Serial No. 277

DEPARTMENT OF COMMERCE

U. S. COAST AND GEODETIC SURVEY

E. LESTER JONES, DIRECTOR

RADIO ACOUSTIC METHOD OF POSITION FINDING IN HYDROGRAPHIC SURVEYS

By

Commander N. H. HECK
U. S. Coast and Geodetic Survey

and

E. A. ECKHARDT, Physicist, and M. KEISER
Associate Electrical Engineer
U. S. Bureau of Standards

Special Publication No. 107

PRICE, 10 CENTS

Sold by the Superintendent of Documents, Government Printing Office
Washington, D. C.

WASHINGTON
GOVERNMENT PRINTING OFFICE
1924

CONTENTS

ILLUSTRATIONS

PREFACE

The Coast and Geodetic Survey steamer *Guide*, a recently converted mine sweeper, was assigned to the development of radio acoustic ranging. Experimental work was done on the New England coast during October and November, 1923. The necessary testing of the completed apparatus and development of routine and methods was accomplished on the coast of Southern California in February and March, 1924. By the end of March the method was in routine use, though minor difficulties remained to be adjusted. As this was an entirely new development in Coast and Geodetic Survey work there were special features in the organization. These will be described, and members of the personnel who contributed to the development of the apparatus, routine, and methods will be mentioned by rank or title in the Coast and Geodetic Survey.

Commander N. H. Heck, chief of the division of terrestrial magnetism, was assigned to expert supervision of the acoustic work, having had previous experience in such work in conection with antisubmarine work during the World War. He was assisted by H. E. McComb, magnetic observer, who at intervals took time from his magnetic survey of the coast of Southern California to give the benefit of his skill in precise physical measurements and in care of delicate instruments, with the result that in these respects the work was placed on a high plane from the start.

Lieut. Commander R. F. Luce, commanding the *Guide*, gave special attention to the development of methods and routine and took over entire supervision as soon as the development period was over.

Lieut. K. T. Adams, executive officer, and Lieut. (Junior Grade) L. B. Clore specialized in cable work. Lieut. Geo. D. Cowie was in immediate charge of radio acoustic ranging. Chief Radio Operator A. M. Vincent made notable contributions to the development work, especially in solving the problem of operating two or more radio transmitters on the same wave length and in devising and constructing under field conditions of a time-recording pen for the chronograph.

Dr. E. A. Eckhardt, physicist, and M. Keiser, associate electrical engineer, both of the Bureau of Standards, developed the radio acoustic apparatus, each taking part in the preliminary tests, and Mr. Keiser was present at the test of the completed apparatus to insure that the desired accuracy inherent in the apparatus was fully developed.

RADIO ACOUSTIC METHOD OF POSITION FINDING IN HYDROGRAPHIC SURVEYS

Part I.—THE HYDOGRAPHIC PROBLEM AND INSTALLATION DETAILS

By N. H. Heck, *Commander, U. S. Coast and Geodetic Survey*

INTRODUCTION

The making of the hydrographic surveys on which the mariner's charts of the waters of the United States and the regions under its jurisdiction are based has been one of the principal functions of the Coast and Geodetic Survey during the century that it has been in existence. During all this time it has been accepted as inevitable that surveying operations are subject to weather conditions. It will undoubtedly always remain true that no attempt should be made to carry on survey work at sea during gales, but until recently it seemed equally true that surveys worthy of the name could not be made during a dense fog. A number of other causes, such as haze, smoke from forest fires, rain or snow, and any other cause which may render the shore invisible have always interfered with and often prevented work entirely. Prior to the World War there was no hope that this condition would be remedied.

The water area of a mariner's chart shows many figures which represent in depth and position the depth of the water as obtained from soundings for a definite state of the tide. The chart also shows the shores and various rocks and islands. Every point on the chart represents a corresponding point on land or sea. The direction joining two points on the chart is as nearly as possible the same as for the actual points, and the distance between them bears the same relation to the actual distance. The same thing is true of the sheet on which the surveys are plotted. On such a sheet the positions of many definite objects are shown whose positions are known as the result of triangulation by the Coast and Geodetic Survey.[1]

The soundings shown on the chart are not taken at random but in accordance with a fixed plan. The plan most used can best be illustrated by assuming that a rectangular area is to be surveyed. A number of parallel lines are drawn on the sheet, and the surveying vessel proceeds to follow the imaginary line through the water corresponding to the line on the chart. In order to do this, it must know at frequent intervals its position on the sheet. This is usually done by means of the three-point fix. The objects plotted on the sheet may be specially constructed wooden structures known as hydrographic signals, or they may be church spires, water towers,

---

[1] See Special Publication No. 26, General Instructions for Field Work, United States Coast and Geodetic Survey, E. Lester Jones, director.

stacks, prominent mountain peaks, the requirement being that the objects be prominent and easily recognized. To obtain a position, three objects are selected which can always be designated as the right, middle, and left objects, respectively. The angles between these objects are measured by two observers on the vessel by means of sextants (the same instrument as used in navigation), one observer measuring the angle between the right and middle object and the other—at the same time—that between the middle and left object. When these angles are set off on an instrument called the three-arm protractor, and the three arms are placed on the sheet so that the edge of each passes through its respective object, the center of the protractor marks the position of the vessel. Whenever a position is obtained the vessel may change course if necessary to remain on the desired line; in any case its path is known.[2]

There are modifications of the plan described and there are methods by which a vessel may extend a survey out of sight of land, but in the last analysis everything depends on the obtaining of positions at suitable intervals. It is for this reason that conditions which affect the visibility of shore objects may prevent a survey of the water area.

There has been peculiar need for a method to overcome the handicap on the Pacific coast, especially the coast of northern California, Oregon, and Washington. In the wintertime frequent gales prevent work, and not infrequently the surveying vessel would be held in port during the favorable weather following a gale by the heavy swells breaking on the bars which are characteristic of all the harbors. In the summer time fog and haze are prevalent.

HISTORY OF THE DEVELOPMENT OF RADIO ACOUSTIC RANGING

The need for methods to use against the submarine menace during the World War led to intensive study of the transmission of sound through sea water. The organization of scientists to work with the military services added greatly to the knowledge of the subject. Methods of transmitting and receiving underwater sounds were perfected. Accurate means for measuring the time of transmission of sound from source to receiver were developed. After the war the velocity of sound was made the subject of study. The subaqueous sound-ranging section of the Army, under Col. R. S. Abernethy, C. A. C., made a practice of firing small bombs suspended below a target, whose position at time of firing was accurately determined, and recording time of transmission to underwater telephones or hydroplanes of known position connected to shore stations by cable. The results published by E. B. Stephenson, physicist, who was associated in this work, indicate that, while the velocity of sound varies through wide ranges with conditions, the variations are according to definite laws and may be known quite accurately. This work was the basis of the adoption by the Coast and Geodetic Survey of a project to apply a similar method in its hydrographic work.

In this method the position of the vessel is not obtained by the measurement of angles as has been described, but by direct measurement of distances from two or three known points, an equally satis-

[2] See Elements of Chart Making, Special Publication No. 38, by E. Lester Jones, Director United States Coast and Geodetic Survey.

factory method. A requirement common to both methods is that the direct control of the observations must be aboard ship, and that the results must be available in the shortest possible time after the observations are completed. No existing methods provided for accomplishing this, and all methods in use were too elaborate and provided more accuracy than required and demanded a large and highly trained personnel.

The method which has been developed is based on the use of the radio longitude apparatus developed by Dr. E. A. Eckhardt, head of the sound section, Bureau of Standards, for use in the longitude work of the Coast and Geodetic Survey. This provided for direct recording of time signals in such distant regions as Pacific Coast States and Alaska of radio signals from Annapolis. The modification of this apparatus for use aboard ship, the development of new and modification of existing apparatus to solve the problem, was undertaken by the Bureau of Standards, the work being placed under the direction of Doctor Eckhardt.

On pages 7 to 23 a full description of the method is given. The organization necessary to carry on the operations is as follows, no mention being made of the reliefs or extra personnel that might be needed, such as cooks:

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. Housing arrangements for the party will not be discussed, as this is a common engineering problem. 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.

CABLE WORK AND HYDROPHONE BASE

The laying of the cable, though essentially a simple operation, is by no means easy. It is usually necessary to exercise considerable skill in taking it through the breakers, and this requires expert smallboat work. The method used so far has been to set up the cable drum, weighing about 5 tons, on the shore so that it is free to turn. The end is hauled through the breakers to a launch, and empty gasoline drums are attached to the cable at intervals to buoy it up. When this is done the launch is able to tow out at least half a mile of cable. When the vessel anchored at the point selected for the hydrophone is farther off, a wire cable from a reel aboard the ship is towed by another launch until the two launches meet. The ends of the wire cable and the conductor cable are connected, and the latter is hauled out by taking the former to the vessel's capstan. If the entire distance is much over three-quarters of a mile, the strain on cables and machinery becomes very great.

Another method is to haul the cable out from the shore as far as it can be readily towed by a launch. Then the end of a similar cable, mounted on a reel aboard the vessel, is towed to meet it. The connection is made in a junction box. The objection to this method is that the splice requires more than an hour, and it is difficult to do the work in a small launch. The advantage is the slight strain put on the cable. The cable is seven-eighths of an inch in diameter and is strong, flexible, and capable of withstanding sea water under high pressure. It is a single conductor cable with specially good insulation.

The hydrophone base (Fig. 1) is designed in accordance with standard practice but is much lighter in weight than is customary. It is found to give good service under Pacific coast conditions. The essential parts are a frame and a holder which securely holds the hydrophone in a horizontal position at a proper height above the bottom, and a junction box. The hydrophone has two conductors leading from it, one of them attached to the conductor and the other to the cable armoring as a ground. The purpose of a junction box is to protect a splice and to provide a means of transmitting strain, so that the cable will not be weakened at a splice. An iron collar known as a Turks-head is slipped over the end of the cable, and the armoring is turned back over it and laid along the cable parallel to its axis. Inside the junction box the cable is clamped so that the Turks-head presses on the clamp when strain is put on the cable. The cable leaves the box through a groove slightly larger in diameter than the cable.

A splice is made with great care. The armoring is laid back so as to give sufficient length of conductor for the necessary operations. The wires of each conductor are bared for several inches, and the adjacent insulation is tapered by means of a razor blade. The wires are connected with care after being carefully scraped, and the whole is washed with gasoline. The joint is covered first with rubber cement and then pure para rubber, which is self vulcanizing, is carefully wrapped around the whole length of the joint. This is then wrapped with ebonite tape and finally with a protective layer of friction tape. These precautions are necessary to keep out the water and give the desired strength to the splice.

BOMB FIRING

As small bombs are used and the position of bomb firing is not determined from the shore no target is necessary and a simple and quick method can be used. The bomb is fired by operating a switch in the radio room, and there must therefore be a continuous circuit from switch to bomb when in position for firing. 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. A rope

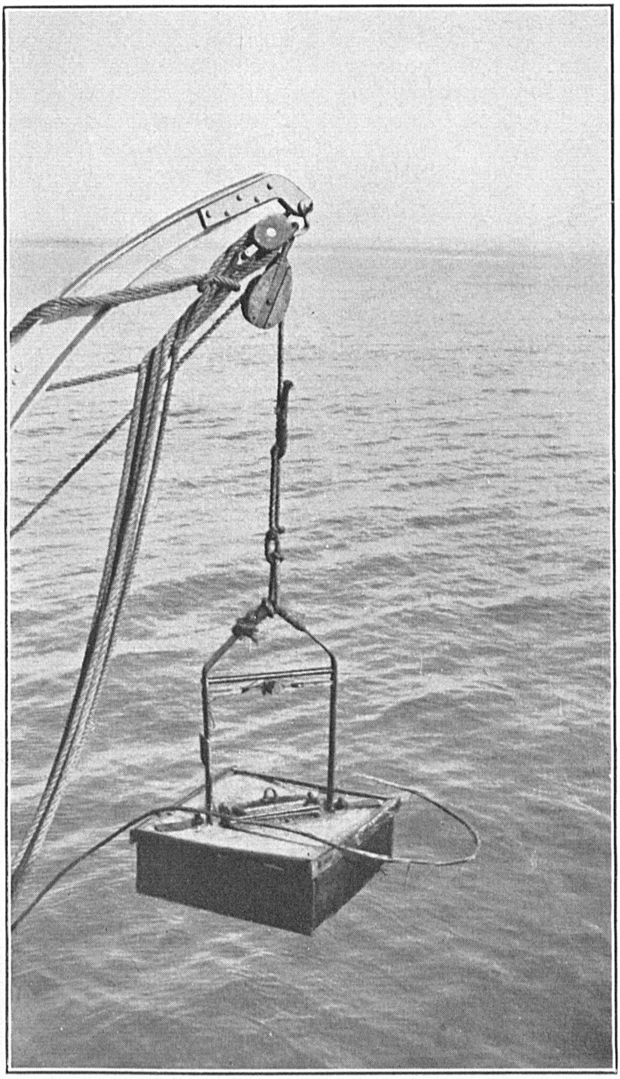

FIG. 1.—Hydrophone base

about 200 feet long marked at 10 fathom intervals has attached to it a twin conductor cable. The rope is attached to the upright wire connecting a five-gallon oil can used as a buoy and a sinker, which may be a 15-pound sounding lead, a short distance from the sinker. The conductor is attached to the rope a short distance from the upright, so that the bomb will be held at the desired depth by the sinker, but it will not be in contact with the sinker or upright, as an explosion when in contact might part the upright. The operation of setting out the bomb and getting back the end of the conductor is very quickly accomplished. A testing lamp should be placed across the ends of the conductors at intervals to see that the circuit is intact.

The bombs that have been used are half-pound, pound, and two-pound tin cans of the commercial type, containing T. N. T. A tube is inserted in the can in such a way that the detonator need not be brought near the bomb until ready to put overboard, a precaution which minimizes the danger from use of explosives. Detonators must not be less powerful than No. 8 electric blasting caps.

VELOCITY OF SOUND

This subject is of great importance to the operation of radio acoustic ranging. It has been studied by British, French, and American observers. As a result of a cruise of the *Guide*, during which known vertical determinations of velocity of sound were made, a theoretical method was devised for obtaining the velocity from known conditions of the sea water. This is discussed fully in the publication Velocity of Sound in Sea Water, by N. H. Heck and Jerry H. Service, published by this bureau. Even with this theoretical knowledge and the various work of scientists of many countries it is necessary to actually fire bombs at a time when accurate visual determinations can be made, and thus determine the velocity of sound and also to make physical determinations of the sea water at intervals. The velocities obtained by taking into account all the data are used in the determination of position.

The question is frequently brought up whether the higher velocity of the explosive wave near the actual explosion introduces a serious error. The conclusions from investigations made by the British and American observers is that the distance through which the higher velocity exists is negligible, and that the wave travels with the velocity of sound almost immediately.

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, and until such a time it is not good engineering practice to make claims in regard to its accuracy. 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.

Part II.—APPARATUS AND METHOD OF OPERATION

By E. A. Eckhardt and M. Keiser, *Bureau of Standards*

The nonvisual determination of the offshore 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.[1] Other methods involve the measurement of time intervals. In one such method the intervals between the arrival times 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.[2] 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.[3] 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. Underwater 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 ship noises. (*c*) Mobility of shore installations. (*d*) Requirement that vessel be the base of operations, including the locating of shore stations.

---

[1] R. Keen, Direction and Position Finding by Wireless. Wireless Press (Ltd.), London; 1922. G. R. Putnam, Radio Fog Signals and Their Use in Navigation, etc. Lighthouse Service, United States Department of Commerce, 1924.

[2] A. Trowbridge, Sound Ranging. Jour. Frankl. Inst., 189, pp. 133–146; 1920. J. C. McLennan, Science and its Application to Marine Problems. Engineering, 108, pp. 128, 129; 1919. C. V. Drysdale, Modern Marine Problems in War and Peace, Eleventh Kelvin Lecture. Jour. Inst. Elec. Eng., 58, pp., 585, 586; 1920. F. E. Smith, Modern Navigation Devices. Eng., 117, pp. 299, 300; 1924.

[3] A. B. Wood and H. E. Browne, A Radio Acoustic Method of Locating Positions at Sea. Proc. Phys. Soc., London, vol. 35, pp. 183–193; 1923. A. B. Wood, H. E. Browne, and C. Cochrane, Speed of Small Explosion Waves in Sea Water, etc. Royal Soc. Proc., 103, pp. 284–293; 1923. E. B. Stephenson, Velocity of Sound in Sea Water. Phys. Rev., 21, pp. 181–185; 1923.

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 two shore stations are sufficient for a position determination. A third shore station provides a check.

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 2 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 second'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 circuit. Its functions are analagous 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

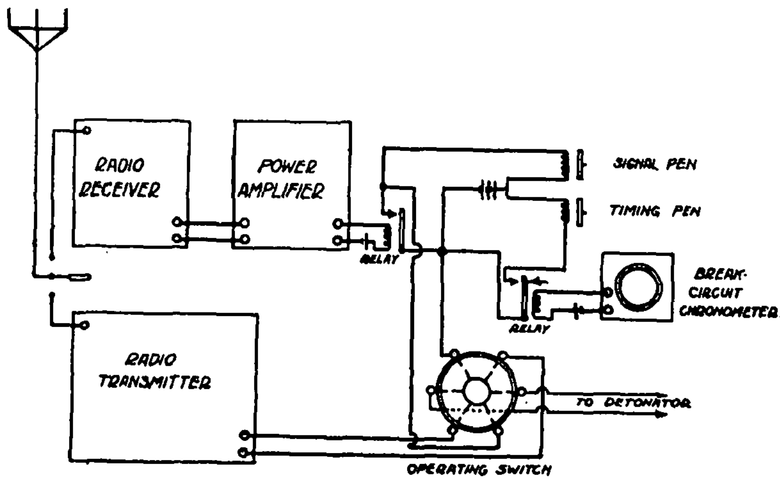

FIG. 2

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 clockwork 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

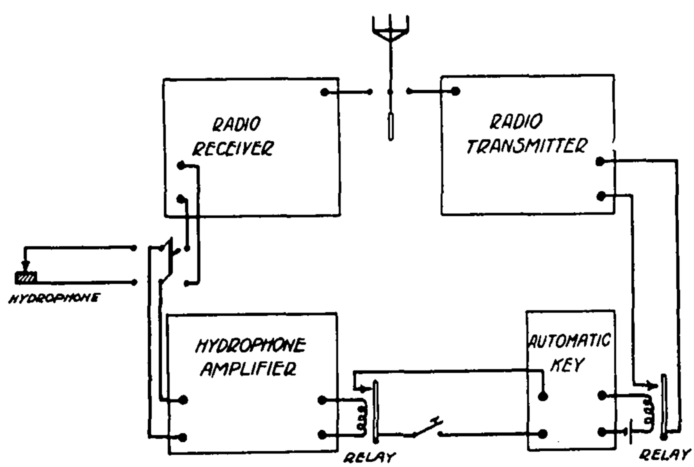

Fig. 3

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 3. 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 résumé of the operations involved in a position determination will now be in order. It is first nceessary to insure 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 radio phone 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 the 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 for 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 conse-

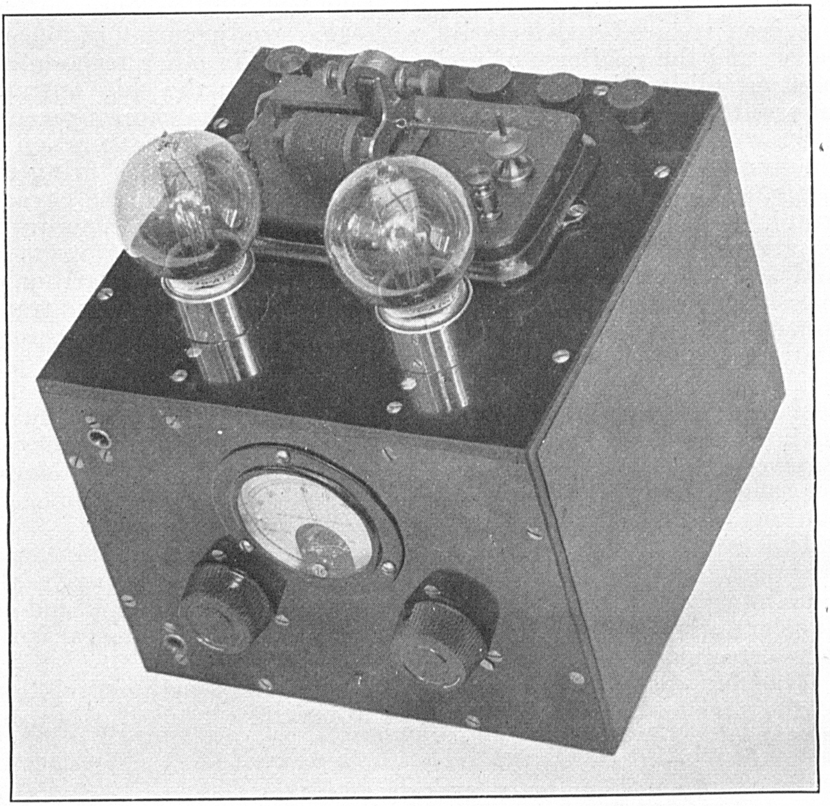

FIG. 4

quent 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.

RADIO RECEIVING AND TRANSMITTING APPARATUS

These units are standard and require no special description except that they cover the broad-cast range of wave lengths, and that the transmitter is a 50-watt tube set permiting 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 4. 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 5.

THE CHRONOGRAPH

The chronograph used for recording the signals was specially built for use on board a ship. It is shown in Figures 6 and 7. The motive power is provided by a series motor the speed of which is

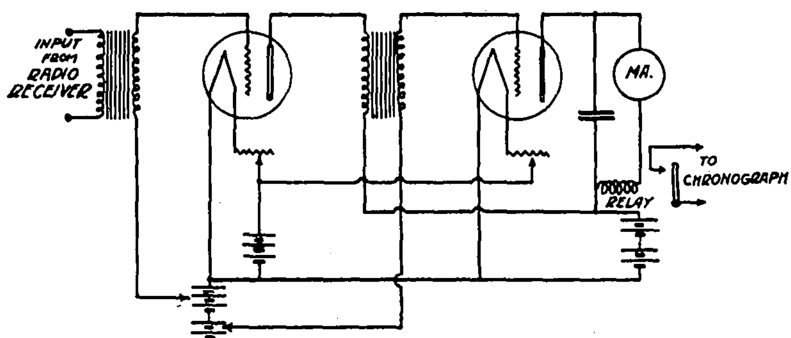

FIG. 5

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 inclosed 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 8. 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

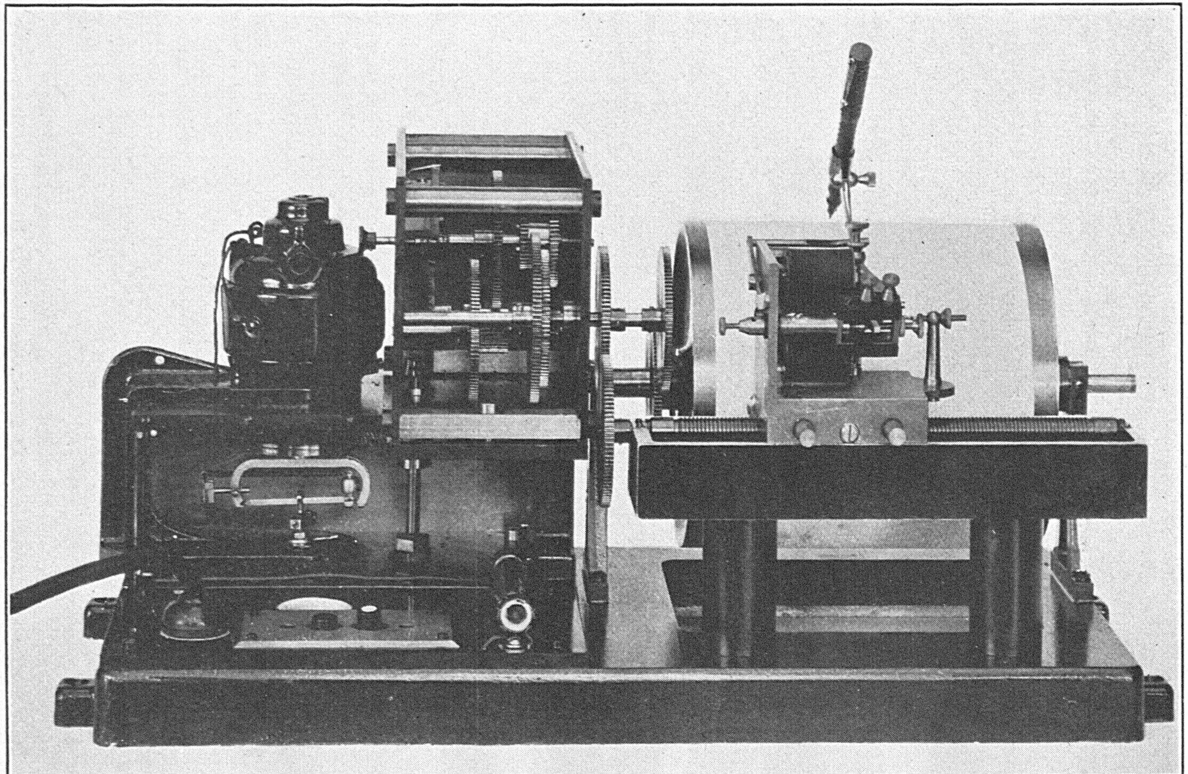

Fig. 6

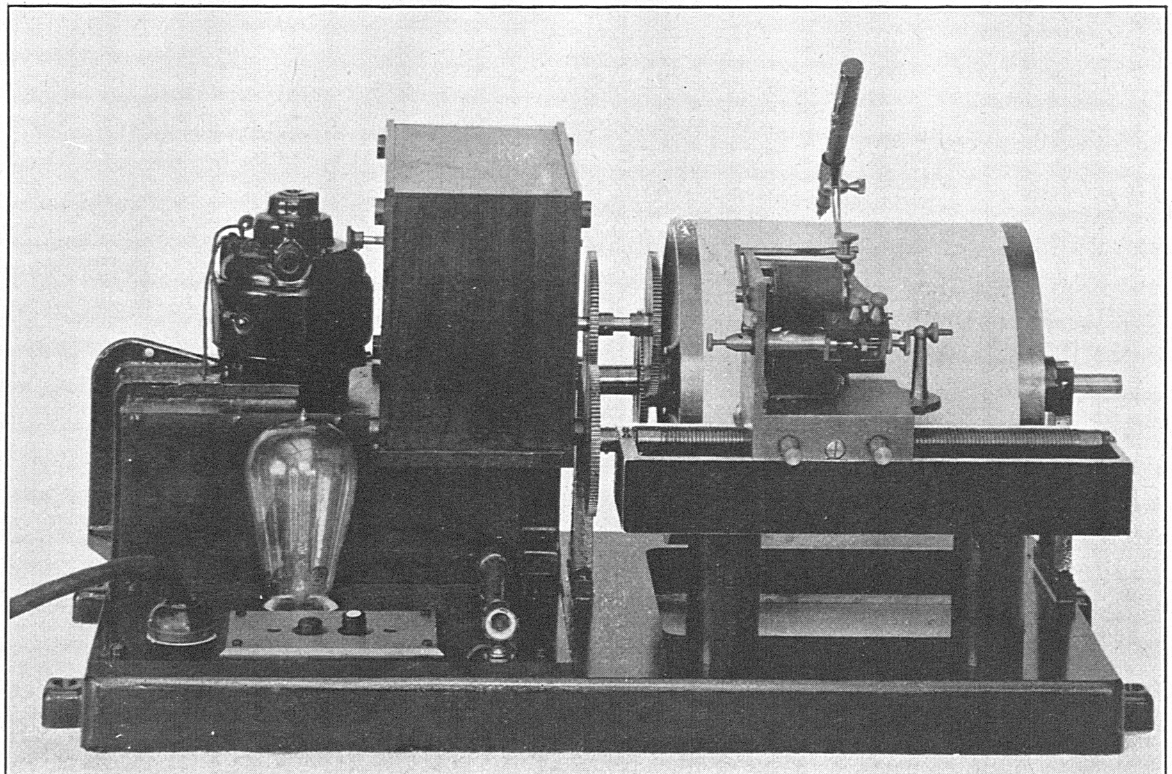

Fig. 7

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

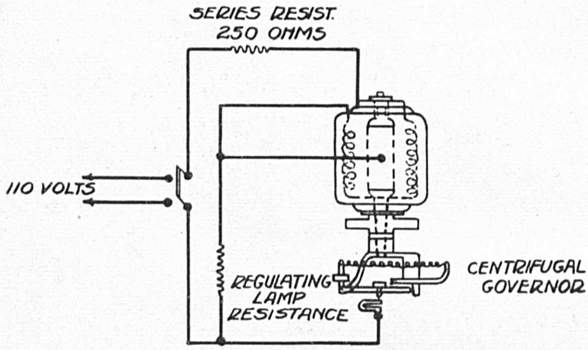

Fig. 8

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 6 and 7, a single pen served to record both operating and chronometer signals, the two coils shown in Figure 2 being wound differentially on

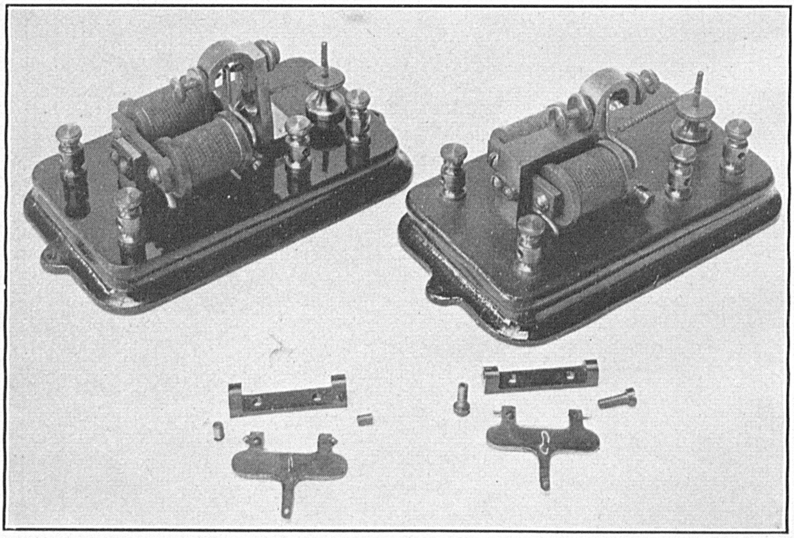

Fig. 9

the same magnet. In view of the small number of operating signals, the operating 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 jeweled bearings 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 9, 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.

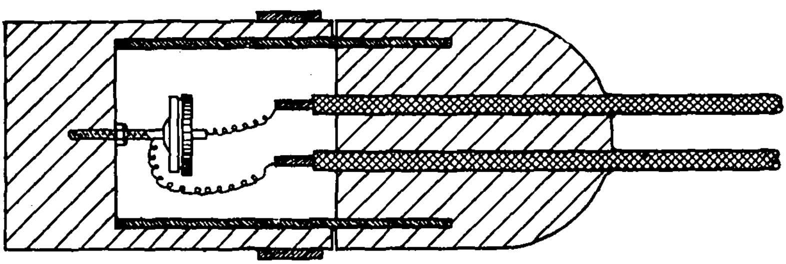

FIG. 10

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 10. 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 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 return circuit is used.

THE HYDROPHONE AMPLIFIER

This 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

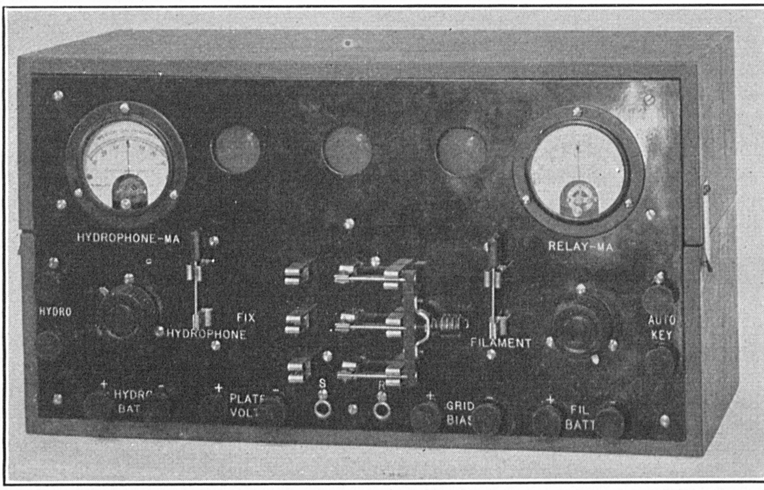

Fig. 11

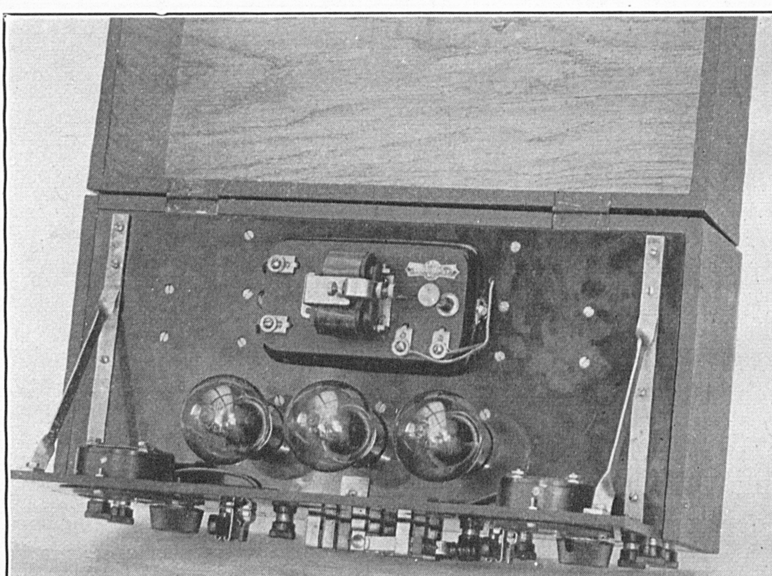

Fig. 12

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 11 and 12. The cable terminals are connected to the binding posts marked "Hydro" (seen in fig. 11). 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 12 shows the relay and amplifier tubes. The schematic wiring diagram in shown in Figure 13.

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 re-

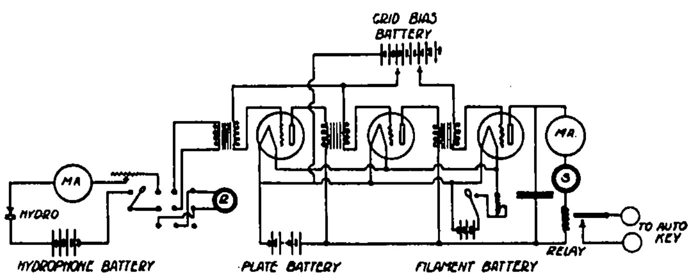

FIG. 13

ceiver. 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 unusually 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 escapement wheel. The clockwork is a modification of a standard metronome mechanism. A notched code wheel (shown at g in fig. 14) 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 15.

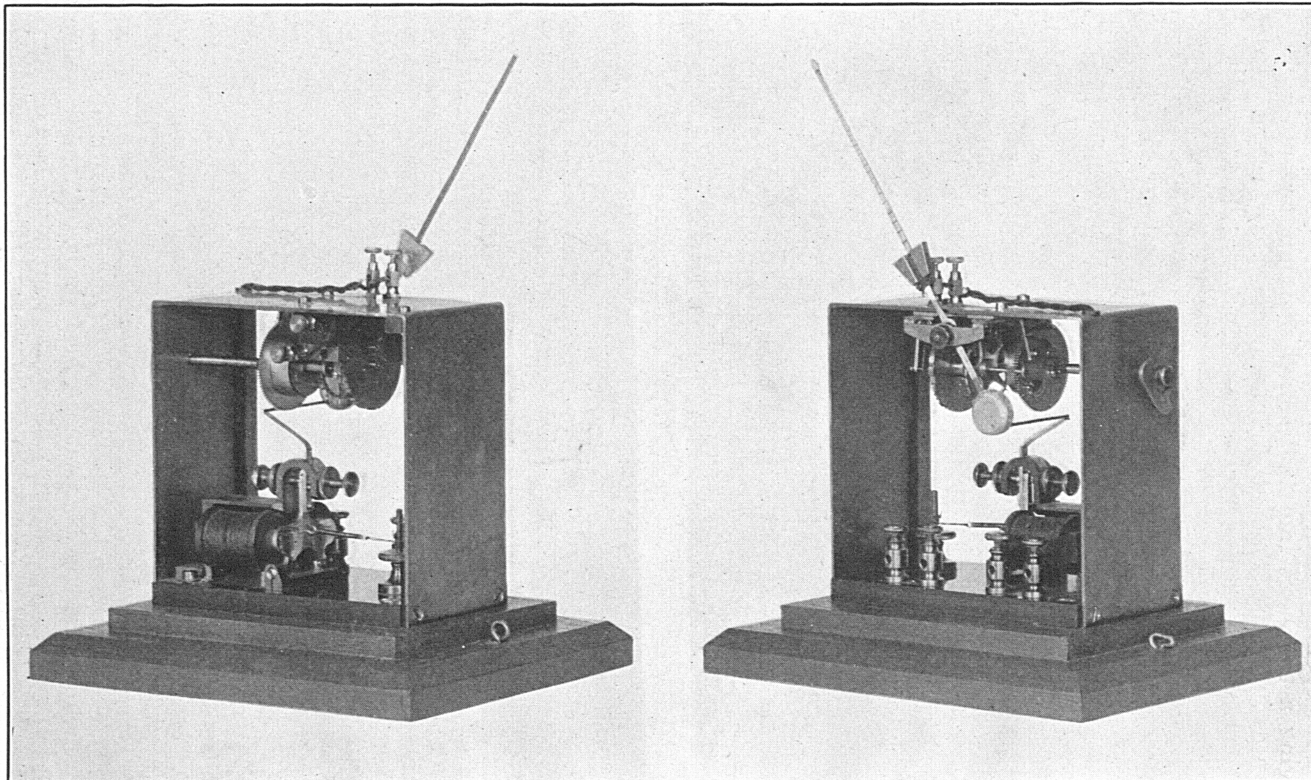

FIG. 14

The starting of the clockwork is effected by the relay *b* (see figs. 14 and 15). 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

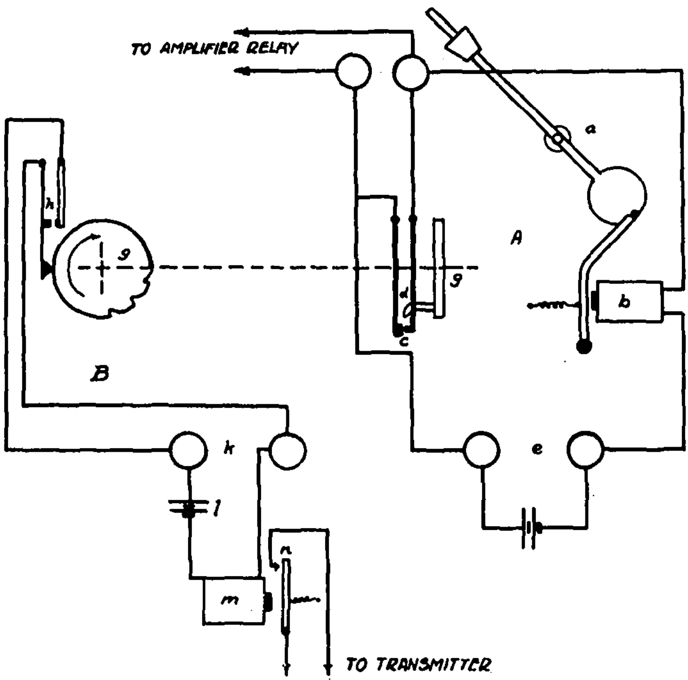

FIG. 15

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. 13) is closed only momentarily. The manner of accomplishing this may be understood from Figure 15. An extension *d* on the code wheel *g* 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 remains attracted until 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 16.

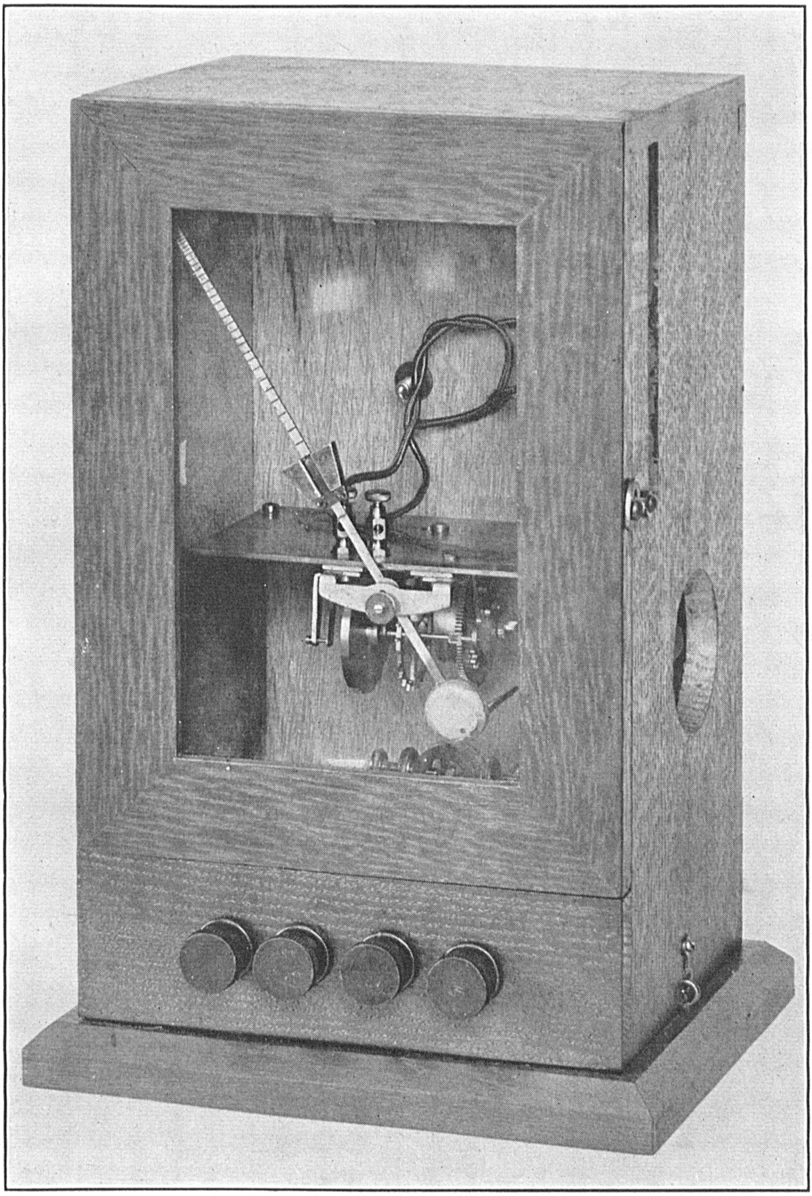

FIG. 16