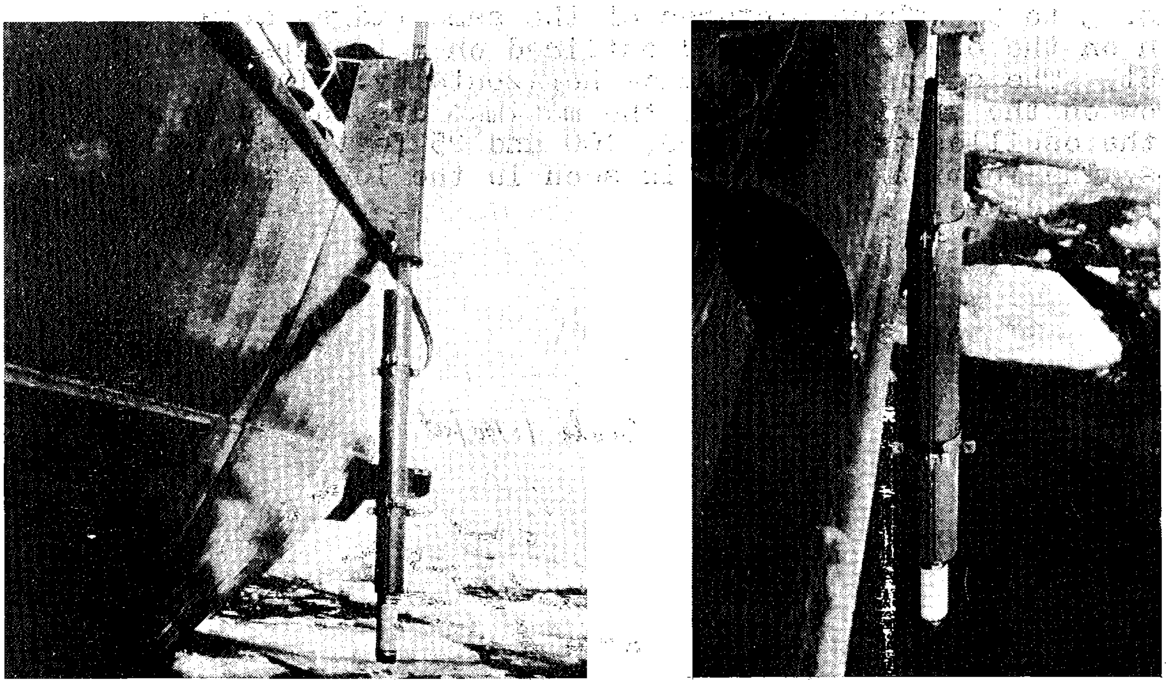

Fig. 1. Scanning sonar installed on the side of an ice-breaker. Obs. The extra tube protecting the (white) scanning head.

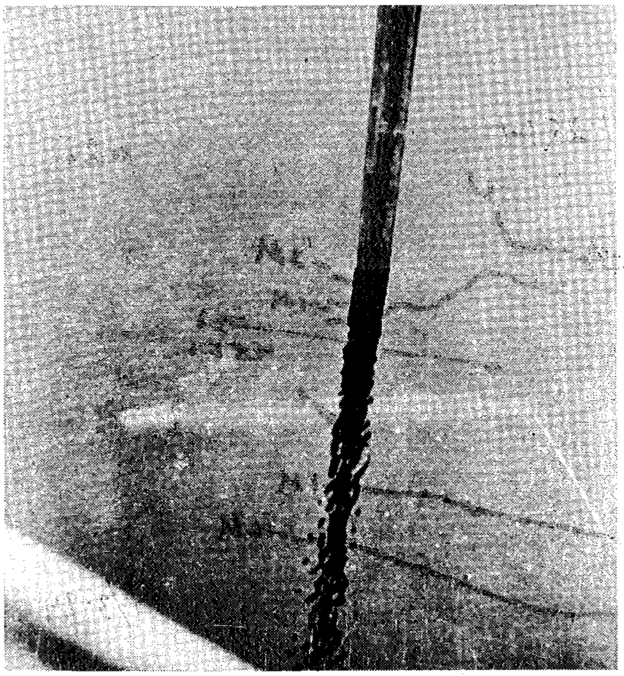

Fig. 2. The scanning head repositioned so it scans vertically. (The scanning head is under the water surface.)

A Narrow Beam Sonar to Measure the Submarine Profile of an Ice Ridge

T. Pousi and M. Luukkala
University of Helsinki
Department of Physics

Abstract

A narrow beam vertically scanning sonar has been built to measure the submarine profile of an ice ridge. The sonar consists of two main parts: the immersed portable scanning sonar head and the central unit containing also the recorder and 220 V Honda generator. The central unit is usually situated in a tent or in a helicopter.

The principle of the use is following: a hole is drilled in the ice and the scanning sonar head is immersed at a suitable depth. The sonar transmits 0.1 ms sound pulses five times per second with 10 W power. Underice features such as ridges scatter sound back to the transducer. The backscattering echoes are received and the echo distance and the corresponding scan angle are shown by two digital parrel meters and recorded by a xy-recorder. The beam width of the sonar is $2,4^{o}$ and the distance resolution is about ±15 cm. During the field experiments the sonar performed according the expectations and the profiles of several ridges were recorded. The distance range of the sonar was about 30 meters but it is planned to be expanded.

Contents

1. Introduction

This project was started when Prof. E. Palosuo (Dept. of Geophysics, University of Helsinki) in his research work concerning with the ice ridges noticed the usefulness of an high frequency narrow beam scanning sonar. Because such an equipment was not available with a graphic display, the sonar was decided to be built in the Dept. of Physics, University of Helsinki.

In the beginning of the work the following demands were stated

1. The sonar must have a graphic display from which the submarine profile of an ice ridge can be seen or computed.
2. The 3 dB beamwidth of the sonar has to be less than 3 degrees.
3. The range of the sonar should be about 50 meters.
4. It should be possible to operate the scanner head at a distance of about 100 meters from the central unit which was planned to be situated in a tent, helicopter or on an ice breaker.

The final construction of the sonar fullfills all these demands except the distance range which was about 30 meters. Our purpose is however to expand the range by increasing the gain of the receiver. The details of the sonar and some theoretical considerations are presented in this paper. In actual measurements in the Gulf of Bothnia in March 1975 the sonar performed well. The results of the measurements are also discussed and some measured profiles are shown.

The electronic central unit of the sonar and tne scanner head are shown in figure 1.

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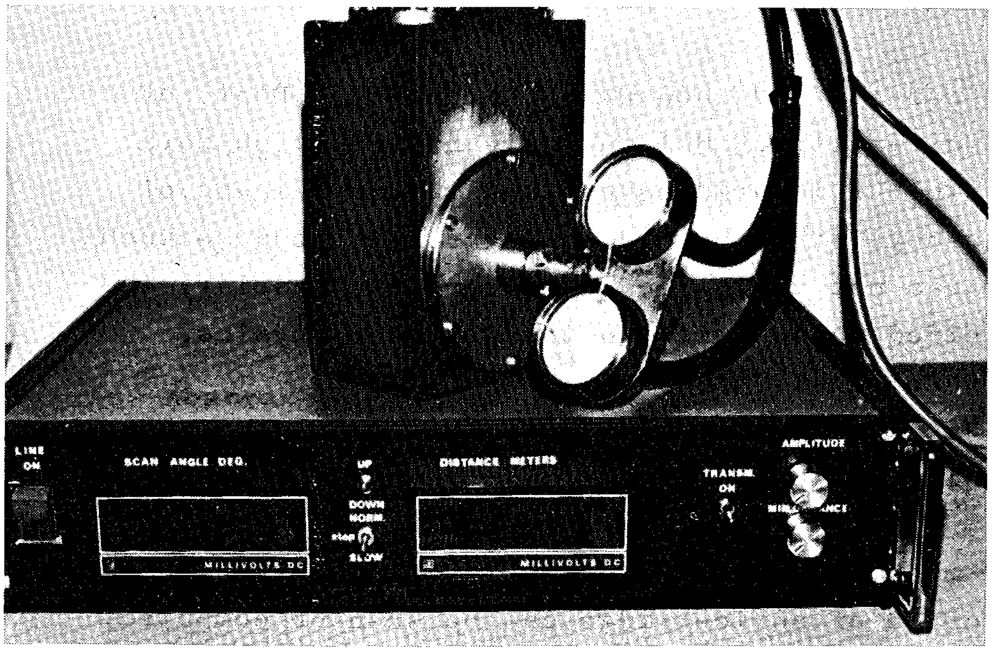

Figure 1.

2. Principles of operation

The principle of the use and the sonar geometry beneath the ice are shown in figure 2.

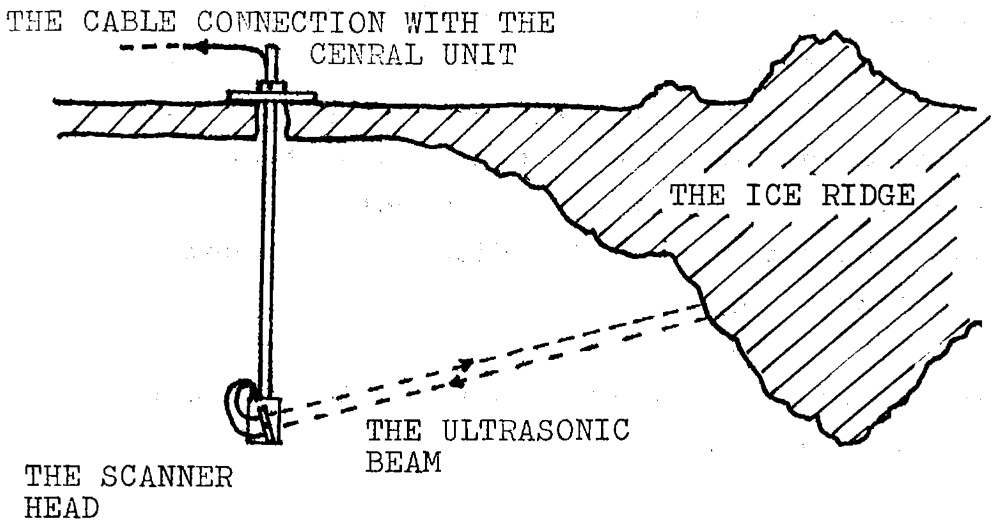

Figure 2.

The equipment consists of two main parts: the immersed portable scanning sonar head and the central unit containing also the graphic recorder and the 220 V Honda generator. The central unit was situated in a Helicopter or on an icebreaker during the experiments. The sonar head is mounted on an aluminium shaft of five 2 m sections and can be lowered to the maximum depth of 10 meters through a 20 cm hole. The ultrasonic scanner head consists of two PZT-5 ceramic discs with a diamer of 5 cm, one transducer being used for receiving and the other for transmitting the signal. The use of two separate transducers is useful in expanding the dynamic range in reception by eliminating ringing effects in the receiver after the transmitted pulse. The 180 degree scanning motion is carried out by a miniature electric motor providing the scanning speeds of 1 degree and 0.5 degree per second. The stainless steel scanner head also contains the receiver with a voltage gain of 80 dB.

The block diagram of the instrumentation is seen in figure 3. The signal source was a 750 kHz pulsed Wien-bridge oscillator. The repetition rate was 5 Hz and the pulse duration 100 μs. The pulses were fed through a power amplifier to the transmitter crystal with a 100 m long 50 Ω coaxial cable. The cable was electrically matched to the output impedance of the amplifier and to the radiation impedance of the crystal (8.3 Ω) using toroidal impedance transformers. The distance of the backscattering object is measured as follows: A linear voltage ramp is produced with a ramp generator simultaneously with the transmitted signal so that the value of the ramp voltage is directly proportional to the time passed since the pulse was transmitted. The received echo pulse is converted into a digital pulse with a monostable multivibrator so that the distance information is transmitted to the central unit as a logic level pulse along a conventional cable thus avoiding the complications caused by handling weak rf-signal. The echo distance is then computed in the central unit by letting the received logic pulse to sample the ramp signal. The corresponding scan-angle is simply given by a potentiometer which is driven by the scanner motor. In connection with the receiver there is also a gate circuit with which it is possible to fix the minimum distance from which the echoes

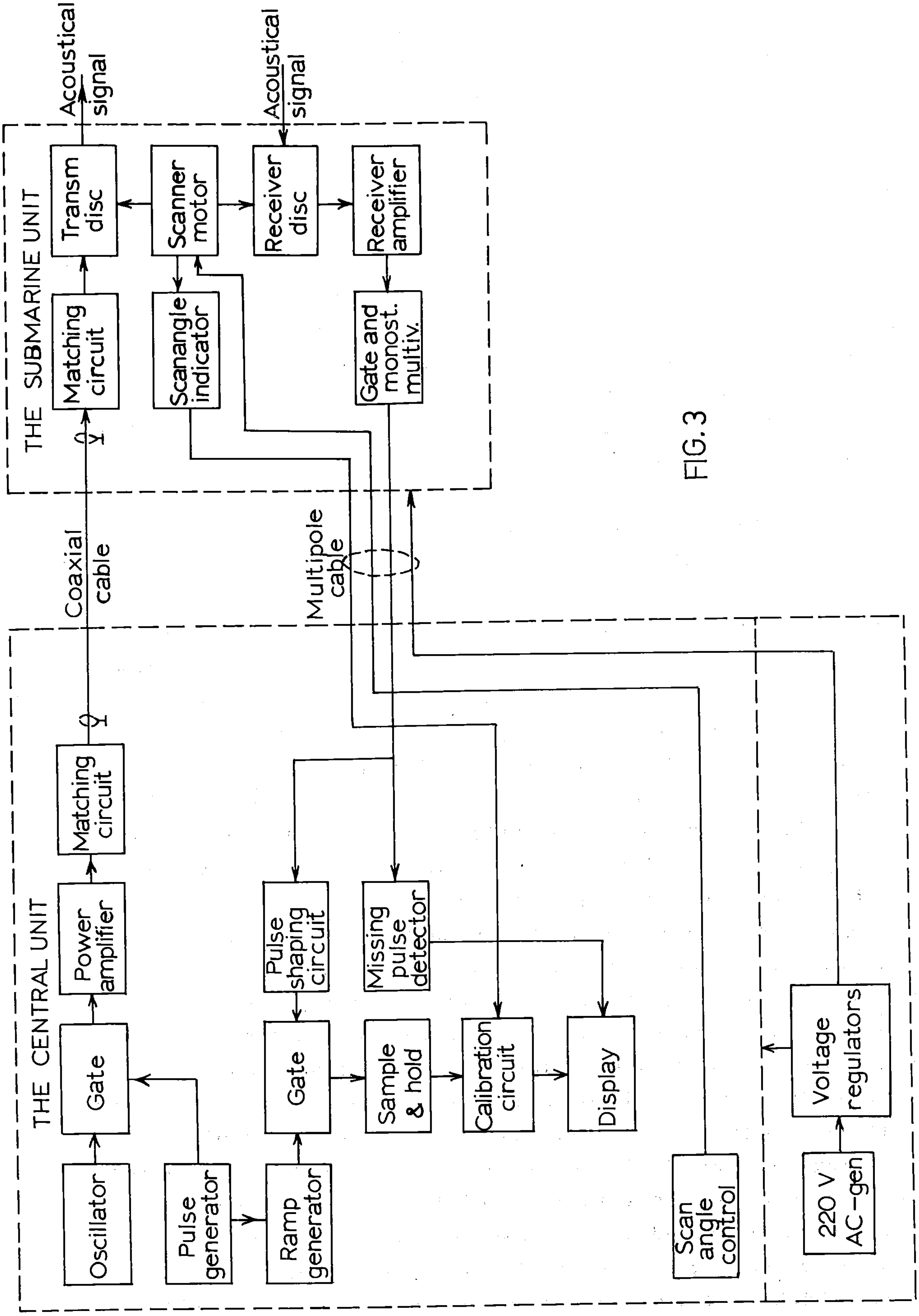
THE SUBMARINE UNIT
Acoustical signal
Acoustical signal
Transm disc
Scanner motor
Receiver disc
Receiver amplifier
Matching circuit
Scanangle indicator
Gate and monost. multiv.
Coaxial cable
Multipole cable
THE CENTRAL UNIT
Oscillator
Gate
Power amplifier
Matching circuit
Pulse generator
Ramp generator
Gate
Pulse shaping circuit
Sample & hold
Missing pulse detector
Calibration circuit
Display
Scan angle control
Voltage regulators
220 V AC-gen

FIG. 3

are received. The minimum distance can be varied between 0 and 10 meters.

3. The transducer construction

A six-terminal model with twoelectrical and four mechanical terminals was used to compute the transducer response in various loading and backing conditions [1]. The equation used to calculate the electrical impedance Z_E of the transducers was following

$$Z_E = R + iX \tag{1}$$

where

$$R = \frac{k_T^2}{\pi \omega_o C_E \delta^2} \frac{(\zeta_a + \zeta_b)\ [2 - 2\cos\delta\pi + (\sin^2\delta\pi)(1 + \zeta_a\zeta_b) - 2]}{(\zeta_a + \zeta_b)^2\ \cos^2\delta\pi + (1 + \zeta_a\zeta_b)^2\ \sin^2\delta\pi} \tag{2}$$

$$X = \frac{k_T^2}{\pi \omega_o C_E \delta^2} \frac{\sin\delta\pi[\cos\delta\pi((\zeta_a + \zeta_b)^2 - 2(1 + \zeta_a\zeta_b)) + 2(1 + \zeta_a\zeta_b)]}{(\zeta_a + \zeta_b)^2\cos^2\delta\pi + (1 + \zeta_a\zeta_b)^2\sin^2\delta\pi} \tag{3}$$

where

k_T = coupling coefficient for thickness mode transducer

$\omega_o = \frac{2\pi v}{2l}$

where v = velocity of compressional wave in the transducer

l = thickness of the transducer

C_E = the electrostatic capacitance of the transducer

$\zeta_a = \frac{\rho_a v_a}{\rho v}$ and $\zeta_b = \frac{\rho_b v_b}{\rho v}$

where ρ_a and ρ_b are the densities of the loading and backing materials, v_a and v_b are velocities of compressional wave in these materials and ρ is the density of the transducer material.

$\delta = \frac{\omega}{\omega_o}$ (ω = the angular velocity)

The final transducer construction is demonstrated in figure 4.

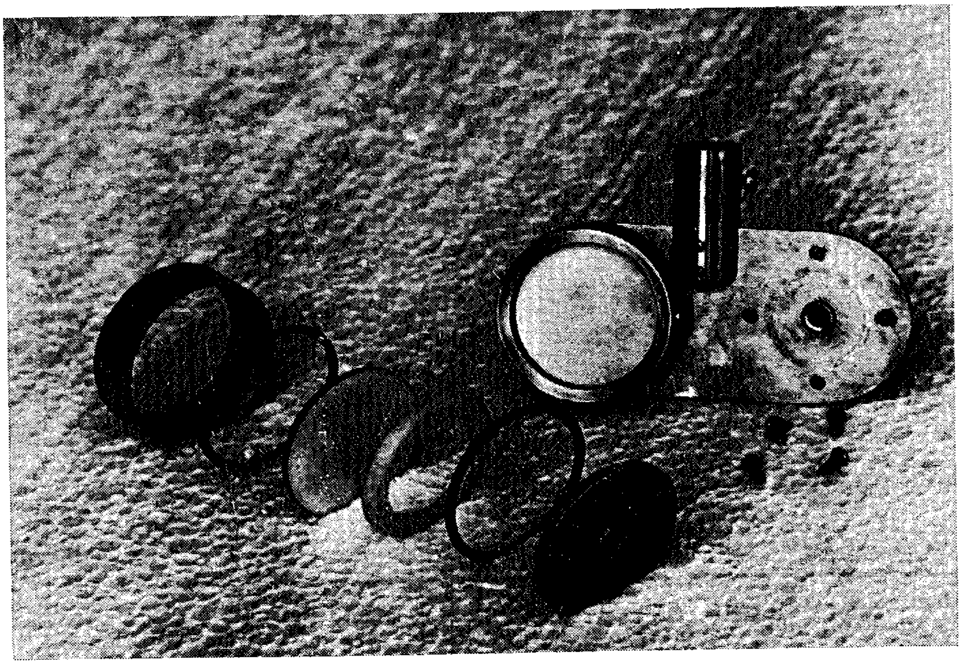

Figure 4.

The transducers are airbacked and directly in contact with water. Before selecting this construction many different backings were tested using mixtures of Araldite and different filler materials. The use of mechanical impedance matching layer [2] on the front of the transducers was also tested with some materials. Both mechanical impedance matching and backing were given up mainly because the difficulty of producing homogenous mixtures of Araldite heavy enough and also for the reason that the results were satisfactory without them.

The theoretical and measured values of the electric impedance of the airbacked transducer above are shown in pictures 5a and 5b. As one can see there is a good agreement between the measured and theoretical values. During the experiments the model described above proved to be very useful in designing various transducer constructions.

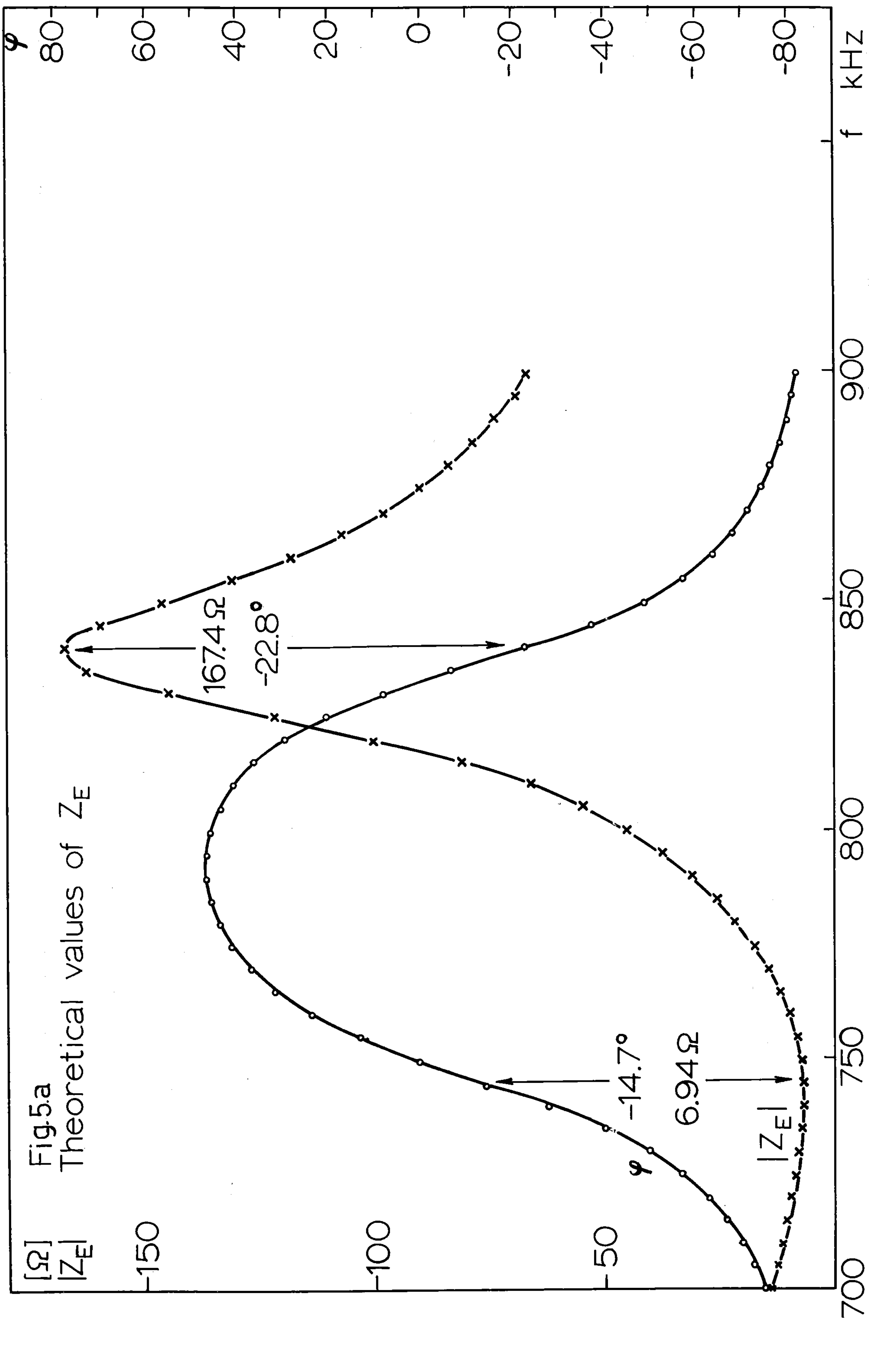

Fig.5a
Theoretical values of Z_E

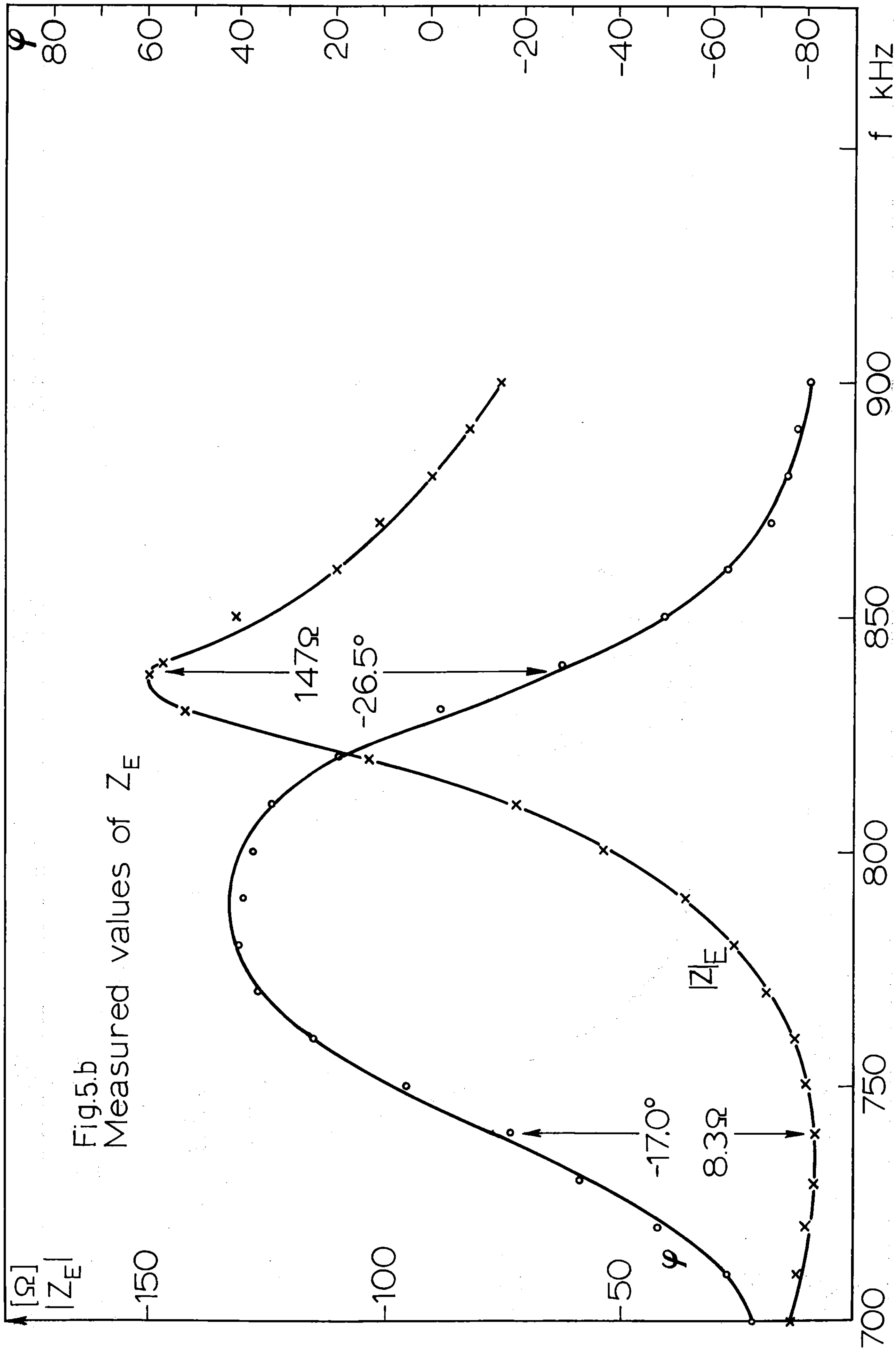

Fig.5.b
Measured values of Z_E

4. Sound transmission losses in sea water

In case of a plane wave travelling in a fluid there may appear several different types of attenuation. However, in case of sea water the most important sources of attenuation are those due to the viscous losses and the chemical relaxation. Because of the relative motion between portions of the medium a frictional form of energy loss occurs, which is proportional to the square of the frequency. The losses due to the chemical relaxation are associated with certain changes in the chemical structure of the molecules. The time dependence of this relaxation process is described by the relaxation time τ_r so that the maximum amount of energy is absorbed from the wave with frequency

$$f_r = \frac{1}{2\pi\tau_r} \qquad (4)$$

The chemical relaxation in sea water is almost completely caused by the $MgSO_4$ salt dissolved in it. The experimental formula for the acoustic attenuation in sea water in the temperature of $+5^o$ C is [3. s. 236]

$$\alpha = \left(\frac{0.036\ f^2}{f^2 + 3600} + 3.2 \cdot 10^{-7}\ f^2\right) \frac{dB}{m} \qquad (5)$$

where the frequency is in kHz and $3600 = f_r^2$.

With the used 750 kHz frequency the part caused by the chemical relaxation is very small and the total attenuation from (5) is 0.17 dB/m.

5. The velocity of sound in the sea

A simplified equation for the velocity of sound in the sea is given by [4. s. 80]

$$v = [1449 + 4.6T - 0.055T^2 + 0.0003T^3 + (1.39 - 0.012T)(s - 35) + 0.017d]\ \frac{m}{s} \qquad (6)$$

where T is the temperature in degrees centigrade,
s is the salinity in parts per thousand and
d is the depth in meters.

The operating conditions of the sonar are approximately the temperature of 0^o C, the depth of 5 meters and the salinity of 3 parts per thousand. The velocity of sound is then $v \approx 1400$ m/s.

6. Directional pattern of the transducers

One starting point was the request that the beam width should be less than 3 degrees. In this case we can limit only to the farfield because the distances from the transducers are large. The minimum distance for the far field or Fraunhofer diffraction is $d^2/4\lambda$ [3. s. 176] where d is the diameter of the transducer and λ is the wave length. In this case $d = 5$ cm and $\lambda = 1.87$ mm so that the minimum distance is 27 cm.

It can be shown [3. s.171] that the far field intensity pattern at the constant distance is

$$I = I_o\left[\frac{2\,J_1\,(ka\sin\theta)}{ka\sin\theta}\right]^2 \tag{7}$$

where I_o is the axial intensity, θ is the directional angle measured from the axis, J_1 is the Bessel function of the first order, k is the wave number and a is the radius of the transducer disc.

The intensity pattern of the transducers used in the sonar has been computed from (7) and is shown in figure 6. The beam width to the half power points is 2.4 degrees and the first side lobe is in the direction $\theta = 3.9^o$ and it is 17.5 dB down from the main lobe.

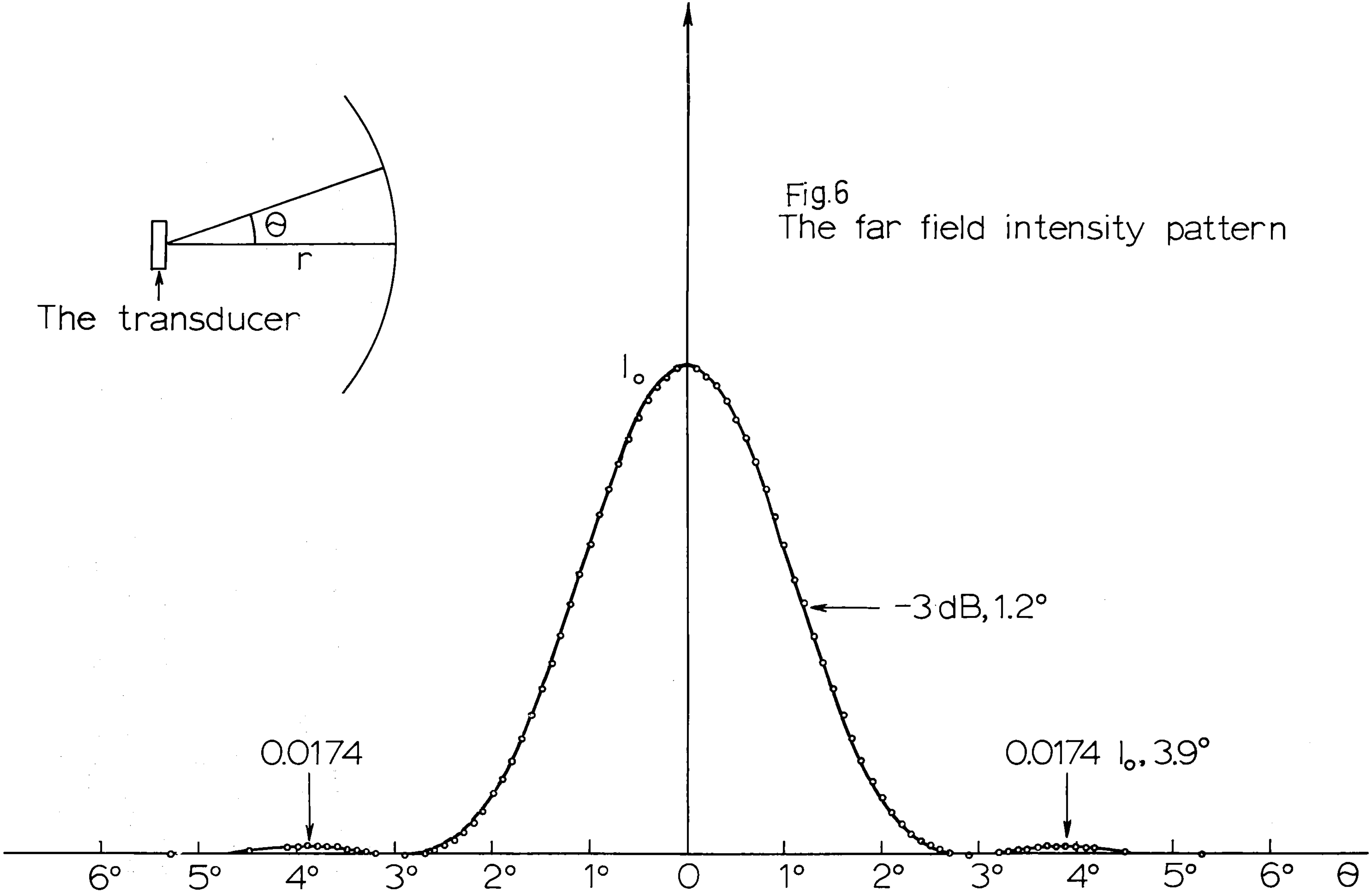

Fig.6
The far field intensity pattern

7. The mechanical construction

The construction of the submarine unit is seen in figures 7 and 8.

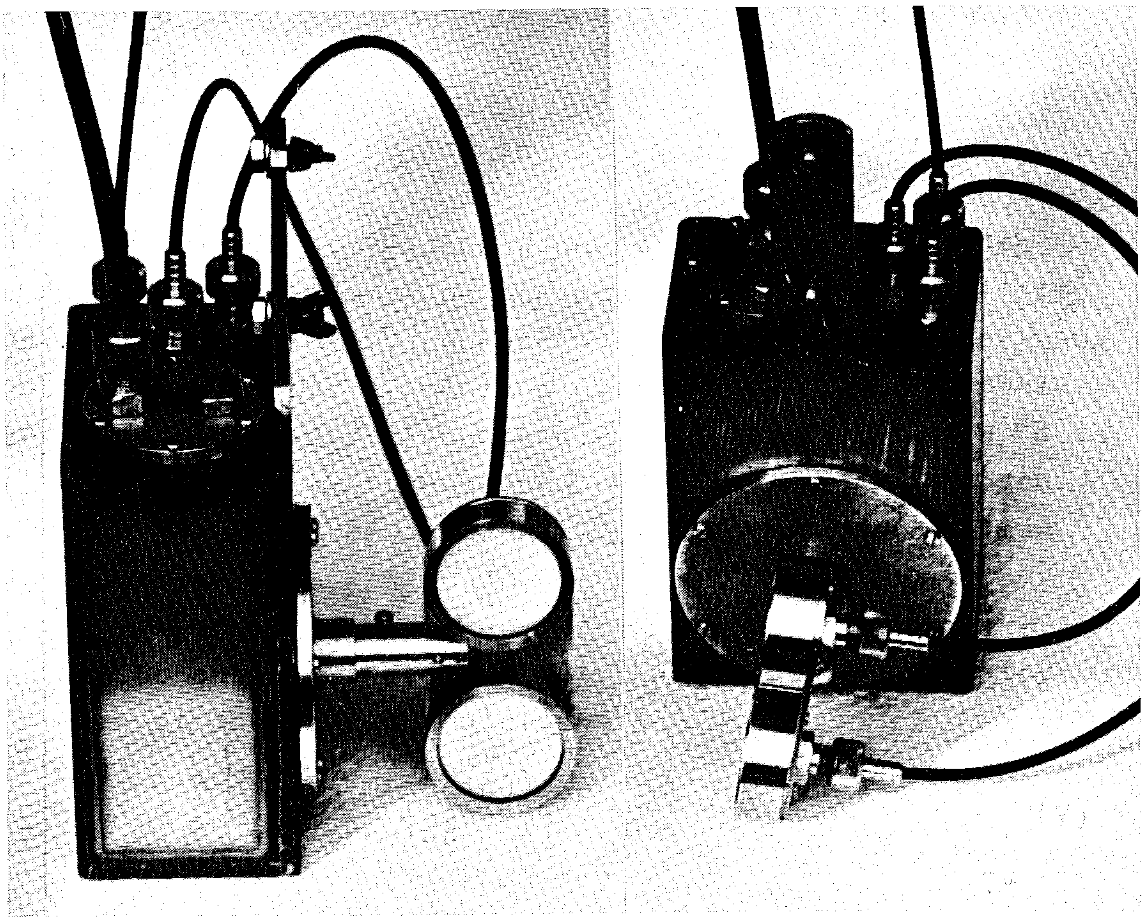

Figure 7.

The receiving amplifier, the scanning miniature electric motor and the gear mechanism were situated in a waterproof steel housing. In the upper part and on one side of the housing there are holes for the receiver and the scanner mechanism. The impedance transformer for the transmitting crystal was also situated in the scanner housing and the cables to the transducers and the central unit were fed through the upper part of the housing. One side of the housing has been extended so that the aluminium lowering shaft can be fixed on it.

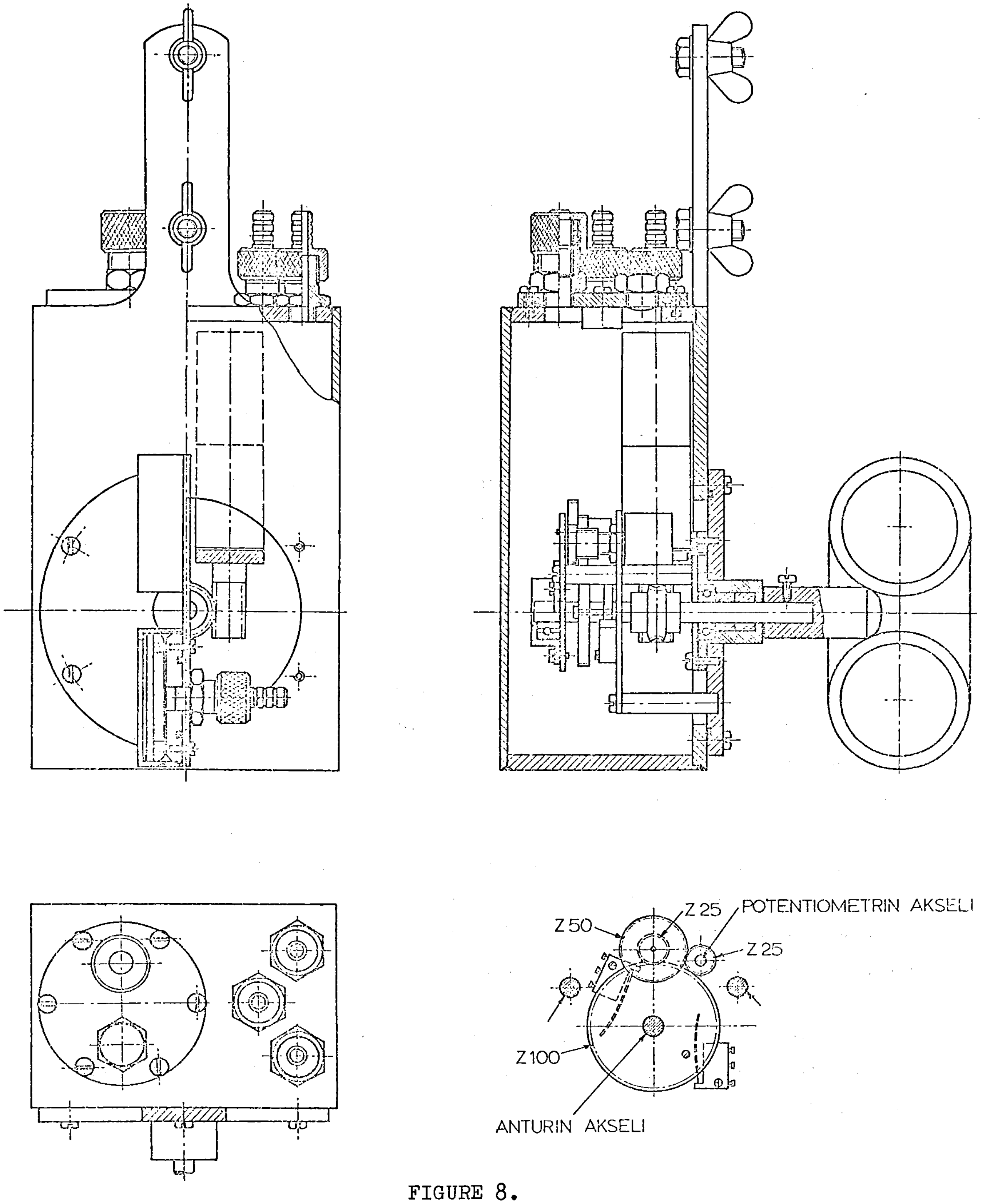

FIGURE 8.

8. The field experiments

The sonar was tested in the Gulf of Bothnia outside the towns Oulu and Kemi during March 1975. Some of these measurements were made in connection with the Scandinavian research project "Sea Ice -75". The results were encourageing and the sonar worked well and according the expectatious. However, during the experiments the need of some improvements and slight changes of which we shall discuss later became obvious.

One typical submarine profile measured with the sonar is seen in figure 9. Notice, that the horizontal and vertical scales are different. The profiles of the figure 9 and the corresponding xy-recorder prints are shown in figures 10-13. These profiles have been drawn by choosing some angle/ distance-points and are thus of course approximatious formed by these points.

The larger profile has been "viewed" from three different depths. As one may see, these profiles are not quite alike, but clearly the parts pointed by arrows correspond each other. One reason for the differences may be the change in the horizontal direction when changing the depth. On the other hand it is obvious that the sound may reflect in different ways when the depth of the transducers is changed. To get more precise information about these variations many systematic measurements have to be made and the results have to be checked for example by diveing.

In figure 14 the underside of an even ice field is shown. The reflection has been received continuosly till the distance of 7 meters.

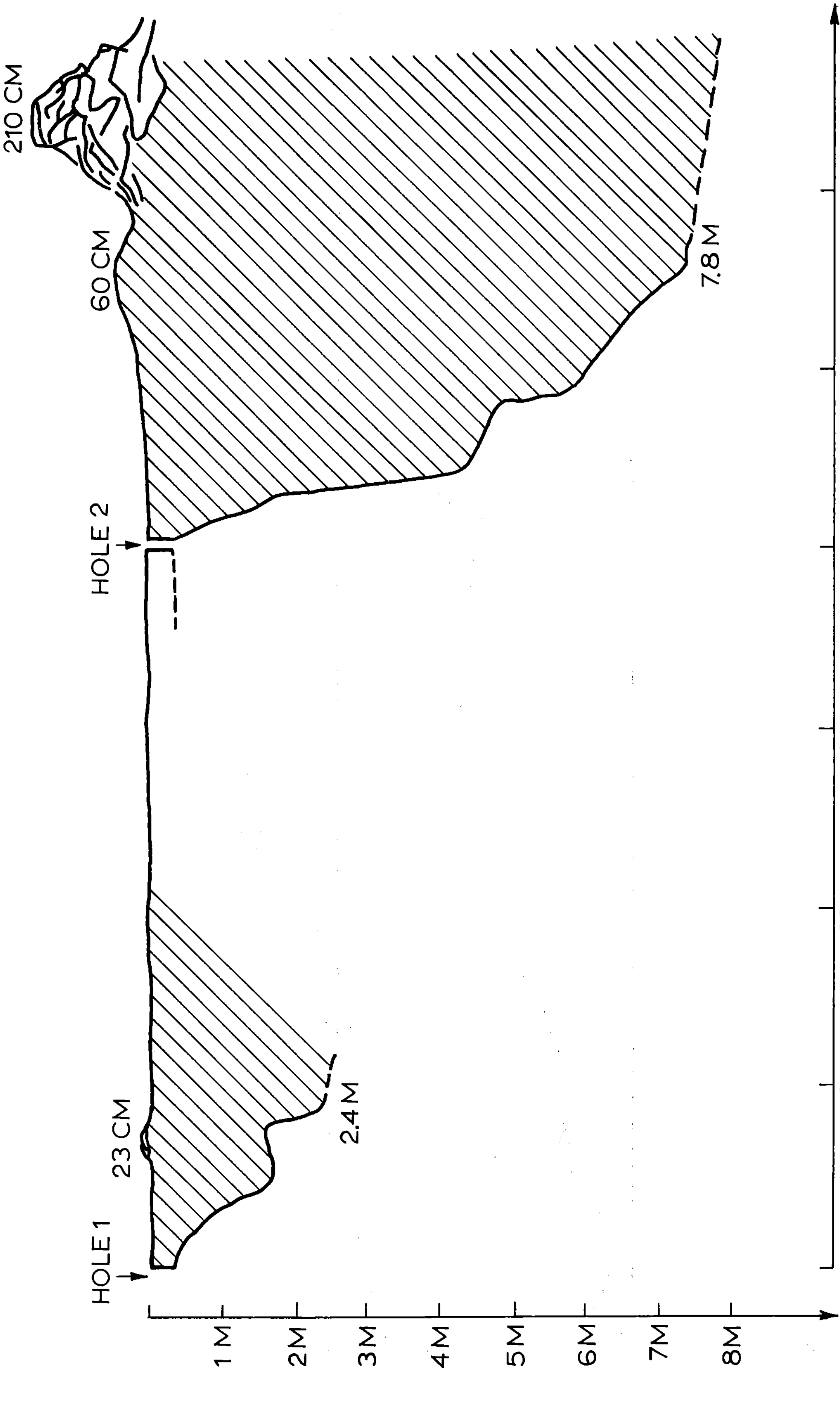
210 CM
60 CM
7.8 M
HOLE 2
23 CM
2.4 M
HOLE 1
10 M
20 M
30 M
40 M
50 M
60 M
1 M
2 M
3 M
4 M
5 M
6 M
7 M
8 M

Fig.9

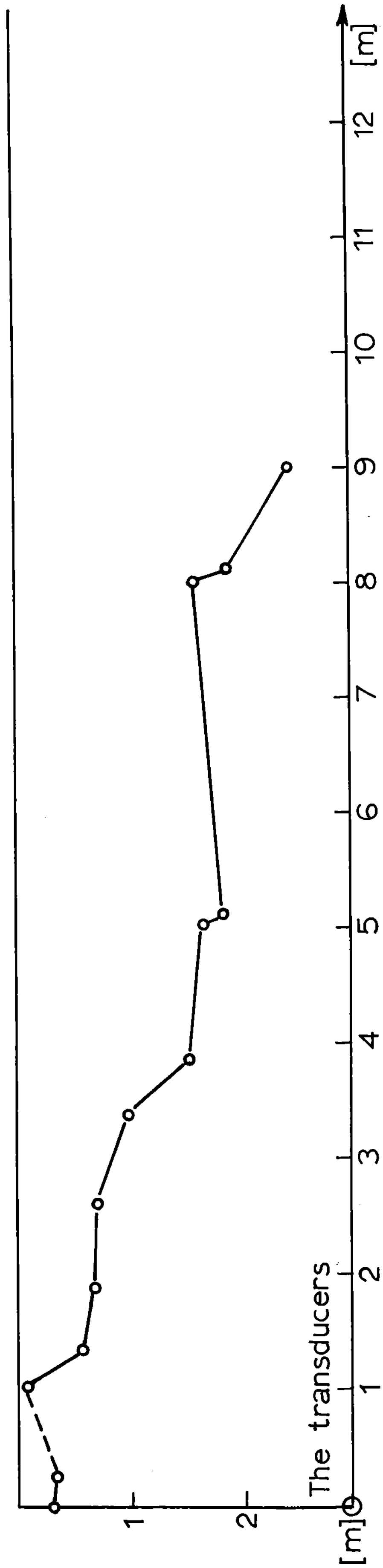

Fig.10.a

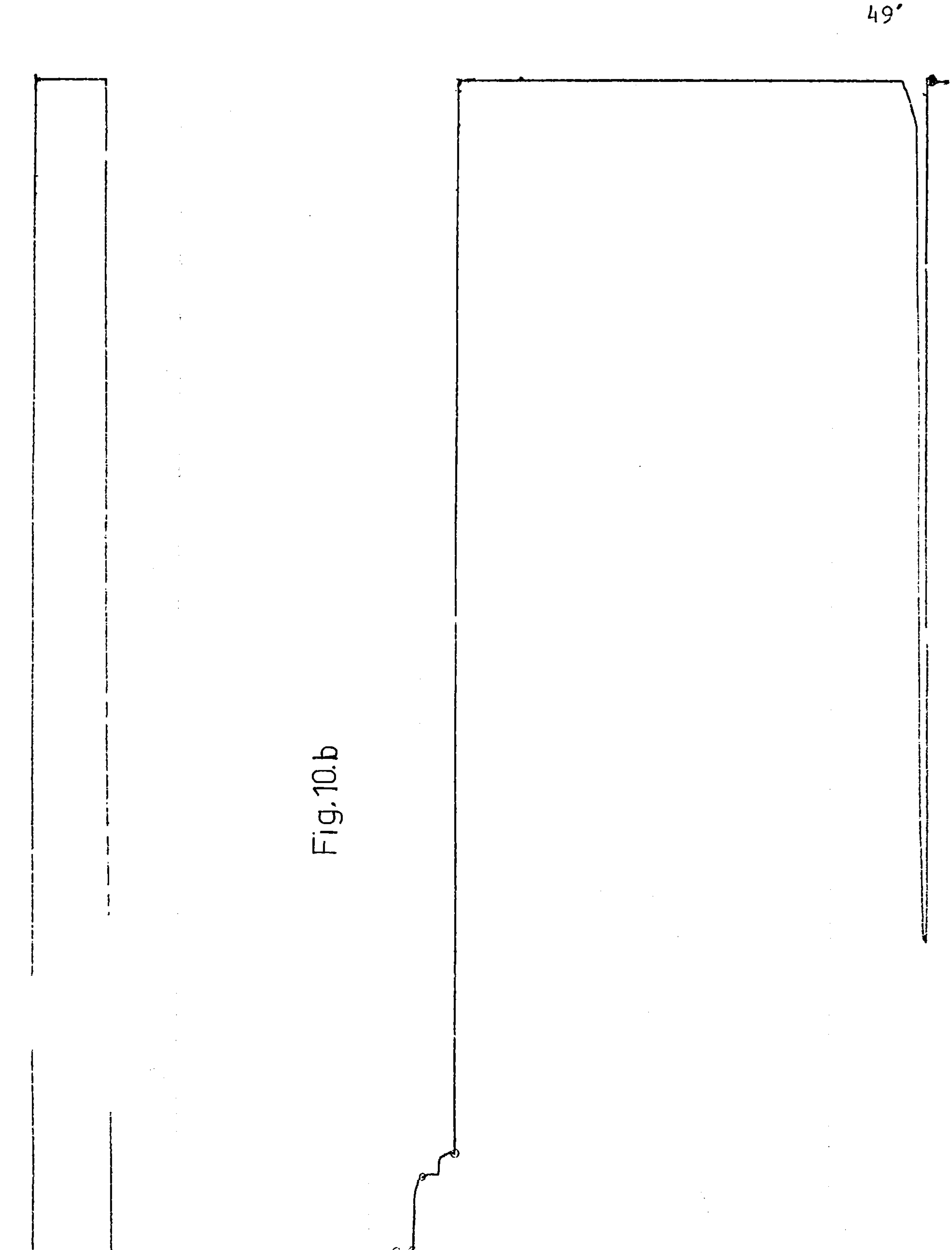

Fig. 10.b

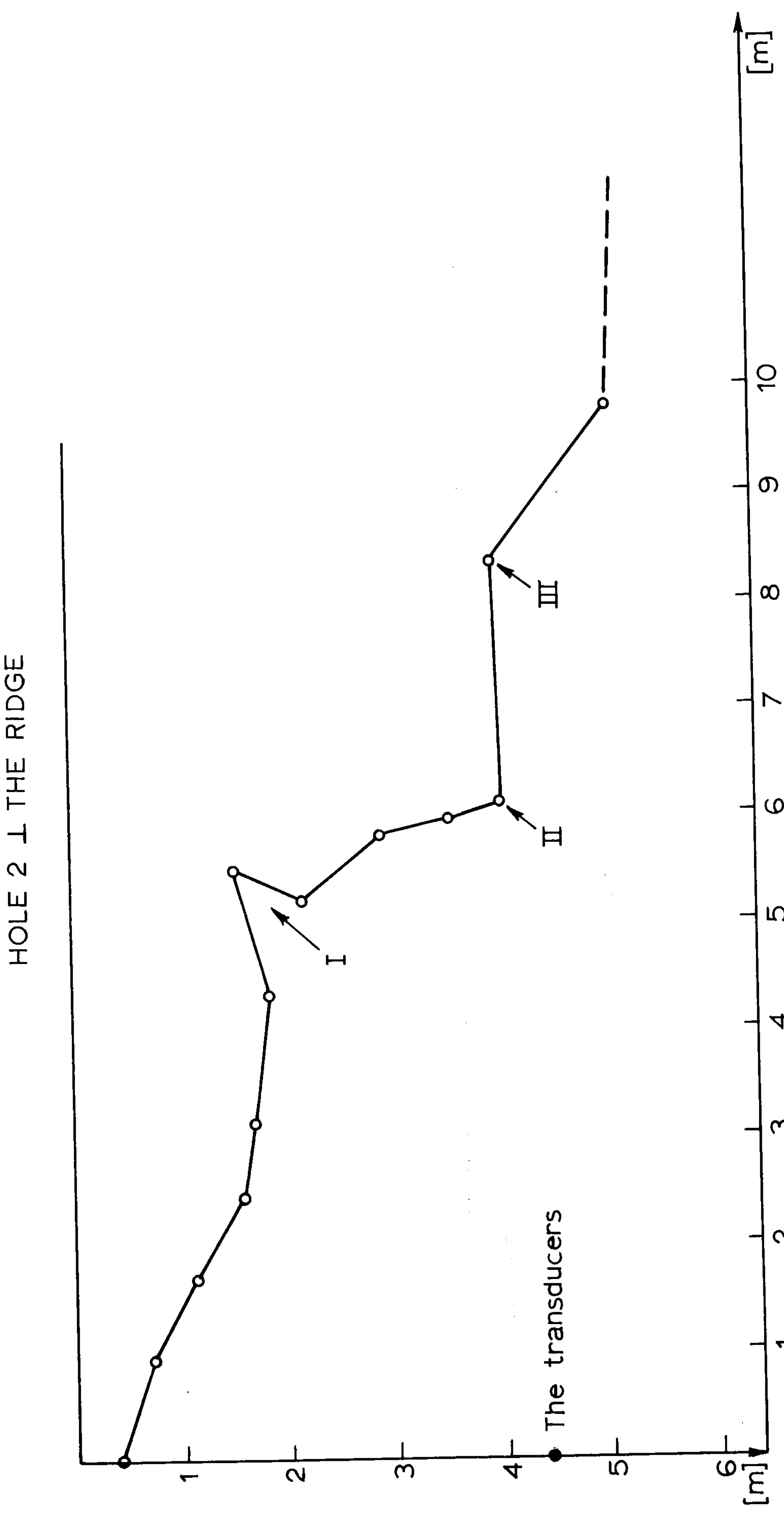
HOLE 2 ⊥ THE RIDGE
The transducers
I
II
III
1
2
3
4
5
6
7
8
9
10
[m]
1
2
3
4
5
6
[m]

Fig.11.a

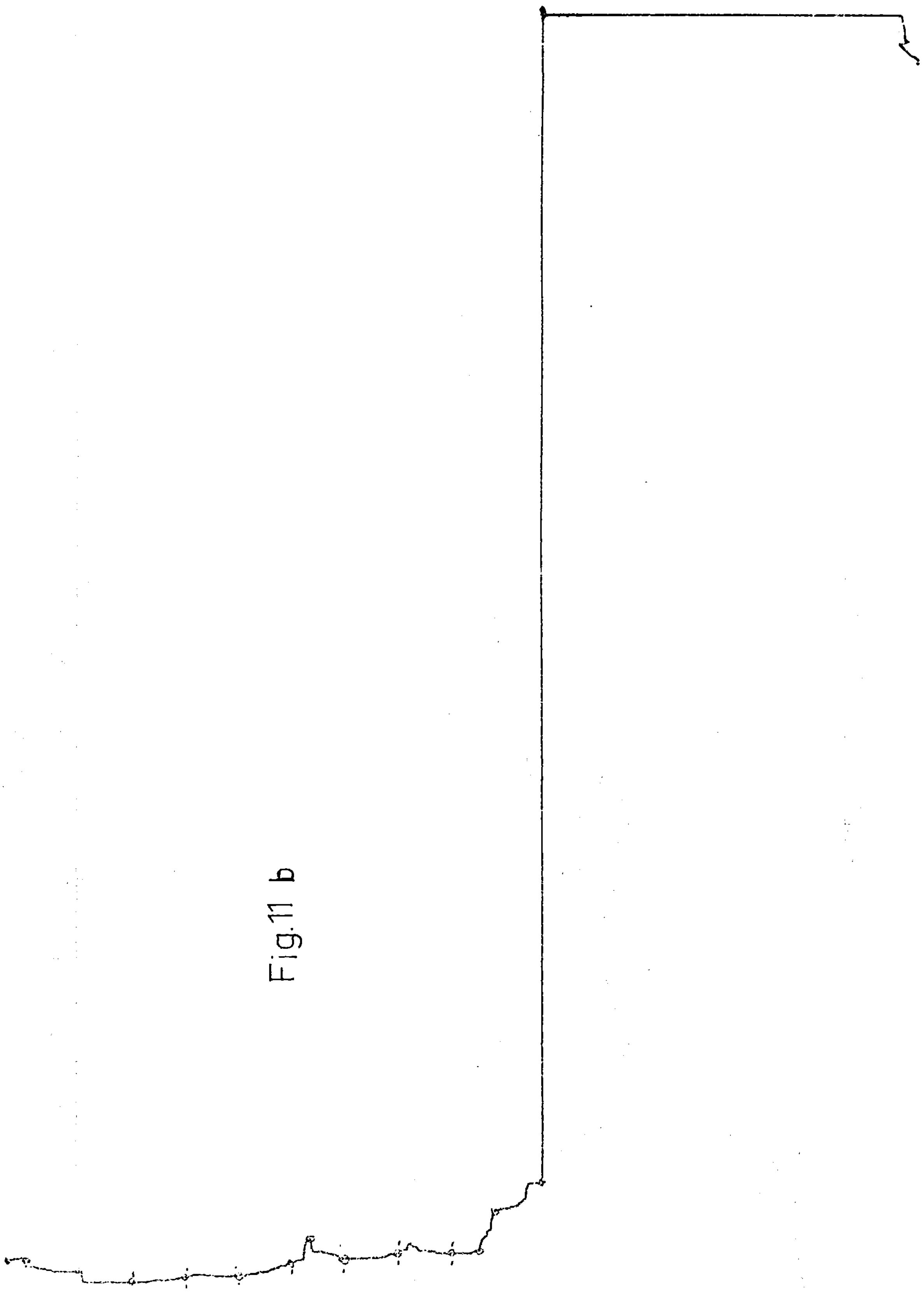

Fig.11 b

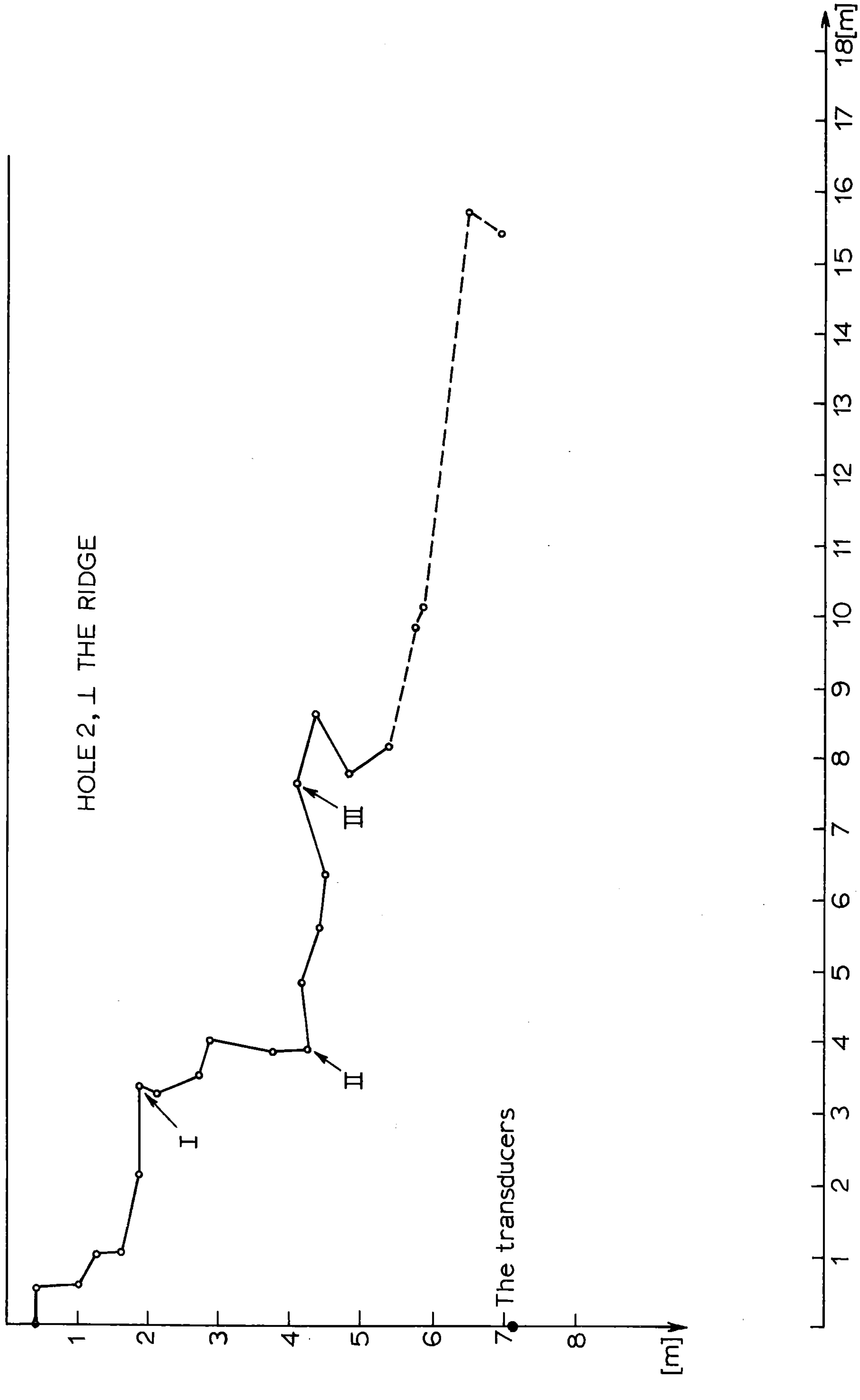
HOLE 2, ⊥ THE RIDGE
The transducers
I
II
III
1
2
3
4
5
6
7
8
[m]
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18[m]

Fig.12.a

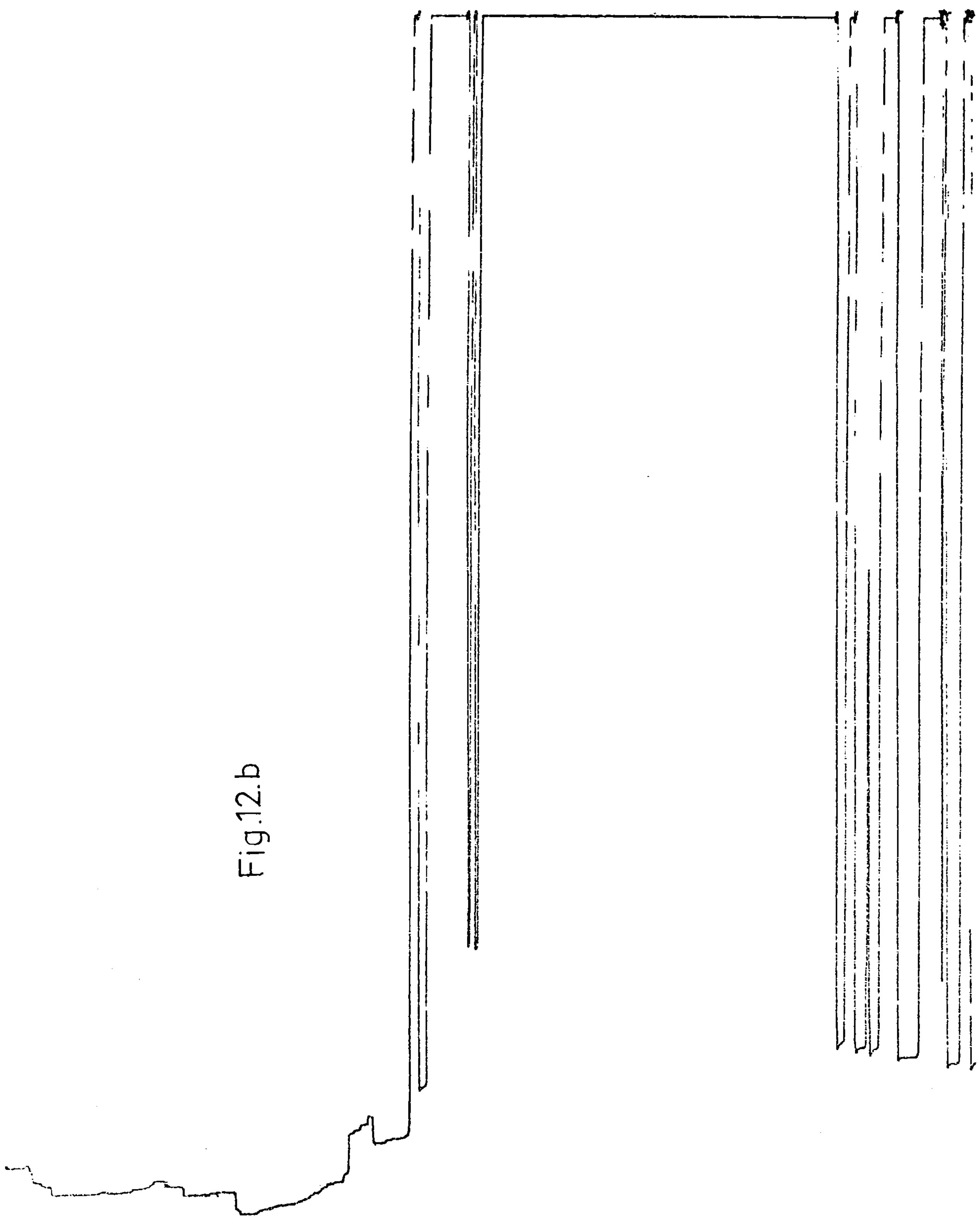

Fig.12.b

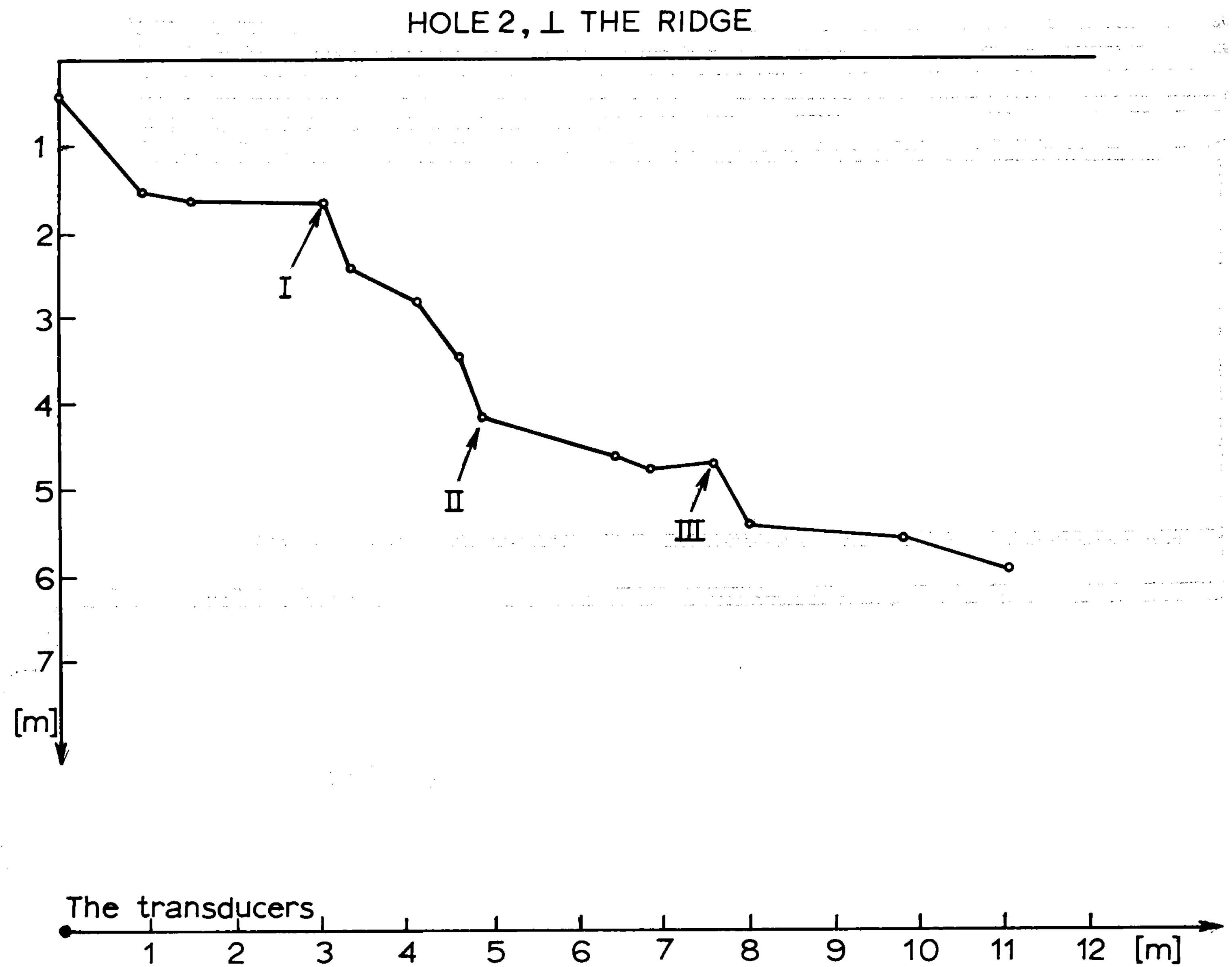
HOLE 2, ⊥ THE RIDGE
1
2
3
4
5
6
7
[m]
I
II
III
The transducers
1 2 3 4 5 6 7 8 9 10 11 12 [m]

Fig. 13.a

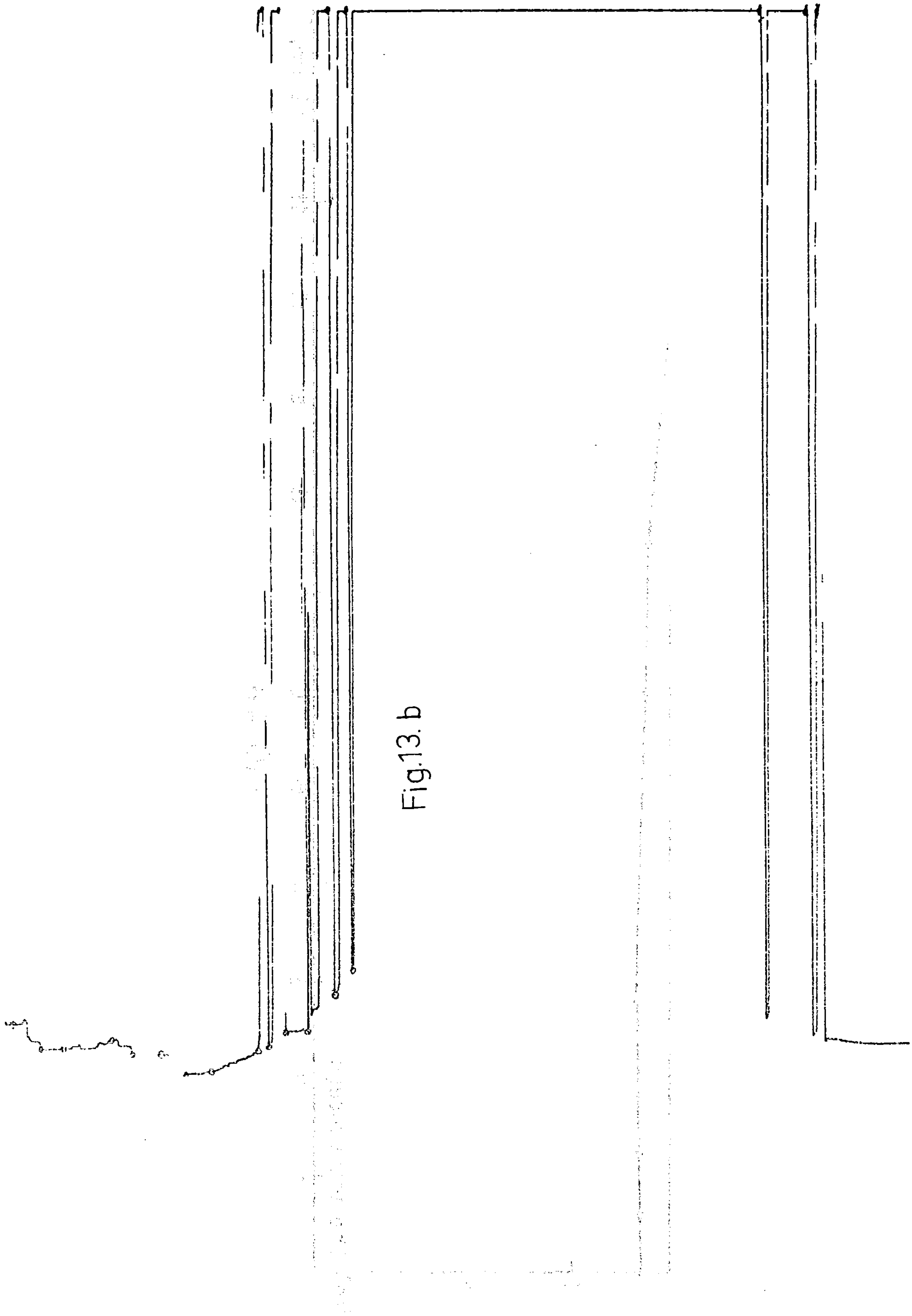

Fig.13. b

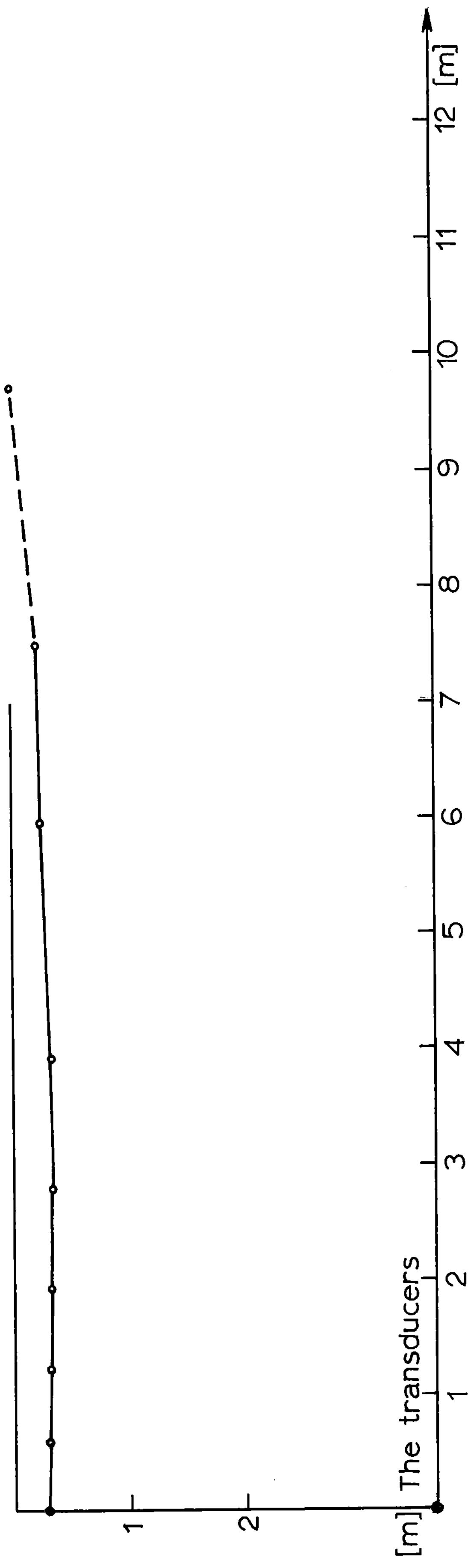

FIG.14.a

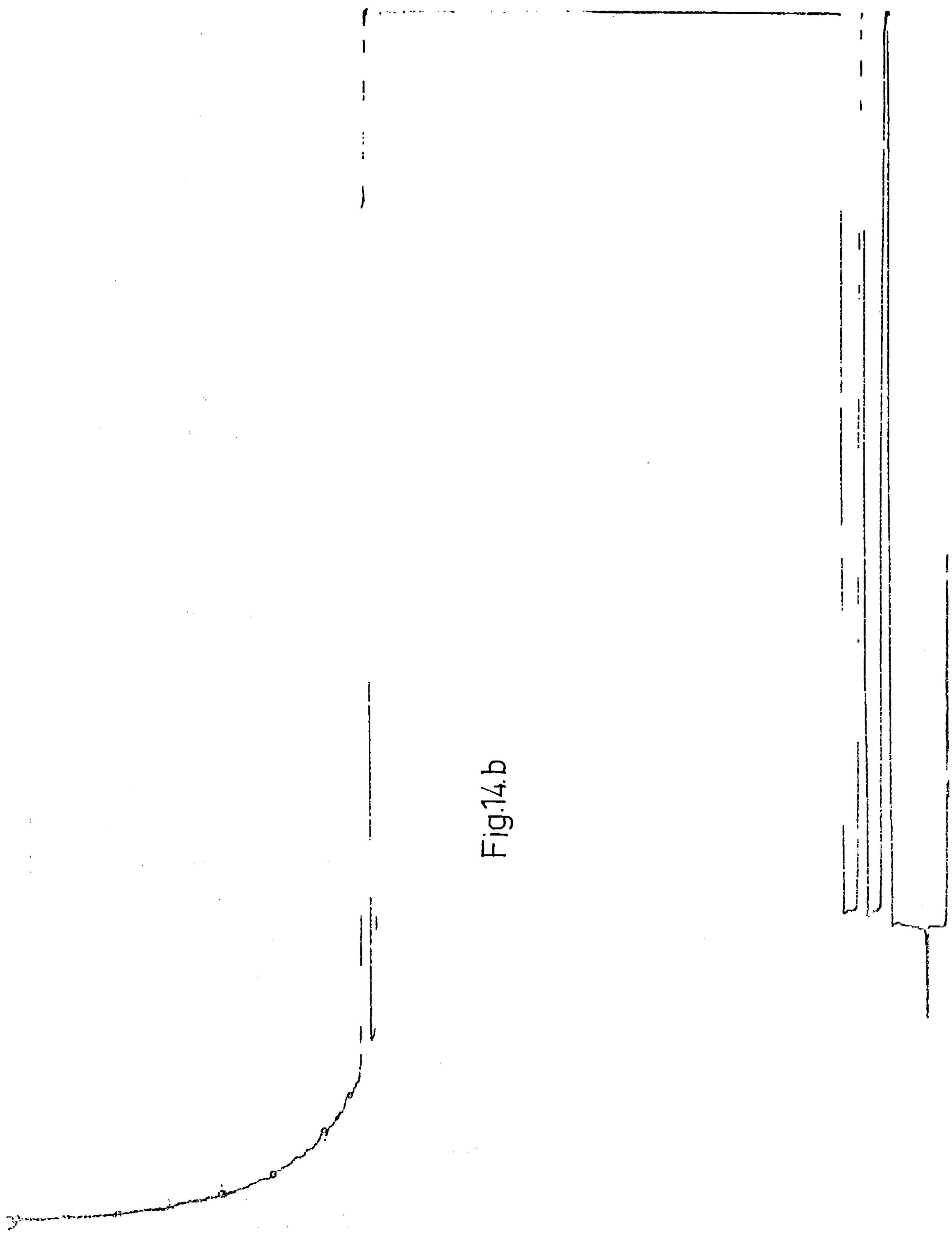

Fig.14.b

9. Changes and improvements

The most important improvement will be to to increase the amplification of the receiver. The gain of the receiver is planned to be raised up to 120 desibels and it may also be necessary to use time variable gain. If the gain variation is made such that it compensates for the signal level decrease as the distance increases it is also possible to use an intensity modulated graphic recorder to study the back-scattering strength.

The display system will be changed so that we shall get the side profile of the ridge directly on the recorder instead of the scan-angle/distance-output. To accomplish this we shall have to multiplicate the distance with the sine and cosine of the scan-angle to get the corresponding x- and y-coordinates. It would also be possible to try to use an oscilloscope display in order to get information about the inner structure and the back side of the ridge.

The water proofness of the scanner head has to be improved because a minor water leak was found during the experiments. There are also some practical improvements like a useful cable reel and a quicker lowering system, which could be made in order to make the use of the sonar easier in the field conditions. In further developments it might be convenient to use a radio transmitter as a link between the central unit and the submarine unit.

References:

1. Roth, W., Piezoelectric Tranducers, Proceedings of the I.R.E., p. 750, 1947.
2. Kossof, G., The Effects of Backing and Matching on the Performance of Piezoelectric Ceramic Transducers, IEEE Transactions on Sonics and Ultrasonics. Vol.SU-13 (1), March, 1966.
3. Kinsler, L.E., Frey, H.R., Fundamentals of Acoustics, John Wiley & Sons, Inc., 1962.
4. Camp, L., Underwater Acoustics, John Wiley & Sons, Inc., 1970.

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