RADIO ACOUSTIC METHOD OF POSITION FINDING IN HYDROGRAPHIC SURVEYS.

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RADIO ACOUSTIC METHOD OF POSITION FINDING IN HYDROGRAPHIC SURVEYS.

On the Pacific Coast of the United States during the winter frequent gales prevent work and often the surveying vessel would be held in port during the favourable weather following a gale by the heavy swells breaking on the bars which are caracteristic of all the harbours. In the summer time fog and haze are prevalent.

In consequence the United States Coast and Geodetic Survey has been lead to consider the application of the method of sound ranging for hydrographic work, the study of which has improved during the war, with a view to determining the position of the ship.

The experiments have been performed on board the "*Guide*" from October 1923 till March 1924 by the personel of the Coast and Geodetic Survey and by the physicists of the Bureau of Standards. The following information relating to the description and operation of the apparatus is extracted from Special Publication N° 107 recently issued by the Coast and Geodetic Survey.

APPARATUS AND METHOD OF OPERATION.

The non visual determination of the off shore position of a vessel with reference to fixed shore points may be accomplished in a variety of ways. Direction measurements can be made on either sound or radio signals. The intersection of two lines of direction through the ends of a shore base line gives the desired position. Other methods involve the measurement of time intervals. In one such method the intervals between the arrival time of a single sound signal at three or more different shore points are observed. The position of the source is derivable from these intervals and the speed of sound. In another method a sound and radio signal are started simultaneously at one point, and the interval of their arrival times is observed at another point. The magnitude of the interval depends on the difference between the speeds of the two signals and on the distance between the two points. The speed with which radio signals progress through space is so great, compared to sound speeds, that the time in which the radio signal passes from the transmitter to the receiver may be ignored, and the arrival time of the radio signal may be considered identical with the departure time of the sound signal. If the two signals are transmitted simultaneously from a ship; the observed interval at a shore station is practically the time in which the sound signal travels from the ship to the shore station. Under-water sound signals are preferably used. The observed time multiplied by the speed of sound in the sea water gives the distance from the ship to the sound receiver of the shore station. Two such distances from two shore stations at the ends of a shore base line completely determine the position of the ship.

In the present instance the following considerations determined the choice finally made:

a) Data for position determination to become directly available on the vessel. This avoids transmission of data.

b) Reception of sound signals to be at shore, avoiding complications due to ships noises.

c) Mobility of shore installations.

d) Requirement that vessel be the base of operations; including the locating of shore stations.

The requirements of the service, therefore, suggested as the preferred method one in which a sound signal is started from the vessel, and in which the arrival of the sound signal at the shore station sound receiver automatically results in the transmission of a radio signal which in turn is received and recorded aboard the vessel. The time interval between the initiation of the sound signal and the reception of the radio signal is measured by suitable chronographic apparatus. This multiplied by the proper value of the speed of sound in the sea water gives the distance of the vessel from the corresponding shore station. All the apparatus is here assumed to function instantaneously. The question of lags will be discussed later. Two distances from the two shore stations are sufficient for a position determination. A third shore station provides a check.

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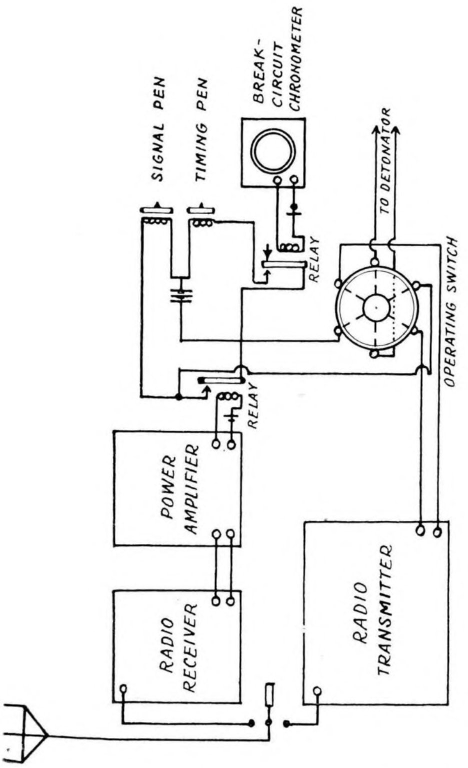

Fig. 1

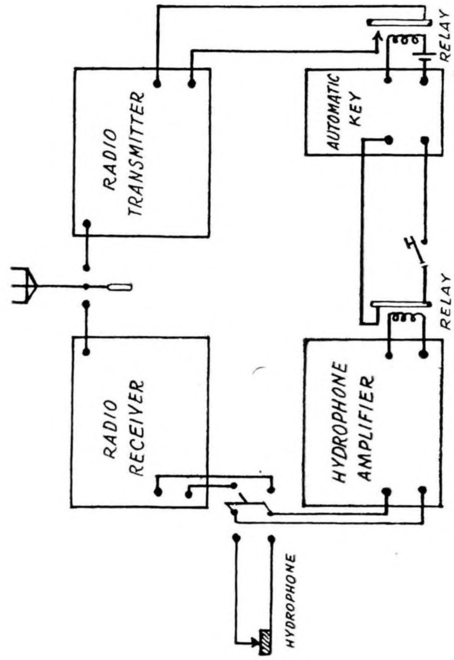

Fig. 2

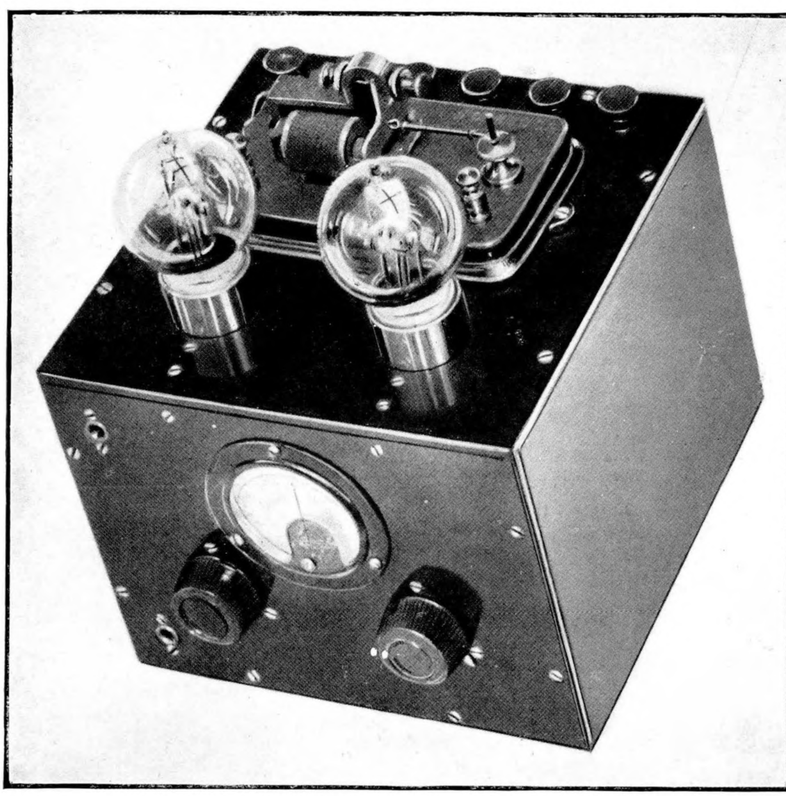

Fig. 3

THE SHIP APPARATUS. — GENERAL DESCRIPTION OF FUNCTIONING.

The apparatus on board the vessel must perform the following functions :

a) Produce the sound signal.

b) Record its departure time.

c) Receive the radio signals from the shore stations.

d) Record their arrival times.

e) Provide continuous calibration of the chronographic apparatus.

f) Provide for communication with the shore stations.

The sound signal is produced by the detonation of a T. N. T. bomb of suitable size suspended by cable from a float being towed by the vessel. Mercury fulminate detonators which are fired electrically are used. The firing is done from a snap switch which closes three circuits simultaneously. One circuit fires the bomb, another keys the radio transmitter, thus sending out a radio signal, and the third operates a chronograph pen which records the instant of firing. This operating switch is actually snapped through the " on " to the " off " position in order that the chronograph record of the time of fire and the radio signal should not be inconveniently long. The radio signal merely conveys the information to the shore operators that the bomb has been fired.

As soon as the bomb has been fired the ship operator switches his radio apparatus from " transmit " to " receive ". The radio signal returned from the shore station then passes through the radio receiver and power amplifier, after which the signal energy has been sufficiently amplified to operate a relay. The relay controls the local power used in operating the signal pen of the chronograph. The schematic layout of the ship apparatus shown in Figure 1 shows how the same signal pen is operated to record both the instant of sound signal departure and that of radio signal arrival. Another pen records a second's scale adjacent to the signal line, the seconds's signals being provided by a break-circuit chronometer.

GENERAL DESCRIPTION OF FUNCTIONING OF SHORE STATION APPARATUS.

The shore station apparatus must respond automatically to the receipt of a sound signal by the transmission of a radio signal and provide means of communication with the ship. At each shore station a hydrophone mounted on a suitable support is planted on the sea bottom and connected by cable to the shore station proper. A hydrophone is a microphone for underwater service. It converts the pressure variations of sound waves in the water into variations of electric current in its circuits. Its functions are analogous to that of the transmitter of a telephone. The current variations are amplified by the hydrophone amplifier, the output of which provides sufficient power to operate a relay. A sound pulse in the water, therefore, results in a momentary closing of this relay. The operation of this relay results in the keying of the shore station radio transmitter, which thus sends out the radio signal to be received on the ship.

The radio transmitting set is not keyed directly by the hydrophone-amplifier relay for reasons among which two are of paramount importance. The direct operation would involve close association of the high potentials of the radio transmitter with the amplifier. This would present great difficulties in the control of the latter. It is furthermore undesirable that all three shore stations should respond with a radio signal instantly on receipt of the sound signal, as this would, in general, make it difficult to identify each radio signal with its station of origin. In order to facilitate this identification, a clock-work mechanism is provided at each shore station which is set in motion by the hydrophone amplifier. This clockwork or automatic key rotates a code wheel which controls the transmission of radio signals at definite time intervals after the clockwork has begun to operate. By having these time intervals properly spaced for the different shore stations the identification of the signal with its origin is greatly simplified.

The delay introduced by each automatic key must be known and subtracted from the recorded time to obtain the actual travel time of the sound. The apparatus is so designed that this delay and the lags inherent in the operation of the apparatus may be currently determined. To this end the radio receiver of the shore station which is used to receive the radio transmission from the ship may be switched so as to replace the hydrophone circuit. When so arranged, the operation of the shore station apparatus may be initiated by a radio signal. It trips the hydrophone amplifier relay, which starts the automatic key, which in turn controls the signal transmission as before. With all of the shore stations switched in this manner for a lag determination the vessel transmits a radio signal and records its departure time. The shore station automatic keys are started simultaneously (except for difference in their respective lags), and each shore station sends back its radio signal, which is received and recorded aboard ship. The times thus recorded give the total lags which must be subtracted from the observed times to give the actual travel times of the sound.

In the lag determinations the operations aboard ship are unchanged except that no bomb is fired and that the apparatus must be switched from "transmit" to "receive" more promptly. This is necessary because the interval between signal departure from the ship and signal return from the shore station is only a fraction of a second larger than the delay introduced by the automatic key. It is for this reason that the automatic keys have been so adjusted that at least five seconds are available to effect this switching operation. It should be noted that in the lag determination practically all the mechanical operations are identical to those taking place in the position determination proper, and that the electrical circuits are identical except for the substitution of the radio receiver circuit for the hydrophone circuit at the shore station. It is quite certain, therefore, that the lag determination is exact within the limits of the other measurements involved.

The general arrangement of the shore station apparatus is shown schematically in Figure 2. The relay intervening between the automatic key and the transmitting set has not yet been mentioned. It is highly insulated, because it directly controls the high potentials of the transmitting set. In this manner the automatic key operates at low potentials which simplifies its design considerably.

Operation.

A brief resume of the operations involved in a position determination will now be in order. It is first necessary to ensure that the radio transmissions of all the shore stations give strong signals at the same setting of the radio receiver aboard ship. If this condition is not satisfied some of the shore station transmitters must be retuned. After code transmission from each of the shore stations has been received satisfactorily without a readjustment of the receiver and the readiness of each shore station in other respects has been established by radiophone communication the ship operator transmits the warning "One minute to go". The shore operators are now all listening on their radio receivers. At the expiration of the minute the ship operator snaps the operating switch firing the bomb, sending a radio dash and recording a signal on the chronograph sheet. At each shore station the following operations result on arrival of the sound. The hydrophone amplifier relay responds and starts the automatic key. Immediately after the starting of the automatic key the shore station operator switches the radio transmitting set to "transmit". At the proper times the code wheel operates to high insulation relay, which keys the transmitter and sends a radio signal from the shore station. Several signals are sent from each station to avoid loss of record from one station owing to interference or other accidental causes. The radio signals are received aboard ship and there recorded. The final record contains the sound departure signal and several radio reply signals from each station.

In a lag determination the operations are entirely similar except that no bomb is fired. The chronograph record on the ship gives the time interval between radio signal departure from the ship and radio signal return from each shore station. This time interval is the lag correction.

Thus far we have confined our attention to the functional relations of the various units making up the apparatus. Some further discussion of the individual parts will follow.

THE SOUND SIGNAL.

An explosive source of sound has substantial advantages. Because of the occasional character of the position determinations the cost does not become a serious factor. A wide range of intensity may be secured by adjustment of the size of the charge to the conditions of operation. The explosive sound provides the further advantage of a steep wave front. The steeper wave front results in greater rate of current variation in the hydrophone circuit, and consequently in a greater voltage in the secondary of the transformer through which the hydrophone is connected to the first tube of the amplifier. The system is thus selectively sensitive to the explosive sounds involved in operation and relatively less sensitive to other perhaps equally loud sounds characterized by lower rates of pressure variation. This theoretical consideration is verified in practice by the relatively great distances at which mercury fulminate detonators alone give strong signals at the shore stations.

Experiment has shown that when a sufficiently large voltage is used for firing the primer the interval between the closing of the circuit and the explosion of the bomb is less than a thousandth of a second and may therefore be ignored.

Sound sources other than bombs such as oscillators, involve the question of the building up of amplitude at the start and the consequent doubt as to the point in the resulting wave train at which the receiving apparatus threshold is reached. Finally, the distance range of commercially available oscillators is insufficient for the purposes of this work.

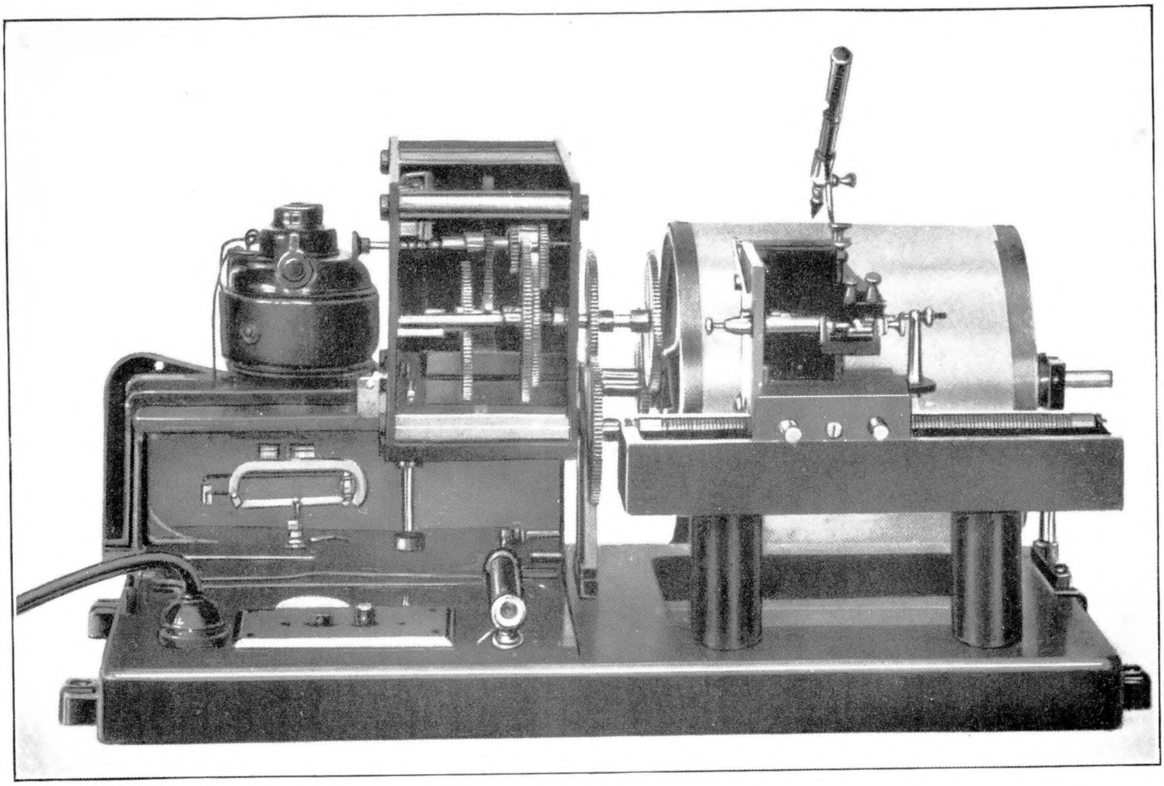

Fig. 5

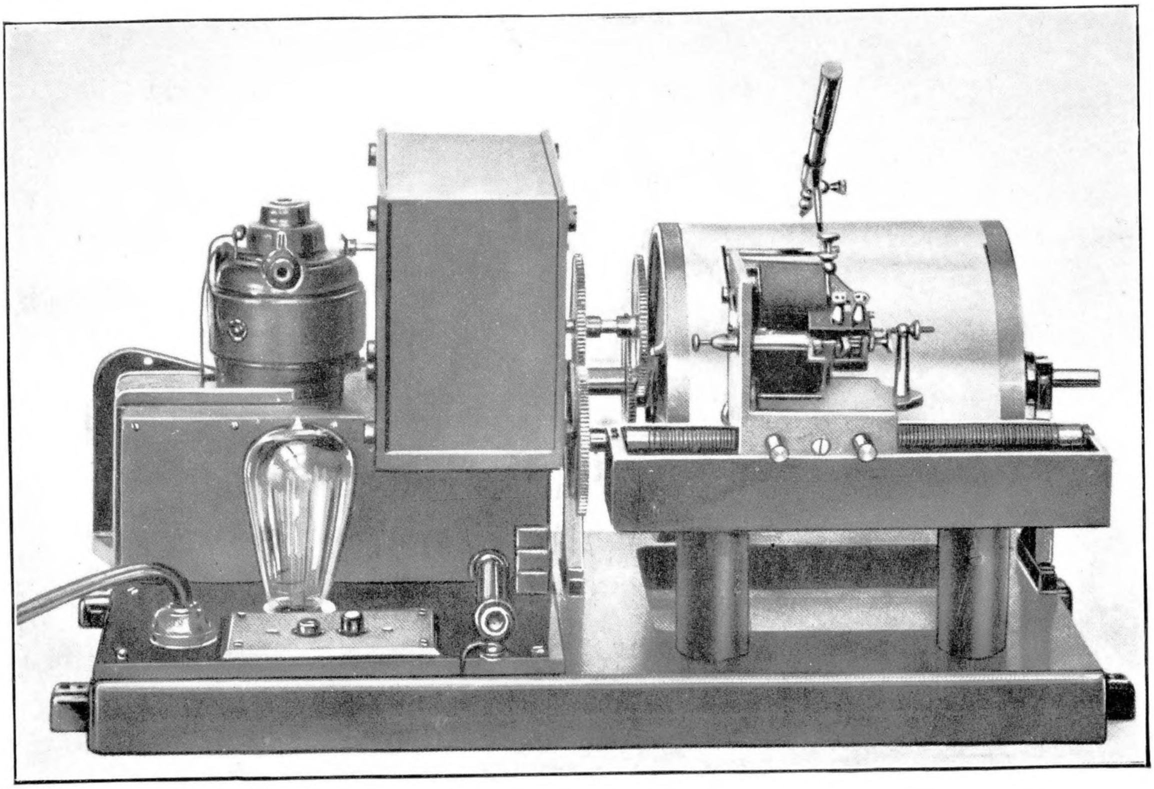

Fig. 6

RADIO RECEIVING AND TRANSMITTING APPARATUS.

These units are standard and require no special description (*See* fig. 3) except that they cover the broad-cast range of wave lengths, and that the transmitter is a 50-watt tube set permitting radiophone, buzzer modulated and continuous wave code transmission. These units are identical for the ship and shore stations.

POWER AMPLIFIER (Ship).

This is a two-stage amplifier with the windings of a relay in the output circuit. The output of the radio receiver is fed into this amplifier. By adjusting the mean grid potential of both tubes the circuit is brought to a condition in which no current flows in the plate circuit of the output tube, and consequently there is no current through the relay windings unless a signal comes through, in which case the current rises sufficiently to operate the relay.

The amplifier is shown in Figure 3. The meter indicates the amount of current available to operate the relay, and therefore serves as a check on the proper functioning of the amplifier. A schematic wiring diagram is shown in Figure 4.

THE CHRONOGRAPH.

The chronograph used for recording the signals was specially built for use on board a ship. It is shown in Figures 5 and 6. The motive power is provided by a series motor the speed of which is controlled by means of a centrifugal governor. The motor speed is 1,800 revolutions per minute, and the chronograph drum speed is one revolution in either 30 or 60 seconds. The reducing gear train includes a gear shift which engages to provide one or the other of these drum speeds or which may be set in "neutral". In this latter position the drum may be rotated freely by hand, which is convenient for mounting the chronograph sheet in place.

The gear train and governor are enclosed in a metallic housing partly for protection against dust and partly to shield outside apparatus from the sparking incident to the operation of the governor. The housing is easily opened to provide access for oiling and adjustments.

The electrical circuit of motor and governor is shown in Figure 7. The motor being series wound tends to speed up. When the critical speed for which the governor has been adjusted has been slightly exceeded the governor functions to open a contact which previously has short circuited a resistance in the form of an incandescent lamp. The throwing of this lamp into the circuit decreases the voltage across the motor terminals and causes it to slow down. This is followed by the closing of the contact, increase of motor speed, and a repetition of the cycle. In normal operation the cycle is repeated some 30 or 40 times a second. When the system is functioning properly, the lamp shows a uniform flicker. Lack of uniformity in the flicker indicates undue variability of the load or else malfunctioning of the governor contact.

In the initial design of pen carriage, as shown in Figures 5 and 6, a single pen served to record both operating and chronometer signals, the two coils shown in Figure 1 being wound differentially on the same magnet. In view of the small number of operating signals, the operation personnel found this system inconvenient and difficult to interpret when an operating signal and a chronometer signal came close together. For this reason independent pens for recording the two kinds of signals were substituted.

RELAYS.

The apparatus involves the use of a number of relays of standard design which have been modified in some particulars, however. A modification common to all is the substitution of jewelled bearing and ground pivots for the makers' mounting of the armature. This is done to reduce pivot friction and to gain a corresponding greater constancy of performance. The relays whose coils are in the plate circuit of an amplifier tube have been rewound to a resistance of approximately 1,200 ohms. This makes the combination of tube and relay more efficient. Finally the highly insulated keying relay (shore station) has its windings carefully insulated from the frame, as the frame is part of a high potential circuit while the coils are in a low potential circuit. This relay is shown in Figure 8, together with a standard unmodified relay. The changes in the manner of pivoting the armature are clearly discernible. It is hardly necessary to point out that the consistent performance of the relays is of fundamental importance in the attainment of the required accuracy.

THE HYDROPHONE.

This is the device which converts the pressure variations of the sound wave into variations of an electric current. A typical hydrophone is shown in section in Figure 9. Its essential parts are a thick rubber diaphragm to which is attached the lighter electrode of a microphone button, the heavier electrode providing inertia. When the rubber diaphragm moves as a result of pressure variations in the water, the inertia

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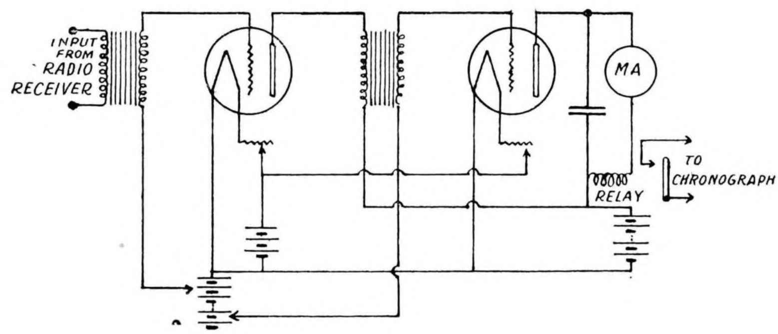


Fig. 4

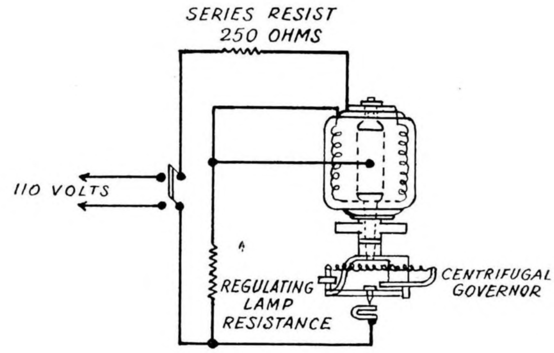


Fig. 7

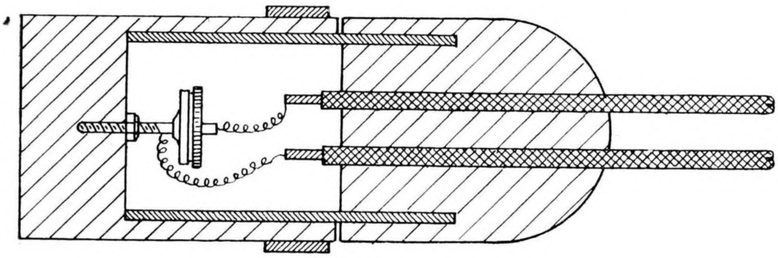


Fig. 9

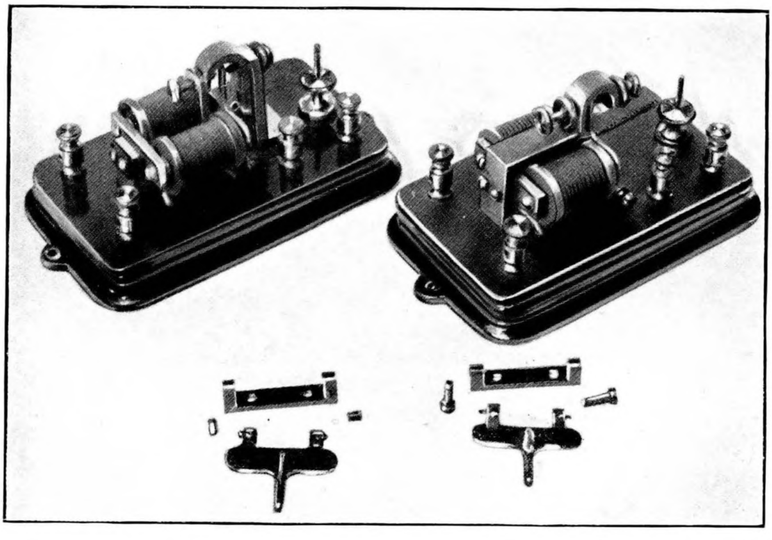


Fig. 8

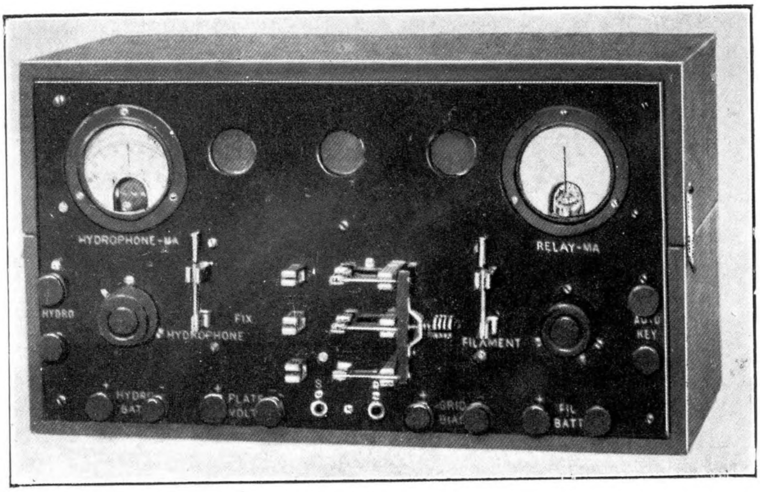


Fig. 10

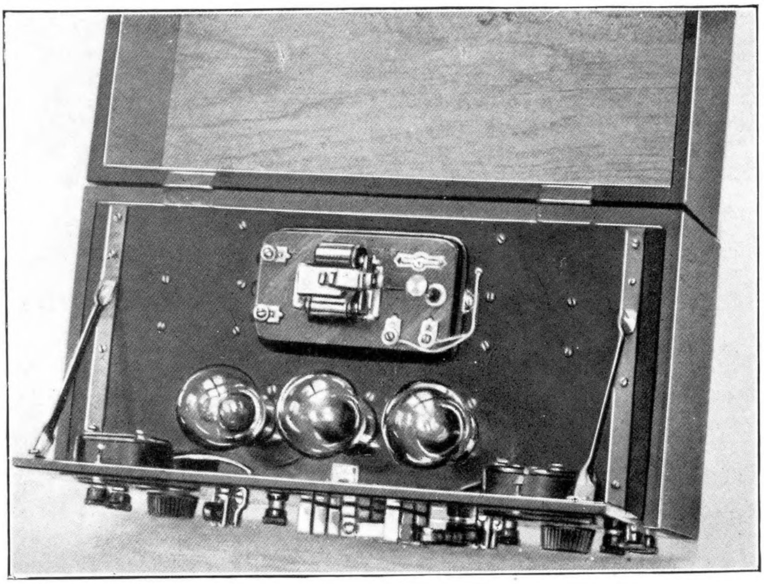


Fig. 11

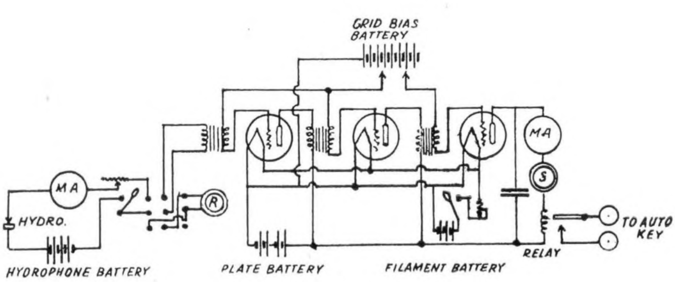


Fig. 12

electrode does not fully share the motion, and there is a relative displacement of the two electrodes of the button which results in a resistance variation. Since a constant E. M. F. is impressed upon the circuit, a current variation is produced in the microphone circuit.

The hydrophone must be planted near the sea bottom at a suitable depth. It is connected by means of a single conductor cable to the shore station. A ground circuit is used.

The Hydrophone amplifier.

The instrument serves two important functions. It amplifies the current variations taking place in the hydrophone circuit when a sound wave passes over the hydrophone until the resulting amplified current is sufficient to operate a relay. It also amplifies the current variations in the radio receiver due to a received radio signal to the same end. The change over from the one function to the other is accomplished by throwing the triple pole switch on the front panel in the appropriate direction. In either case this relay initiates the subsequent operations involved in the transmission of a series of radio signals.

The amplifier is shown in Figures 10 and 11. The cable terminals are connected to the binding posts marked "Hydro" (seen in Figure 10). The terminals for the hydrophone supply battery, the control rheostat, the current indicating meter, and the single-pole switch for opening the hydrophone circuit are seen at the left. By plugging a telephone into the jack S the amplified effects of disturbances in the hydrophone circuit may be heard. The jack R is used to connect the radio receiving set to the amplifier. In the middle is shown the triple pole switch, the position of which determines whether the amplifier relay response is to a sound or a radio signal. The meter on the right indicates the current in the relay circuit, and the switch and rheostat serve for the tube filament control. On the extreme right are the output terminals which are connected to the automatic key. Figure 11 shows the relay and amplifier tubes. The schematic wiring diagram is shown in Figure 12.

The grids of the tubes are adjusted to a potential which is negative with respect to the filaments, so that no current flows in the relay circuit when the hydrophone current is steady or in the "lag" switch position when no signals are coming through the radio receiver. This grid potential adjustment is commonly known as a "bias". The bias permits the use of the relay at the adjustment for maximum sensitivity. The biasing has a further advantage that if at the adjustment just described water noises and other extraneous disturbances occasionally trip the relay the grids may be made more negative until no further trouble from this cause results. This adjustment, to be sure, decreases the sensitivity to the sound signal; but this can be offset by using an increased explosion when unusally noisy sea conditions require heavy biasing. Normally water noises can be rendered harmless by moderate biasing.

The Automatic Key.

The automatic key is a clockwork mechanism which is set in motion by the arrival of a sound or radio signal and which resets itself after a complete cycle of its motion. This cycle is one revolution of the excapement wheel. The clockwork is a modification of a standard metronome mechanism. A notched code wheel (shown at *g* in fig. 13) is mounted on the escapement-wheel shaft. A small wedge at the end of a short stiff spring rests on the convex surface of the code wheel and falls into the notches as they pass. This operation closes a circuit at *h*, which in turn operates the radio transmitter keying relay. The schematic diagram of the code wheel and its associated circuit is shown at the left of Figure 14.

The starting of the clockwork is effected by the relay *b* (*see* figs. 13 and 14). The coil circuit of this relay is open except when the clockwork is in operation. In the "stand-by" condition the armature of the relay is therefore held away from the magnet by the spring. An extension of the pendulum rests on an extension of the armature; with the pendulum held in approximately the position of maximum displacement. When the signal comes in the armature of the relay is attracted thus removing the pendulum support. The armature remains in the "attracted" position until the clockwork cycle is completed, whereupon it is released. The release is so timed that it catches the pendulum at its maximum displacement and holds it. It is now ready for the next operation. Winding of the spring is the only attention required in normal operation.

The armature of the automatic key relay is held in the "attracted" position from the beginning to the end of the cycle, although the hydrophone amplifier relay which controls this operation (*see* Fig. 12) is closed only momentarily. The manner of accomplishing this may be understood from Figure 14. An extension *d* on the code wheel *q* opens the contact *c* on the last swing of the pendulum in the cycle. On the first swing of the next cycle the arm *d* advances, so as to permit this contact to close. It remains closed until again opened by the arm *d*. In this manner the coil *b* remains energized, and the armature attracted until

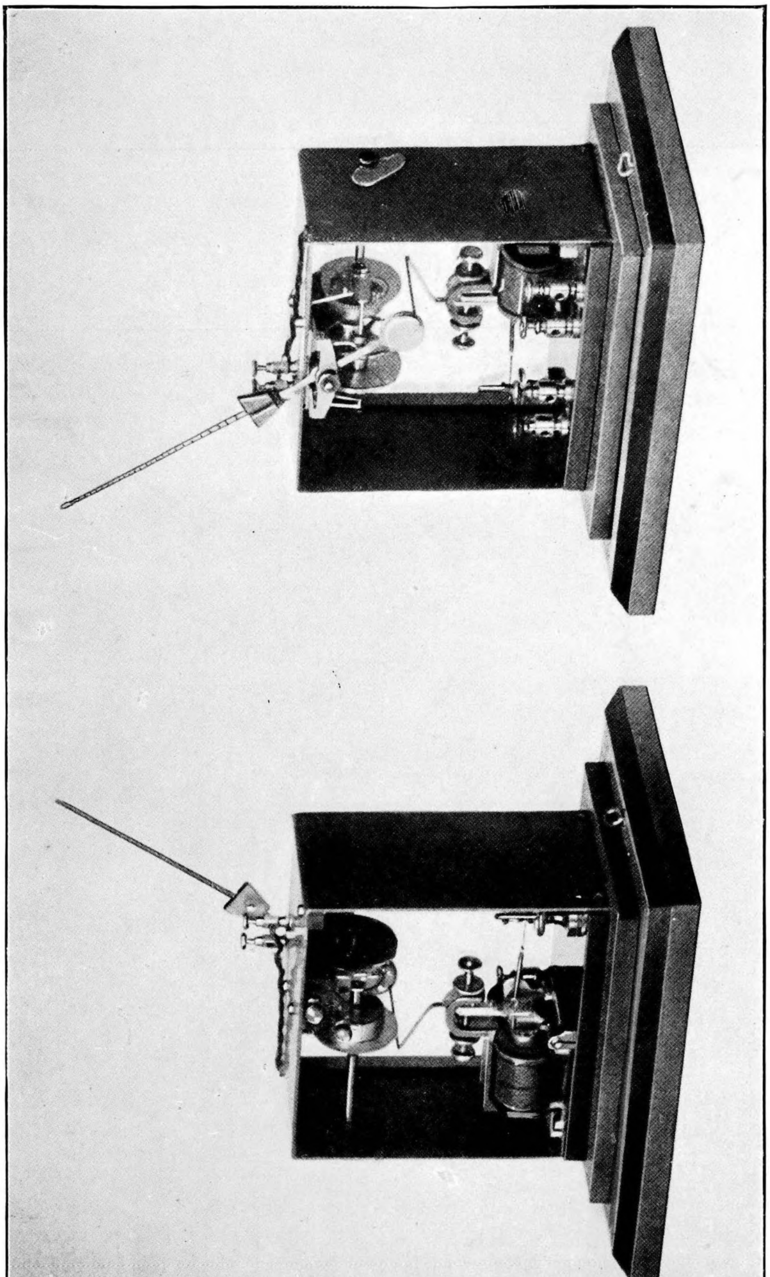


Fig. 13

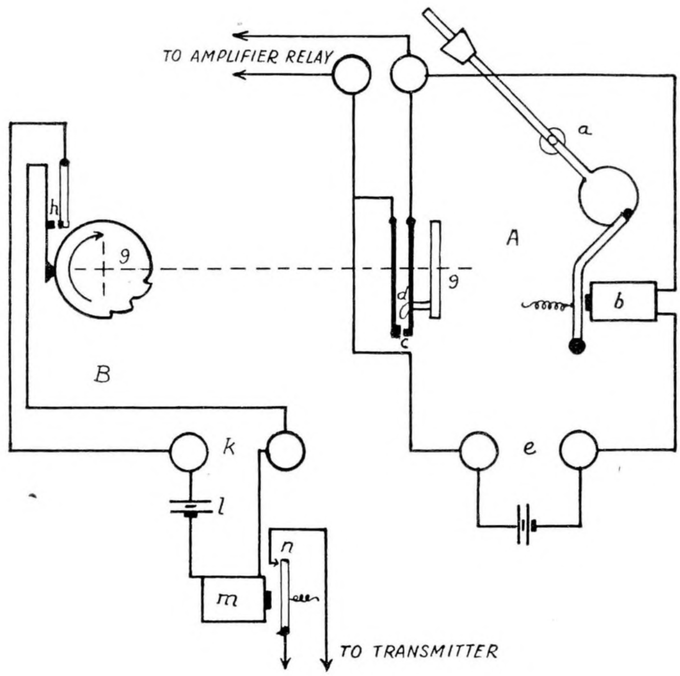


Fig. 14

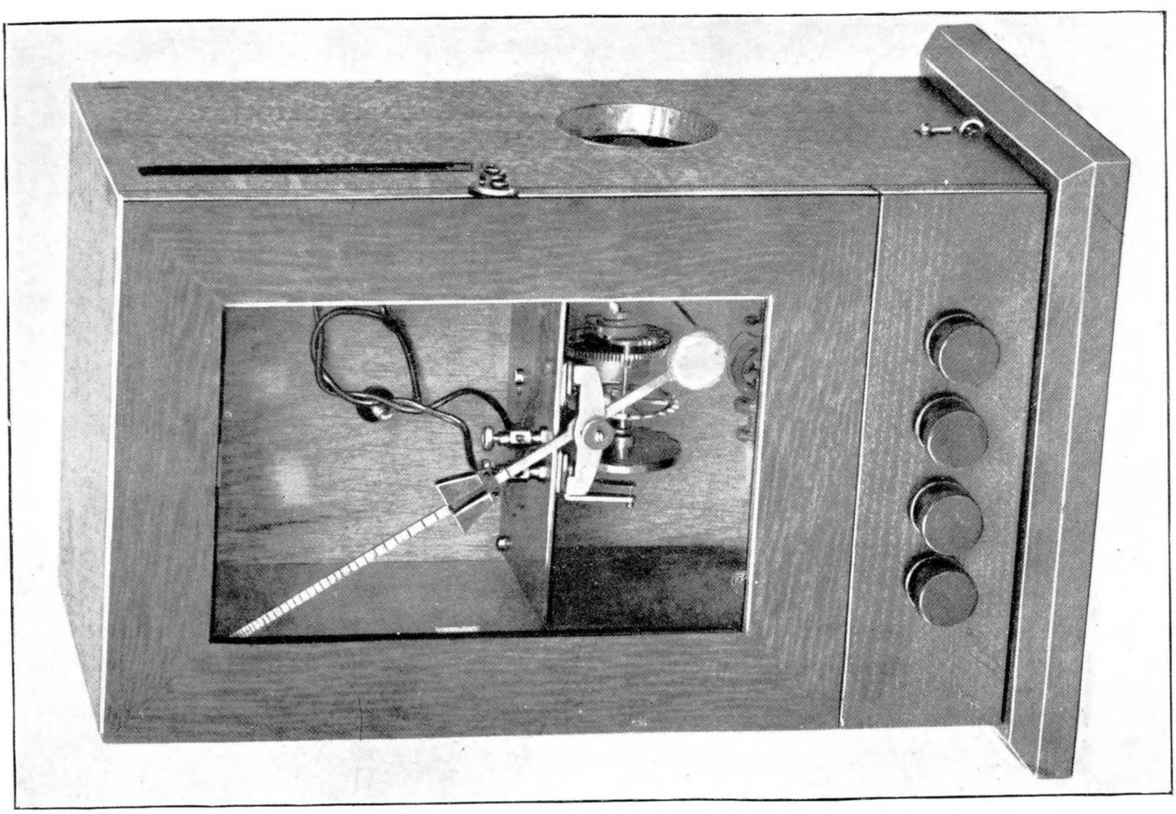


Fig. 15

the cycle is completed. Since the contact *c* is in parallel with that of the amplifier relay, the functioning of the automatic key is independent of the latter after the start.

The spacing of the notches on the code wheels is different for the different stations. This difference in spacing is an aid in identifying the recorded signals with their station of origin. The interval from the starting of the clockwork to the first signal of the code may be altered by changing the position of the arm *d* with respect to the notches on the code wheel. The interval between signals may be adjusted by changing the pendulum rate, using the sliding weight on the pendulum rod *a* for this purpose. The automatic key with cover in place is shown in Figure 15.

The necessary personnel includes: on board the vessel, officer in direct charge of obtaining distances from chronograph sheet; chief radio operator, who operates the apparatus under his direction. On shore, officer in charge of stations and one radio operator for each station. Officer lives near one station and is provided with autotruck to carry equipment, provisions, and supplies and to transport himself between stations.

Selection of shore station sites.

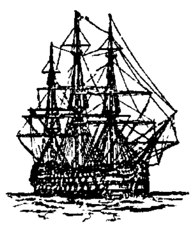
A suitable place for the hydrophone must be found in a depth of about 60 feet, preferably not more than three-fourths of a mile from the shore. The shore should be sandy, and the area intervening between the point selected on shore and the hydrophone should be free from rock. This will usually be indicated on the Pacific coast by the absence of kelp. In any case there should be no rock between the high and low water lines. In this case the cable will soon bury itself to the depth of several feet, and the heaviest breakers will not affect it. There should be space above the high-water line, preferably above the storm high-water line, for the station building. Whenever practicable an existing building should be used, but a building can be put up which will meet all the requirements without great cost. It is important that the rain be kept out, and that the generator equipment should be protected from sand. The stations should be, in general, 15 to 20 miles apart, though this will vary with possible sites, character of work, accessibility of the site, and other circumstances.

Figure 16 shows the adopted device for hydrophone base.

The bomb is fired by operating a switch in the radio-room. There is a permanent circuit from radio room to stern which contains a safety switch which is kept open at all times until ready to fire bomb. The bombs that have been used are half-pound, pound and two pounds tin cans of the commercial type, containing T. N. T.

Accuracy of determinations.

The work has been carried on such a short time under field conditions that there has not been a great accumulation of observations on which final conclusions may be reached. The indications are that the radio acoustic determinations will give accuracy quite as satisfactory for the work at present being carried on by the method as is given by visual methods.



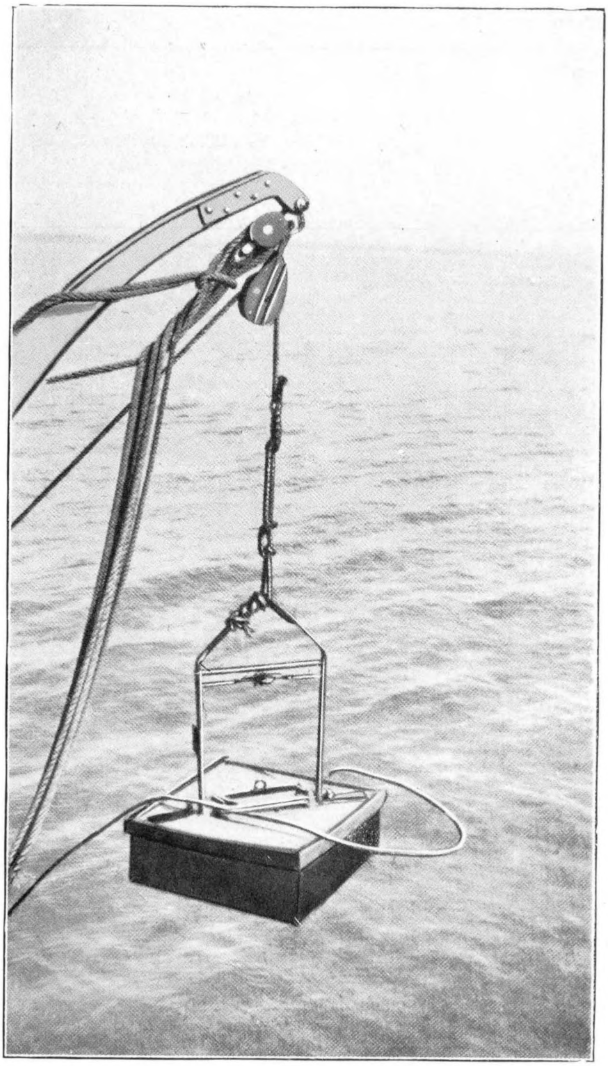


Fig. 16