

ELECTRONICS IN HYDROGRAPHIC SURVEYING

I. — HOW DEEP IS THE OCEAN (1)

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The *primary objectives* of an hydrographic survey are to determine the depths of the ocean as accurately as possible and to correlate these measurements precisely to their shores. It can easily be understood that a precisely measured depth at an unknown position is of little real value regardless of the amount of information obtained. But just how are soundings obtained ?

Soundings in the oceans have been taken from time immemorial. Records of soundings taken several milleniums before Christ are found in Egyptian art ; depths of the waters of the Nile River were quite well known in the age of Herodotus when oceanography became a real science. In fact, the effect of the moon on the ocean tides was a subject for serious study more than 2000 years ago. The Greeks actually made oceanography a science and led the world in this study for many centuries. There is a record of a sounding of 1000 fathoms near Sardinia obtained more than a century before Christ. It was not until the 14th and 15th centuries that other nations became interested in oceanography — only a few hundred years ago.

In the early records, sounding lines were described as being made up of a metal weight on a thin hemp line. Lead did not become the popular metal until in the 15th century. Early lines were called « sounding lines » for relatively shallow water ; and « dipsie » lines for deep water. « Dipsie » is, of course « deep-sea » ; but the original pronunciation is still in common usage. The lead line is still used extensively in depths less than 25 fathoms, and especially in depths less than ten fathoms ; and it has retained its original form, even to the markings of the depths, to a remarkable degree.

Sounding with the lead line was a tedious and slow process, even at best. It was always necessary for the boat to proceed at a very slow rate so as to give the leadsman time to get his measurements with the line perfectly vertical ; and he had very little time to « feel » the bottom before the line angled too far astern. By arming the leads, it was possible to bring up small quantities of bottom material, and therefore, a complete survey resulted, showing both depths and bottom characteristics.

The « dipsie » line has not changed much in principle, either ; but streamlined weights and specially strong steel wires have been made use of, thus permitting the measurement of very great depths without the necessity of splicing lines as was so common in the very early days. The old lines seldom exceeded a length of 100 fathoms and were actually marked off at 5-fathom intervals. One of the early records of our Navy tells of a cannon ball attached to 60,000 feet of strong line, marked at 100-fathom intervals. The cannon ball and considerable of the twine were lost at each sounding. There is even a reported depth of 46,000 feet ! In due course of time, it was learned that the very weight of the twine itself would cause it

(1) Beginning a series of articles by Rear-Admiral Burmister on the use of electronics in hydrographic surveying. Subsequent instalments will appear in forthcoming issues of this Review.

to pay out indefinitely and that any depth greater than 1200 or 1500 fathoms was quite unreliable. However, by taking some precautions, fairly accurate soundings were made in depths up to about 4000 fathoms. Maury did some especially significant work by standardizing the time of descent of the weight in various depths: that the rate of descent varied with the depth of the water, and that bottom had been reached if the expected rate were exceeded. In 1854, a detaching rod was devised by Midshipman J.N. Brooks which not only released the weight when it touched bottom but also sampled the bottom.

Sounding with the « dipsie » line was slow and laborious at best, even with the latest devices. The weight sank relatively slowly even though the line or wire were not restrained in running out. The haul-back was even slower. A sounding in 1000 fathoms would often take as much as an hour's time to complete, especially if the weight did not trip off on reaching bottom. The friction of the other equipment attached to the line (thermometers, water and bottom samplers, etc.) was considerable.

The first really efficient device for sounding in depths of less than 100 fathoms was developed by Lord Kelvin. This was a pressure tube closed at one end. The inside was coated with a chemical which would change color when wetted with sea water. The tube was lowered, open end down, into the water; the pressure of the water compressed the captive air permitting water to enter the tube. The length of the discolored section indicated the depth. The tube was weighted and lowered at the end of a strong steel wire which was handled on a winch. A spring-operated tube was also devised by Lord Kelvin which would record maximum pressure.

The Tanner-Bliss tube was developed a little later; this was a spiral ground-glass tube which was only wetted, and the depth of the water was indicated by the transparent portion of the tube. This had a particular advantage over the Kelvin tube since it could be quite easily dried out, and, so, could be used over and over again, while the chemical discoloration in the Kelvin tube was permanent and only successively greater depths could be measured by one tube; hence its life was generally quite short. The sounding tube permitted operation at slow to moderate speeds.

The ultimate pressure tube was developed in 1912. The Rude-Fisher tube became the standard sounding instrument in the Coast and Geodetic Survey for all soundings in depths less than 100 fathoms because of its accuracy and simplicity in handling. The tube itself was of brass; it was fitted with a cap in which a capillary spiral was machined. The water entered the tube through this spiral capillary as it descended downwards. The compressed air was released only when the tube surfaced on being hauled out. The depth of the water was measured by inserting a rod of fixed dimensions into the tube. The rod actually measured the amount of air space left in the tube. The rod was inserted until the captured water just came to the top. A slider on the rod indicated the amount of rod inserted; this length compared to a special scale indicated the depth of the water. It was usually customary to use two of these tubes for each sounding as a mutual check.

For deep-sea work, the most efficient mechanized version of the Maury-Brooks device was developed by Commander Sigsbee of the U.S. Navy. By this device much oceanographic data could be collected at a single cast: bottom samples, water samples at various depths, water temperatures, and so on. The system was completely mechanized with a reel containing as much as 10 or 12 miles of piano wire on it, a special device to regulate the wire tension, and a registering wheel to indicate the amount of wire payed out. Of course, the ship had to be dead in the water to use the machine, and all surveying processes were very slow and tedious.

Nevertheless, with the development of mechanized sounding apparatus, oceanographic activity increased greatly.

It was only a few years later that the next great innovation in sounding came into being. This was the use of « Sound ». Now, practically all sounding is done by a sound of some frequency, and, with the perfection of this system, oceanography has come into its own as a science. The fact that sounds of various sorts would travel great distances through water has been known for many centuries. Native boatmen have signaled to each other by tapping submerged earthen jars to produce sharp clicks heard many miles away in another boat when holding the ear close to its bottom. However, there are no records of any scientific work on the transmission of sound through water until about 1826, when some interesting work was done on Lake Geneva, Switzerland. Two men, Calladon and Strum, stationed themselves about ten miles apart. One struck a submerged bell with a hammer; the other listened for the sound with an ear-trumpet. Professor Lucien Blake of Kansas made many tests with an underwater bell and a submerged microphone, with a published report in 1889. Some independent investigations were conducted at about this same time by Arthur J. Munday and Professor Elisha Gray (of telephone fame). They used similar devices to those used by Blake, but were not aware of Blake's experiments. The work by Munday and Gray eventually led to the modern concepts of underwater signaling which are most important not only in the field of oceanography but for detecting obstacles in the water through which a ship may be passing.

Munday used a microphone housed in metal case with a thick diaphragm. The button of the microphone was attached to this thick diaphragm by a slender rod. If the thick diaphragm was agitated, the effect was to change slightly the small current flowing through the microphone. This change was detected by telephone receivers, the variations being translated into sounds. An electrically-operated bell was used to produce the sounds.

The first use to which this new idea was put was as a position-finding device to permit a ship to obtain its position in a fog. The atmospheric effects on fog signals — either horns, whistles or bells — were often very confusing. It was believed that the underwater signal would practically eliminate these disconcerting effects. The system was installed on several ships but the noises from the engines and propellers often drowned out weak bell signals. These were almost perfectly eliminated by installing the microphone in a wooden fish towed by the ship — but this was much too cumbersome for practical usage. These objectionable engine noises were finally eliminated by suspending the microphone in a small tank attached to the ship's hull. With the tank filled with water, the objectionable noises remained largely in the hull plating, but the desired signal would pass through the hull into the tank to the microphone. By installing two such tanks, one on each side of the ship, the direction from which the sound came could be determined. This was first done by turning the ship until the intensity of the sound in the two microphones was equal : the ship then pointed directly towards or away from the signal source. The necessity of changing a ship's course was later eliminated by using a compensating network; the amount of compensation was a measure of the direction of the signal relative to the ship's heading. All of this work was done by the newly founded Submarine Signal Company (in 1901) which, since then, has been a leader in underwater investigations.

Various types of bells were designed : pneumatic and electric for near-by and remote operation. Many of these were installed on lightships and could be heard

for distances as great as ten miles. But very few ships were equipped with listening devices, so very little advantage was taken of this new aid to navigation. An amusing incident is reported in the files of the Submarine Signal Company's office relating to the installation of an electrically operated bell on Egg Island: « It seems that a man who was digging a well many miles inland heard a bell ringing. He was terrified and called neighbours and friends to listen. His friends who questioned the man's sanity were both relieved and mystified when they, too, heard the bell. The well was dug near a ledge of rock which extended far out under the sea, and as rock is a good sound conductor, the ledge carried the sound of the submarine bell far inland to the spot where the well was being dug. »

The development of the oscillator by Prof. Fessenden was the turning point in the development of underwater signaling. His device, an electro-magnetic oscillator, is the basic unit of all echo-sounding and echo-ranging systems now in use. The early oscillator had a diaphragm about two feet in diameter and the whole unit weighed nearly half a ton. The driving unit was a sort of induction motor with a very short stroke—about one thousandth of an inch, striking the diaphragm at a rate of 540 times per second. With all strokes of equal amplitude, an enormous amount of energy was generated. The diaphragm actually formed a part of the ship's hull, being inserted in a hole cut in the ship's plating, and therefore in direct contact with the water. The ease with which codes could be sent by this oscillator revolutionized underwater signaling. Twenty words per minute were easy to send, and by 1914 excellent underwater communication was common over distances as great as thirty miles. Many ships of the U.S. Navy installed the system.

It was the *Titanic* disaster which really led to the development of echo-sounding. Underwater signaling had been considered the only use for the Fessenden oscillator and all efforts were being bent on improving them. It was during the early part of 1914 that an oscillator was installed in the Coast Guard Cutter *Miami* for the purpose of trying to detect icebergs by echoes. Experiments were made on an iceberg on April 27, 1914. Tests were made by sending out short signals, listening for the echoes, and timing their return by stop-watch. Echoes were easily obtained from the iceberg with apparent disregard of what the underwater shape of the berg might have been. It was also noted that, regardless of the distance to the iceberg, there was another echo coming in at a nearly constant time interval corresponding to about one mile, which was found to be the depth of the water.

This oscillator was used both to send out the signals and to receive the echoes. It was reported that the ship's officers could hear the echoes in the ward-room without any receiving apparatus. The results of these experiments showed conclusively that echoes could be obtained from the ocean bottom as well as from objects in the water. This was really the origin of echo-sounding and echo-ranging.

It is, indeed, a far cry from the original stop-watch method of timing signal to echo intervals to the present day automatic fully recording echo-sounding equipment. Development was slow during the next years, World War I intervening, and all efforts were expended on devising the most efficient submarine detectors possible. Three large companies : the Submarine Signal Company, General Electric and Western Electric, joined forces to speed up this perfection as much as possible. It was during this period that the « Pliotron » and the « Audion » were developed that made it possible to hear almost inaudible signals—even to hear movements of ships at distances of many miles : noises caused by propellers, engines, pumps, and so on. All this experimentation towards improving submarine detection also aided in the final development of the echo-sounder.

Among the early models of the echo-sounder to be installed in Coast and Geodetic Survey ships was a type designed and built by the Bureau of Engineering of the U.S. Navy Department. In this instrument the time intervals between transmitted signals and the returning echoes were measured mechanically. The time between successive transmitted signals could be varied from infinite to one-tenth (0.1) second, by means of a turntable driving a friction wheel which was adjustable radially from the center (where the rotation would be zero) to the outer edge (where this wheel turned ten times per second). This friction wheel, in turn, drove through a splined shaft, a contactor (or keyer) which could be adjusted to send out the signals at the desired rate. The position of the friction wheel along the splined shaft was adjustable from the center, or stopped, position, to the outer edge of the turntable by a long screw and crank. A dial attached to the crank indicated the relative position of the friction wheel on the turntable. The instrument was designed for a velocity of sound in water of 800 fathoms per second. The signals were sent out by a Fessenden oscillator with a very large diaphragm installed near the keel of the ship almost under the bridge. The sound produced by the oscillator was very powerful and could be heard all over the ship, and often a mile or two away through the air.

The instrument was operated as follows: After a brief warm-up period, the turntable was started with the friction gear set somewhere near the center of the table in order to produce signals at relatively long intervals. With the aid of a hand-set, and listening for the echoes, the position of this wheel was so adjusted that the echo returning from one transmitted signal would coincide exactly with the next out-going signal. When this condition was obtained, the vernier on the crank was read, and the depth of the water determined by reference to a conversion table attached to the instrument. In depths of water greater than 100 fathoms, quite good coincidences could be obtained by most operators and results were very consistent. But, in depths shoaler than 100 fathoms, coincidences became poorer until, at depths of 40 to 50 fathoms, the readings were merely « indications » rather than soundings. In such depths, the Rude-Fisher sounding tube was used exclusively. Nevertheless, with all its shortcomings, this echo-sounder speeded up materially the surveys in water depths greater than 100 fathoms.

Great improvements in echo-sounding equipments were made during the early part of the 1920's. In the years 1925 to 1926, most of the vessels of the Coast and Geodetic Survey had been equipped with the latest sounding device. This instrument was the Model 312 made by the Submarine Signal Company, and it was the first really automatically indicating instrument. It was designed for use primarily in waters of depths less than 100 fathoms, but could be used to any obtainable depth, too. The instrument differed markedly from the Bureau of Engineering model then in use. By comparison, the transducers (oscillators) were very small, being only 12 inches in diameter. Two were used, one installed on each side of the keel; either transducer could be used at the discretion of the operator. Hydrophones (microphones) were installed in tanks on either side of the keel, but well forward so as to be as far from machinery noises as possible. The primary components of the indicating instrument consisted of a disc, driven by a constant-speed motor, rotating back of a graduated dial. The disc shaft also carried a contactor through which the transducers were keyed. The dial was opaque except for an open ring about eight inches in diameter and about 1/4 inch wide. The inner circle of the ring was graduated into 100 parts, each representing one fathom, or a total of 100 fathoms for the full circumference. The outer ring was similarly graduated, but each division represented 10 fathoms. The rotation of the disc

could be either 4 turns per second or one turn in 2 1/2 seconds. This disc carried a small neon tube at a position near the point of rotation at which a signal was sent out, and corresponded with the Zero of the graduated scales. The position was adjustable so that correct alignment could easily be made. The circuitry which operated the neon tube was the invention of Dr. H.G. Dorsey, then of the Submarine Signal Company, but later to become head of the Electronics Section of the Coast and Geodetic Survey where he remained for more than 20 years. In the original circuit the neon light was operated by a very sensitive relay in a vacuum tube circuit ; but this relay was later replaced by a power tube which was much more reliable. The Zero of the dial was adjustable with respect to the transmitted signal so that the depth reference would be the surface of the water rather than the position of the transducer-hydrophone base, thus eliminating the necessity of correcting soundings for this distance. This setting could be changed as conditions required ; and the setting was checked at least once a day.

In depths of less than 100 (or 200) fathoms, the disc revolved at a rate of four times per second. A signal could be sent out at each revolution, or every other revolution. The signal was sent out at a point near the zero of the scales : if the submerged depth of the transducer was 3 fathoms, the neon light would indicate 3 on the scale. If the depth was less than 100 fathoms, the echo would return at some interval less than 1/4 second, or before the next transmitted signal. This echo was amplified in a four-stage amplifier which caused the relay to close and to ignite the neon tube. A momentary glow appeared at this time interval and the scale then indicated the depth of the water. This flash appeared to be fairly continuous, since it appeared four times per second. This was called the « red-light » method of sounding. As the depths increased, and approached 100 fathoms and increased to 200 fathoms, a switch cut out every other signal, and the « red-light » could often be useful in depths approaching 200 fathoms. The modification of the circuit eliminating the relay eliminated much of the erratic « wandering » of the red-light flash.

For depths greater than 100 (or 200) fathoms, the rotation of the disc was slowed to the speed corresponding to 1000 fathoms per revolution. Now, a white light (ordinary flash light type) replaced the neon light, and the depth of the water was determined by an ear-eye coordination process. That is, the observer spotted the position of the « white light » on the return of the echo. As long as echoes were good, a quite accurate measurement of depth could be made. This system was a considerable improvement over the coincidence method (previously described), but still lacked a great deal for complete reliability.

With the invention of the « red-light » system, echo-sounding really came into its own. From that time to the present, there have been many great changes and improvements, both in the transmitting and receiving sections, as well as in the measuring devices. But, the basic principle is the same.

Most of the efforts were bent towards greater reliability in operation. For a short period in the early 30's, an impact oscillator was developed and a number of instruments employing this type were used in Coast Survey Ships. The impact oscillator (which was a variation of the old submarine bell) was quite satisfactory as long as it remained in good order. Mechanically, it was very weak, and required a great deal of maintenance, usually at considerable expense to survey time. One of these instruments (a Model 515) was fitted with one of the first graphic recorders. Recording was done on a specially coated (waxed) paper by a fly-back stylus. The stylus was moved from left to right by a mechanical coupling to the disk system at

such a speed that it made a complete traversal of the paper and returned to Zero on each revolution of the disk. As the fly-back was not instantaneous, a full recording of 100 fathoms was impossible. The recording actually covered the interval from about 5 fathoms to somewhat less than 100 fathoms. Some very interesting « graphs » were obtained from this instrument. The only installation of this equipment in Coast Survey Ships was on the *Oceanographer*.

All of the instruments up to this time employed sound signals well within the audible range, mostly of the order of 1000 to 1050 cycles. The concept of the frequency necessary for best results changed materially during the 1930's, and by the end of that decade most all new systems employed sound frequencies well into the ultra-sonic ranges, and so were no longer audible. This era saw the development of the magnetostriction type of transducers. Nickel had been found to be quite easily deformed dimensionally when it was placed in a high - frequency electric field, and an alternating - current frequency could be determined which would cause the greatest deformation. The transducer could be made up of a block of thin nickel plates (laminations) with a suitable coil wound through and around them; or, a number of small nickel tubes fixed to a diaphragm, each tube being surrounded by its own coil. A small amount of electrical energy applied to such a unit, properly « tuned », would create a signal of considerable strength—one that could be « heard » many miles away through sea water.

In 1938, the Coast Survey obtained a number of *portable* depth recorders from the Submarine Signal Company. These were among the first of the true recording instruments. They were designed for use in small boats (e.g., Ship's launches) and for use in water from 2 or 3 fathoms in depth to about 180 fathoms. Two transducers were used, one to send out the signal, and the other to receive the echo. They were identical, consisting of a block of nickel laminations with a coil wound around and through them, mounted in a stream-lined « fish » towed alongside the launch. These units were actually called « transducers », since a high - frequency deformation of the nickel plates would cause a small current to flow in the coil in a manner reversed to the high - frequency current in the coil causing a deformation in the plates. The receiving unit actually replaced the hydrophone.

Recording was done by a « sweep » rotating at constant speed, the speed being adjusted so that the stylus at the end of the sweep would traverse the paper in a time interval corresponding to 70 feet (or fathoms). The paper used for the record was an electro-sensitive paper, grayish in color, which was blackened when a high - voltage impulse passed through it from the stylus tip to the back-up plate. The record was permanent and practically smudge-proof. Since the recording was done on an arc, the depth graduations (lines running the length of the paper) conformed to the arc intervals. The paper moved slowly under the stylus so that, at each traversal of the stylus, each successive recording was displaced from the previous one by a very narrow gap, resulting in a continuous profile. The position of the stylus arm (sweep), with respect to the keyer, could be adjusted so that true depths from the surface of the water could be recorded. The instrument could record depths in either feet or fathoms, at the wish of the operator. When recording in feet, the sweep rotated at about 8 r.p.s., and the paper traveled at a rate of about an inch per minute. When recording in fathoms, both motions were reduced by a factor of 6. Electronically, this system was very similar to the old « red-light ». The stylus replaced the neon-tube, but was actuated by an amplifier of similar but greatly improved characteristics. When depths near 70 feet (fathoms) were reached, the keying device could be advanced by 50 units, then the recording was done in

depths ranging from 50 to 120 feet (fathoms) ; similarly, a second advance of 50 units would permit recording in a range of 100 to 170 units ; and a third in a range of 150 to 220 units.

This instrument was so successful that it became the standard for many years in the Coast and Geodetic Survey, not only in small boats, but in large ships as well. (Many thousands of this type of equipment — with some modifications — were used during World War II by all Navy and Army amphibious operations.)

The ultra-sonic frequencies tended to remain in the range from 10 to 25 kilocycles during the war period. The transducers were greatly improved in their operational efficiency, both for transmitting and receiving signals as ranging equipment, but also for detecting other underwater sounds. With World War II, emphasis was again on underwater communications, but all developments for communications strengthened the position of the echo-sounder. Sound ranging of great accuracy became a necessity, and units of great directional efficiency were developed. Various types of crystals were used as well as nickel. Some of the crystals were Rochelle Salts, A.D.P. (ammoniumdihydrogenphosphate), and ceramics of various forms. The ceramic crystals have great stability, and various sizes and shapes are used. All these new materials have permitted a great reduction in the size and a great improvement in the efficiency of the transducer. Many crystal units now operate on frequencies up to several hundred kilocycles ; and several echo-sounding equipments employ ultra-sonic frequencies well above 100 kilocycles.

Echo-sounding equipment of the present day is almost completely automatic in its recording of the depths of the water. Equipments vary in size from some very small portable units weighing less than 50 pounds total and for use in depths less than 100 feet in some cases, to very large and powerful units suitable for large ships where definitely legible records can be made of any depth yet encountered. Most recording is done on electro-sensitive paper which leaves a permanent black record, though there are a few instruments which still use electro-chemical paper where only a semi-permanent record is made, the record fading into a general overall discoloration of the paper with time. Some of the larger units record on a relatively large scale, in bands 400 fathoms wide on a width of 10 inches; the correct recording band is selected by the operator, and it is identified by a special coding marker.

Surveying can now be done at fairly high ship speeds and great areas can be covered in relatively short times. It is only necessary to stop occasionally for the traditional bottom sampling, temperature and salinity tests of the water, and other data necessary to make the survey complete.

The effects of temperature, salinity and depth of the sea water have long been known, and a very comprehensive study of their effects, on the velocity of sound both individually and collectively, has been compiled. One of the better known compilations on this subject is *Velocity of Sound in Sea Water*, by Commander N.H. Heck and Ens. Jerry H. Service, both of the Coast and Geodetic Survey. This publication contains a discussion of the velocity of sound in sea water from a theoretical standpoint and a large number of tables showing the effects of salinity, temperature and pressure individually and in combination. According to these tables, the velocity of sound will vary as much as 60 fathoms a second, from a value somewhat under 800 fathoms per second to more than 850 fathoms per second, depending upon the combinations of the various parameters.

A completely practical process whereby these velocity change effects could be automatically corrected for in an echo-sounding equipment has long been studied. While there are several instruments now in use which do this, the general practice is to design the instrument for a fixed velocity, e.g., 800 or 820 fathoms a second, and then make the necessary corrections after the work has been completed. Generally, the real velocity is not known until a large amount of work has been done, so a certain amount of adjustment is necessary ; and, while the task of making the adjustments may be somewhat boring in character, the work is not at all difficult. There has even been some thought of making no corrections whatever, since most instruments are calibrated for a velocity of sound in sea water of 800 fathoms per second. In this idea, it is thought that the adjustments are somewhat academic, though correct ; and, since the majority of navigators will not have the necessary information at hand to make them, such soundings as they do take should be readily correlated with depths indicated on the nautical chart, this being a check on the ship's position.

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