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LOW FREQUENCY DETECTORS OF UNDERWATER SOUND

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ABSTRACT

Under contract Nonr 680(00), the Field Research Laboratories of the Magnolia Petroleum Company has designed and constructed a directional indicator for underwater sound and an acoustic impedance meter. Both instruments required acoustic pressure and velocity sensing detectors for frequencies between 20 and 500 cycles per second. The pressure detector employs a barium titanate crystal cylinder as a sensitive element and represents only a slight modification of the usual hydrophone design. The velocity detector employs a geophone of a type used in geophysical prospecting as a sensitive element. In this report velocity detector design criteria are discussed and proper methods are mentioned for successful detector application to waterborne sound problems. This detector is new in the field of acoustics and has several attractive features.

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LOW FREQUENCY DETECTORS OF UNDERWATER SOUND

I. INTRODUCTION

The Field Research Laborabories of the Magnolia Petroleum Company, under Contract Nonr 680(00), has developed two types of underwater sound instruments which exploit the low audio frequencies. The first to be completed was a passive intensity meter which gives the direction of arrival of underwater sound. This equipment has been described in previous reports, and has been sea tested for applications in both transient and steady state sound fields.[8,9] The second instrument was a bottom impedance meter which has been given only preliminary operational tests. Both pieces of equipment operate by an appropriate correlation of acoustic pressure and velocity signals.

Unique detectors have been constructed to provide these signals, and their development constitutes a completed phase of the project. The pressure sensitive detectors represent a modification of the 3A hydrophone design to permit operation at low frequency. The velocity detectors incorporate geophones as the responsive element. More detail has been considered in adapting geophones to acoustic problems because results have been obtained which supplement those of other investigators.[11,12] In all recent acoustics work with geophones they were placed in contact with the sea bottom. Substantially contrasting behavior has been obtained by means of good water coupling to the geophones and good isolation from the bottom.

Specific velocity detectors are described and their design criteria discussed, but their characteristics should make them attractive in other types of acoustic equipment. In any case, it is especially recommended as a small, sturdy, cheap substitute for pressure gradient detectors. It is extremely sensitive to velocity (the equivalent of pressure gradient) over a band of frequencies at the low end of the spectrum. It should, of course, be used only when the factors affecting its operation, as pointed out herein, are properly considered. The pickups to be described were required to have flat response from 20 to 500 cycles with high and stable sensitivity. They were to be rugged, small, and light weight for portable operation from either small craft or heavy vessels. A major feature achieved in the Magnolia prototype equipment design is the use of long-wave sound for acoustic directivity without large, bulky, or heavy arrays of detectors, or complicated electrical or mechanical scanning systems.

II. GENERAL

A frequency band of 20 to 500 cycles per second was selected as a desirable band for operation of the sonic bearing indicator and the impedance meter. In this band, the attenuation of undersea sound is low, and sound generation by ocean going vessels is high.(1) At all frequencies in this band the detectors were small in comparison to the wave length of sound. Velocity sensitive geophones, or seismometers, for this frequency band are conventional, but their use under water is unusual. Piezo-electric pressure detectors in water are conventional, but their use in this frequency band is new. Both velocity and pressure sensitive types of pickups are necessary parts of the prototype equipment. Since suitable detectors are commercially unavailable, their design and construction became a distinct phase of the project.

The construction of special pressure detectors for our application appeared to be advisable. No extensive investigation of all available pressure sensitive detectors was conducted, but type A-3 hydrophones, which were available and appeared to be the most suitable, were tested. The signal-to-noise ratio was poor throughout the low frequency band; however, these hydrophones were intended for use at much higher frequency. Piezo-electric type pressure detectors for geophysical use have been reported and might have been tested but exact specifications of any available units have not been publicized. Satisfactory detectors representing variations of the typical hydrophone design were specially constructed for our apparatus.

An acoustic velocity signal value may be determined from the pressure gradient by using only pressure detectors, but this method is known to have low sensitivity and would have required very large spacing between detectors in low frequency application. It was presumed that detectors could be constructed which would be more suitable.

Geophones ordinarily employed in seismic prospecting are normally used on land or on the sea bottom as velocity sensitive pickups. Their use in underwater prospecting is a comparatively recent trend, and underwater models commercially available are considered unproven in other acoustic applications. The high sensitivity throughout the low frequencies indicated that suitable acoustic detectors could be constructed incorporating geophones as the sensitive element. This type of detector has been used in some underwater sound investigations but geophysical seismometers have not found favor in underwater acoustics work.(11) Most tests have employed these units in their normal manner -- vertically sensitive and acoustically coupled to the sea bottom. The British have been most active in this field(12) but have reported only limited success.

The geophones used in the construction of underwater pickups are commercially available,(4) and no effort has been made to build them under the Magnolia contract. Their construction is similar to that of a permanent magnet dynamic loud speaker with no cone. Some detail may be found on geophones in literature on vibrographs or seismometers.(2,3) The mass of the geophone's "voice coil", and the stiffness of the coil suspension comprise a damped mechanical oscillator with one degree

of freedom. Normal geophone operation occurs at sound frequencies above that of resonance of this mechanical system. The shock mounted coil remains stationary, and the magnet and its field move with the vibrations of the geophone housing.

Geophones mechanically resonant at 40 cycles and at 14 cycles have been selected because they have good sensitivity to the low frequency components of the noise produced by ship board machinery. Also their output voltages have a constant phase relationship at the higher frequencies usually found under water as propellor noise. The 14 cycle unit normally is sensitive to vertical vibrations only and must be specially ordered for horizontal use. Its good response to a very low frequency disturbance, which makes it more desirable for studying low frequency sounds, also makes the 14 cycle unit more susceptible to ship motions in unsteady sea conditions. The 40 cycle geophone is less sensitive to ship roll, is useful when oriented either horizontally or vertically, and is in general of more rugged construction. Its use is recommended if future tests show that the 14 cycle units response has no additional merit. Both units are commercially available, and are interchangable in the final velocity pickup assembly.

Testing of the pickups has been done in the laboratory and at sea. The overall behavior of the prototype equipment at sea is the best test of the detector operation. Individual calibration of the detectors in water is beyond the scope of the contract. A calibration of the geophone units has been made by means of a shaker table.(10) Controlled vibrations

are impressed upon the geophone housing with this device, and the resulting signal voltage is measured at the coupling transformer secondary. A value of 13 volts per inch per second at 100 cycles is obtained across a 1.1 megohm load resistor. This value is not a valid figure for the operation in water as the acoustic coupling between water and detector is not unity.

III. DETECTOR DESIGN CRITERIA

It is desired to have ambient sea noise on a quiet day produce more voltage at the amplifier output than the electronic background. Only then, in normal operation, will the signal-to-noise ratio always be determined by the sea rather than by the quality of the instruments. Efficient use of sensitive detectors and of low noise amplifiers is necessary for obtaining this high quality, and no step may be ignored in the transformation of acoustic energy in the water into electrical energy of the amplifier input circuit.

The electrical aspects of the geophone operation and the associated amplifier input circuit are similar to those of a high fidelity, low impedance audio microphone system. The problems are centered in the design of a suitable coupling transformer. Transformers are used in geophysical work to match the low impedance geophone coils to the high impedance grid circuit. A voltage gain of 74 has been realized in the transformers of the Magnolia underwater sound apparatus.

The geophone elements used in detector construction give about 155 microwatts per inch per second. This value is considered good for such small units (325 gm). Ambient noise in the earth may be detected with this sensitivity on a quiet day. Greater sensitivity is required for horizontally directive sound detectors 50 feet below the water surface if ambient sea noise is to be comparable to electronic noise.

Mechanical coupling of the geophone to the earth or to the sea bottom is not usually difficult in geophysical work, but coupling to

the water becomes an important aspect of an underwater sound detector design. An expression for the coupling of the water and an immersed sphere has been derived by Wolf.[5] The expression is valid for any shaped object if it is small compared to the wave length of sound in water. His formula for this case has been used to compute the coupling between the geophone (non-spherical) and the water. It reduces to:

$$U/V = \frac{3}{1+M/m}$$

where: U = geophone acoustic velocity

V = water particle acoustic velocity

M = geophone mass

m = geophone's displaced fluid mass.

U/V is defined as the coupling, and the phase shift between U and V is zero in this case. The formula indicates good coupling for detectors with low specific gravity (density).

An aluminum can for the geophones shown in Figure 1 was designed with this in mind. The large air space and light metal construction reduce the specific gravity from 5.5 for each geophone to a value of 1.3 for the complete assembly containing two geophones. The coupling coefficient also happens to be 1.3 and represents 30% more sensitivity than is indicated by the shaker table tests mentioned in Section II.

There is danger in trying to get further sensitivity increases by this method. Greater reduction in density would probably cause lower rigidity of the can. Less rigidity might place the frequencies of

spurious modes of can resonance within the band between 20 and 500 cps. Such resonances are to be avoided because singularities in the geophone response spectrum are often produced by them.

Necessary dynamic balance in the detectors is obtained when they behave as a homogenous solid in the sound field. Consider any homogeneous solid object of small size placed in an underwater sound field. A balance of forces will always exist such that no rotation or rocking of the object will be produced by the water vibration. Non-homogeneous solids will also have only translatory vibrational motion if the center of gravity coincides with the center of volume as it does for homogeneous solids. The non-homogeneous solid then has dynamic balance. A reasonable effort has been made to maintain this condition in the velocity sensitive pickups. Geophones are not sensitive to angular velocity, but their output would be proportional to their distance from the rotational axis. This means that a geophone signal could be made weak, made zero, or reversed in polarity depending upon its position inside the detector housing.

IV. MOUNTING AND EXTRANEOUS INFLUENCES

Sensitivity to the desired acoustic parameters has been achieved in the pressure and velocity detectors, but improper application and mishandling may impair their operation. A reasonably homogeneous water environment for the detectors is necessary. The influence of a large air bubble upon the nearby sound field has been described[1,7] in terms of scattered energy. The influence is shown to be small for small bubbles and for long wave length of the sound. Even though no bubbles are present at the listening stations, similar scattering of energy should be produced by the detectors themselves. No effect of sound field distortion by the detectors has been observed during operation of the Magnolia apparatus, and the influence has been presumed small.

Even slight contact between the velocity detector and anything solid would produce good acoustic coupling to this solid and decoupling of the detector from the water. For this reason, a low frequency detector suspension of rubber shock cord has been used as an underwater support. It has been mentioned that no mechanical scanning is done with the acoustic bearing system developed under this contract.[8] The mountings for the detectors are required only to support the detectors at a fixed or mobile location in a vertical position with known azimuthal orientation. Figure 4 is a cut-away view of a tripod about 6 feet high used in intensity meter operation. The rocker arm assembly provides for self-leveling of the detectors in the event that the tripod settles on a rough or soft bottom. The suspension of the detectors on two cords insures steady

orientation of the velocity sensitive detectors. The elasticity of these cords provides the necessary vibration isolation and acoustic decoupling. The rubber screen provides protection from tide and wave action, but does not have a significant influence on the sound field. This screen has been removed in all lake tests previously reported. The tripod has been satisfactory for all shore based tests.

The photograph of Figure 5 shows the original plan for mounting the detectors for bottom impedance measurement. The spherical velocity detector has sufficient buoyancy to support the pressure pickup and the necessary cable junction box. The use of shock cord provides mechanical (acoustic) isolation from the 90 pound anchor. The sphere is secured in a manner which provides self-righting ability in the presence of water currents. This model does not permit the sound detectors to be near enough to the bottom nor near enough together for the shortest wave lengths anticipated, and its use has been discontinued.

The tripod of Figure 6 permits a shock cord suspension of the pickup. Random azimuthal orientation is permissible in this case. This design also allows self-righting of the detector unit with mechanical isolation. The airplane shock cord has provided good elastic properties to the detector mountings. The rubber has not deteriorated in a month's use under salt water; however, it is not recommended for permanent installations.

V. RESULTS

Detectors have been constructed permitting underwater sound direction indication from a single instrument station with system sensitivity over a frequency band from 20 to 500 cycles per second. The figures in the appendix show these detectors and merit some additional discussion.

Several forms of velocity signal detectors or pickups have been constructed which use geophones as sensitive elements. The sketch of Figure 1 indicates the general form of a velocity detector used in tests at San Diego[9] and at Beavertail Point, Rhode Island.[8] It has been discussed in Section III. The can which is anodized to retard corrosion is 4½ inches in diameter and 5¼ inches high. The unit weighs 5½ pounds. A mounting bar at the top is provided for suspending the detector by a shock cord. Water proof electric plugs connect the signal cable to the geophones through the bottom end plate. Both the top and bottom plates screw into the aluminum can with an O-ring seal. Two geophones are shown recessed in an aluminum block within the can. Mounted in this way, they provide two horizontal components of acoustic velocity signal. The sensitivity is about 278 microwatts per inch per second. The source impedance is 215 ohms.

A slightly taller model has been constructed containing three geophones. The construction is similar to that of the two element detector with an additional vertically sensitive geophone mounted in the top of the block. This device gives three perpendicular components of acoustic velocity signal. The specific gravity of this detector unit is 1.7 which

gives a coupling of 1.11, as mentioned in Section III.

Figure 2 shows a detector used in acoustic impedance measurement. The sketch of Figure 3 indicates the pressure detector construction more clearly. The sound pressure is transmitted to the barium titanate through the rubber at the sides and through the metal plates at each end. The crystal cylinder is 4" long X 2" O.D. with a 3/16" wall.(6) Its sensitivity is 15 microvolts per dyne per square centimeter. A preamplifier employing a type GE 5751 vacuum tube provides a signal amplification of 100, and an output impedance less than 10 ohms.

The detectors shown in Figures 1 and 3 are mounted as shown in Figure 4. The tripod, described in Section IV, is used as an instrument station on the sea bottom for sound direction indication.

As a component of the bottom impedance meter, a velocity detector was used having a density (gravity) less than one gm/cm^3. In this model, shown in Figure 5, a large laminated wooden ball 18 inches in diameter was used for floating and coupling a vertically sensitive geophone. (This was discussed in Section IV.) With a density of about 0.33, the wooden ball velocity detector has a water coupling of 1.8. This drops to 1.4 at 1000 cps when a phase shift of about 4 degrees occurs between the ball and the water. The unit has not had adequate tests for spurious resonant singularities in its response curve. The use of this detector has been discontinued because it is too large in terms of wave length at 500 cycles.

A new detector has been constructed for the impedance meter. It consists of a barium titanate cylinder in a rubber sleeve with an amplifier

and geophone inside. The parts are shown in Figure 2 and the assembled unit supported by a tripod is shown in Figure 6. The geophone unit is electrically separate from the pressure detector and amplifier, although its leads are brought to the instrument panel through the same plug and cable. This unit has a density of 3.1 which corresponds to a velocity coupling to the water of 0.73. Complete dynamic balance of the impedance meter units has not been attempted as it is to be used in only the vertical position with vertically traveling sound waves.

VI. CONCLUSION

Low frequency detectors with wide practical applications in underwater sound may be constructed for response to either pressure or velocity. Good sensitivity is obtained with conventional design if attention is given to the details presented in this report. Similar detectors have been used for both bottom impedance measurement and for acoustic intensity measurement. Other sonic devices may also be adapted to the low frequency spectrum partly by incorporating these low frequency detectors.

The velocity detectors described offer several possibilities which have not been emphasized. Their cosine low sensitivity pattern permits directional effects which are impractical at long wave lengths by any other method. Their lack of a diaphragm, or window, or sensitive surface makes them indifferent to static pressure effects or other forms of rough service. Their small size permits great flexibility in their application. Since their operation is independent of special materials or phenomena, an accurate sensitivity calibration will be maintained over a wide range of temperatures and vibration amplitudes. It is hoped that this report will promote their popularity in the field of underwater sound.

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APPENDIX

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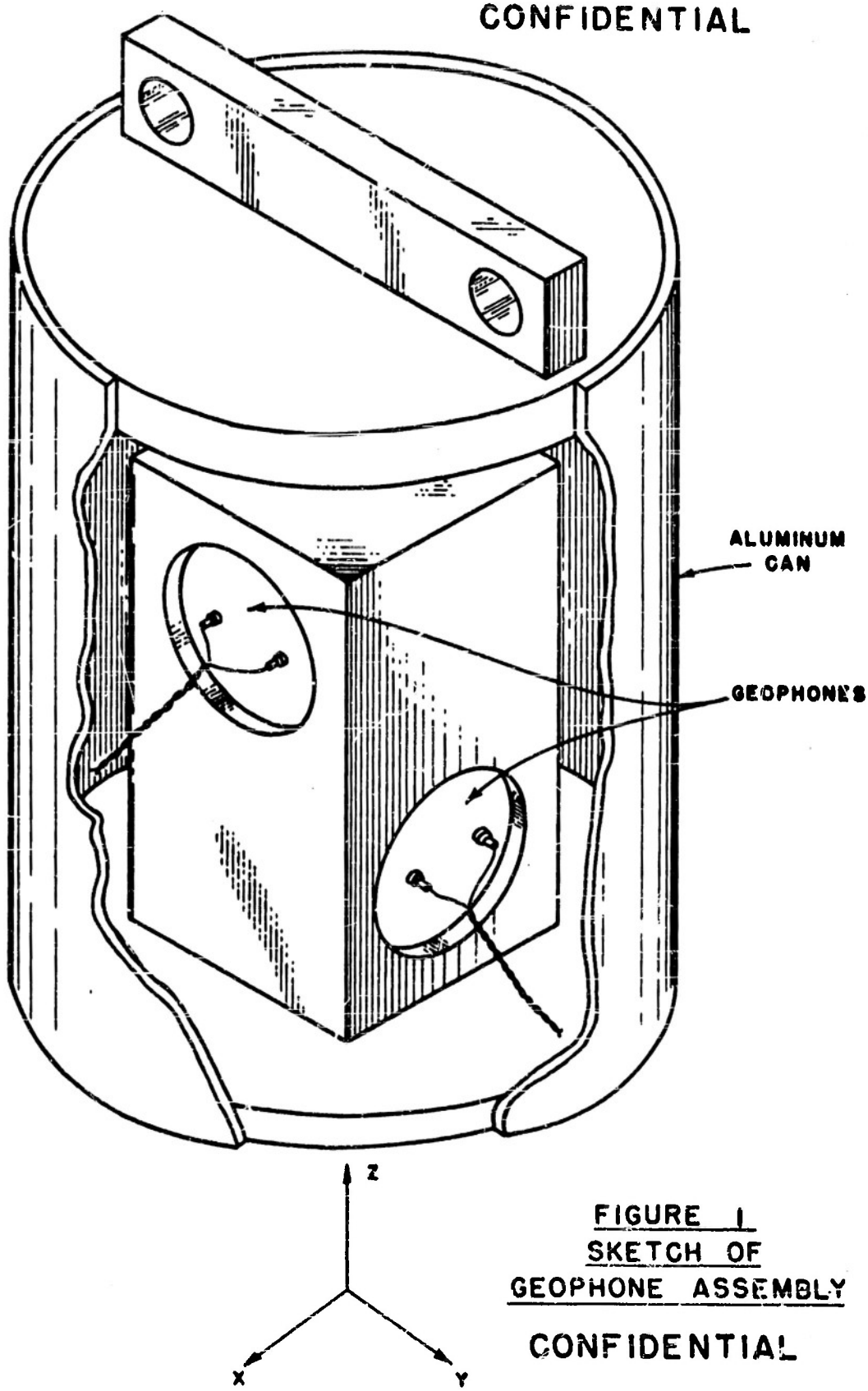

FIGURE 1
SKETCH OF
GEOPHONE ASSEMBLY

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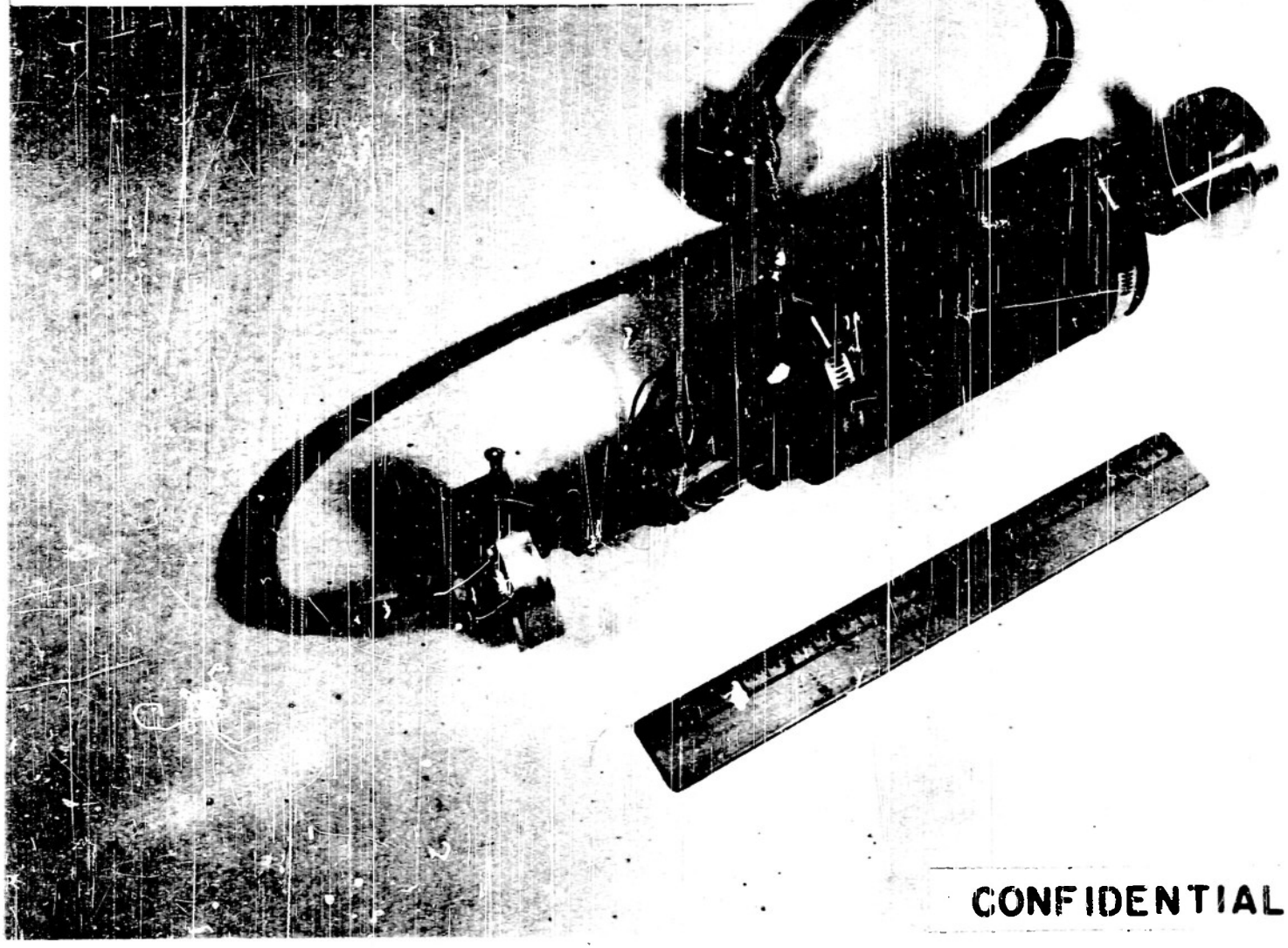
FIGURE 2

BOTTOM IMPEDANCE METER PICKUP



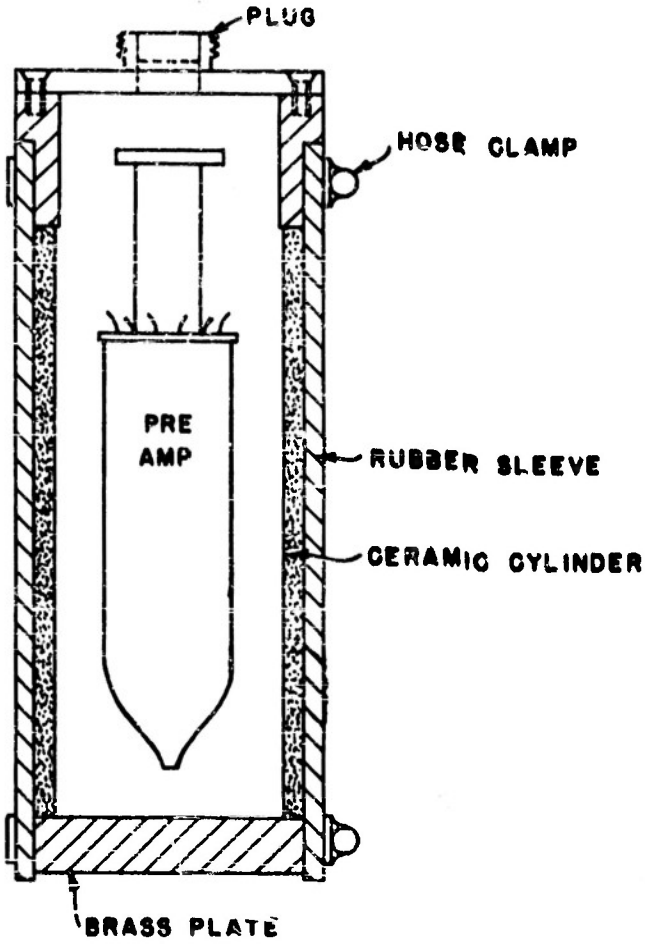


FIGURE 3
PRESSURE DETECTOR

FIGURE 4

SONIC BEARING INDICATOR TRIPOD

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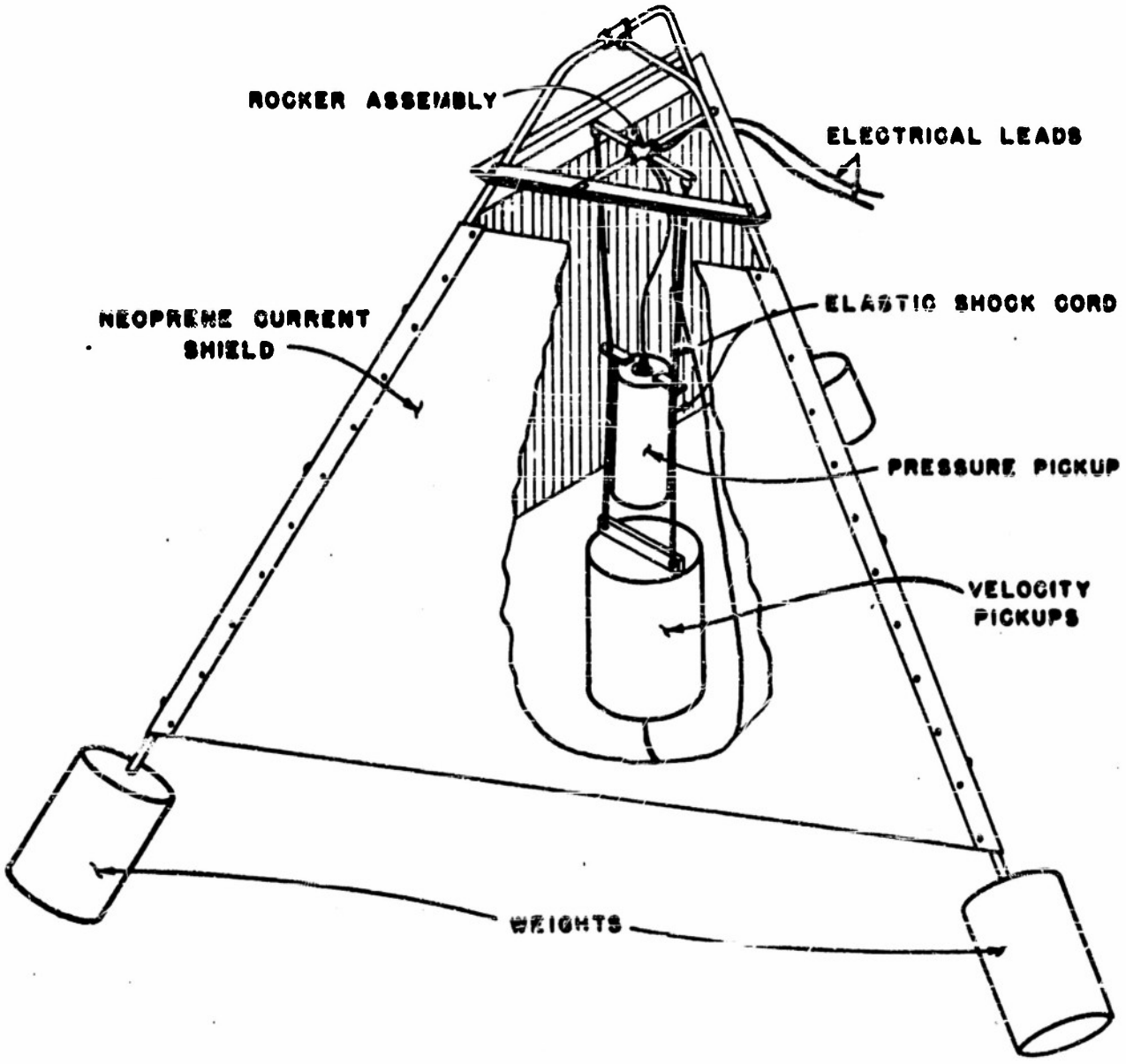

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FIGURE 5

BOTTOM IMPEDANCE METER PICKUPS

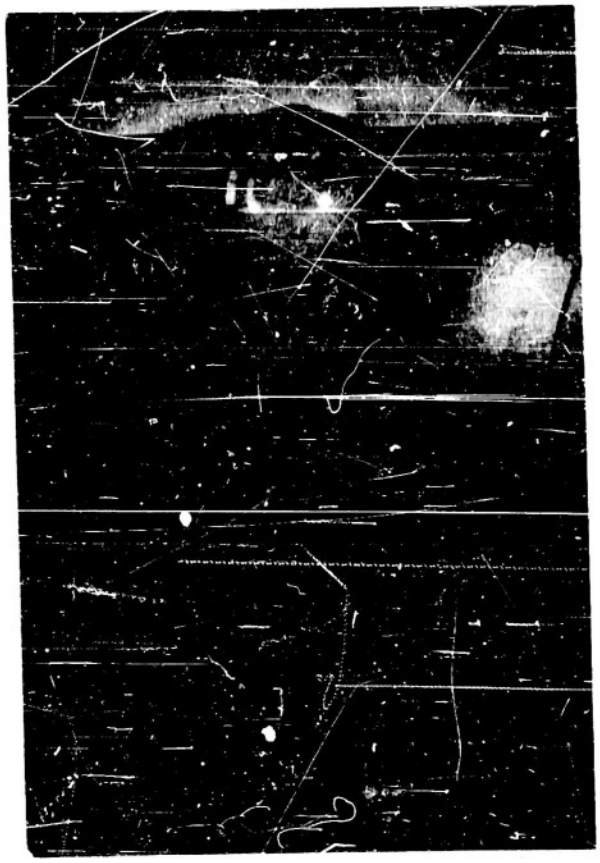

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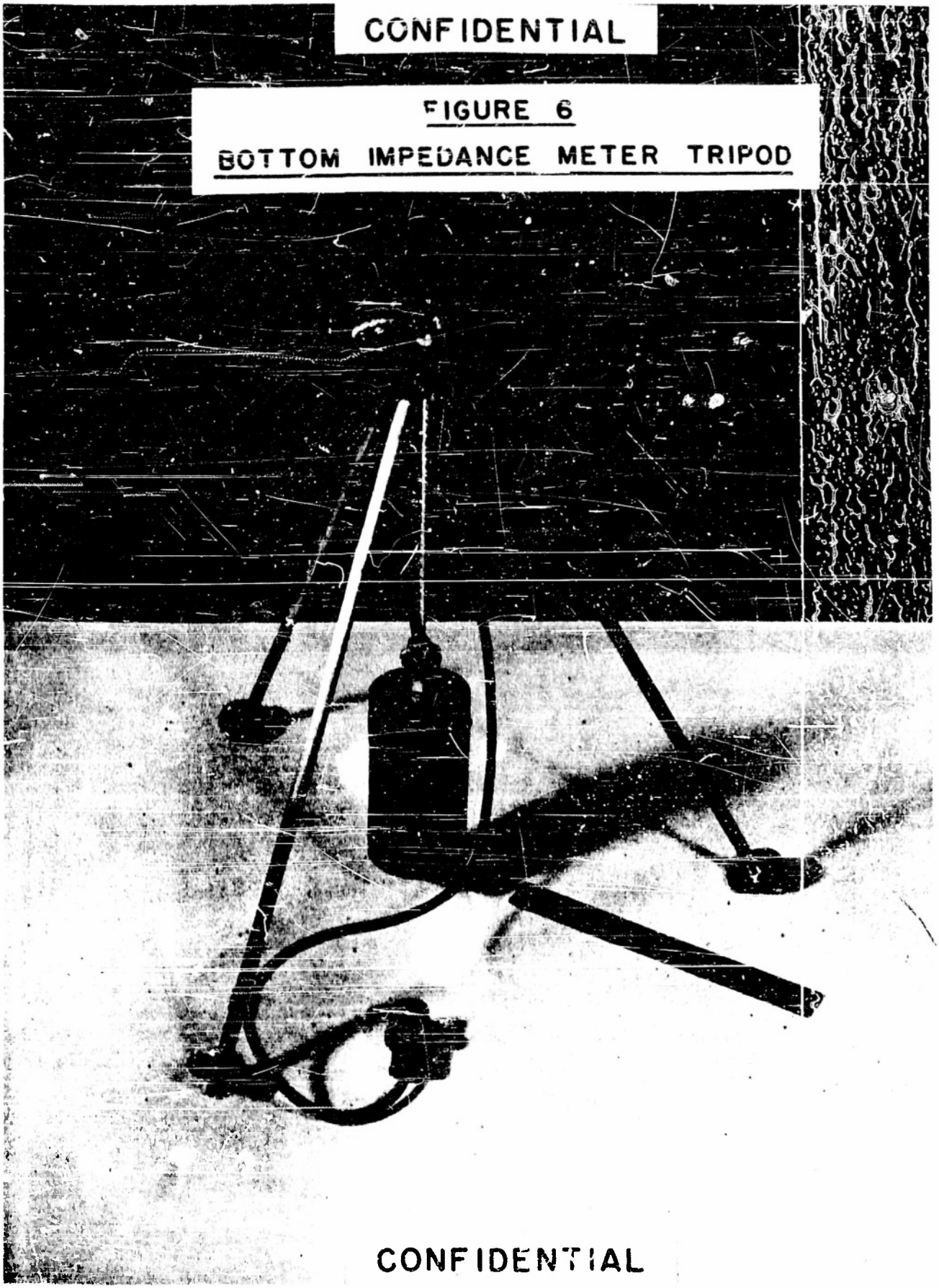
FIGURE 6

BOTTOM IMPEDANCE METER TRIPOD



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