INFLUENCE OF ECHO SOUNDING ON HYDROGRAPHY.

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With the change from sail to steam, the men who go down to the sea in ships have demanded from the men who draw the sea a more rapid and extensive production of sea charts, showing the coast line, shoal water, harbours and their approaches with the adjacent deep water channels, not forgetting dangerous shoals and submerged rocks.

All these were required with increasing urgency and no profession works harder and with more devotion to accuracy and detail than Hydrographers, past and present. Their printed records throughout the world abundantly testify to this undoubted fact. To this end they have to study the tides, astronomy, terrestrial magnetism, radio and acoustic signalling, gravity, all varieties of surveying, and the many problems involved in determining the depth of water. All these subjects are welded together in their minds for the provision on charts of a meticulous and concise abstract of their mass of notes on soundings accurately located from shore trigonometrical points with proper correction for tidal rise and reduction to chart datum.

In studying the history and world-wide growth of Hydrographic Departments the increasing need for equipment and sea-going surveying ships is seen to be continuous, for, from the beginning of the nineteenth century up to the present, Hydrographic Departments were striving against such inadequacies to present a ridiculously small section of the work crying to be done. Every important maritime nation now makes detailed surveys of its coasts and adjacent waters and publishes nautical charts of the world's sea routes as well, but few of the coasts of the world have yet been charted in the detail now demanded. Constant changes in the sea bed and coast in many parts of the world necessitate frequent and sometimes monthly revisions of existing work. The use of steam vessels in hydrographic work was an epoch-making innovation, and it then became possible to carry out rapid detailed surveys of large areas of the ocean ; later, the motor boat speeded up the execution of coastal and river survey even without the equipment and echo sounding technique of the present day.

The Hydrographic Surveyor is necessarily a painstaking and hardworking man, and few more stirring tales of work at sea, such as that carried out on the coast of Australia and on the east and west coasts of America in the early days of boat and ship survey, can be told. It was a heroic and successful battle for the accuracy required, but with little chance of getting the best instruments or even suitable boats, and up to 1914 the pressure for charts in the Merchant Navies increased beyond all expectation as the size and speed of ships increased apace. In addition, the demand for safety measures at sea greatly accentuated the need for accurate charts in large quantities ; hand in hand with this requirement came the need for constant chart correction, which in turn called for rapid world-wide publication of notices to mariners incorporating the very last word of the Hydrographer.

It was not only by the gradual development of the modern Survey Ship and equipment that the work progressed, but changes occurred in the very nature of hydrography. Up to 1914 this involved astronomical fixing on sea and on land, trigonometrical and topographical survey 25 miles out to sea and ten miles inshore, and also detailed observations of tides ; but the present-day Hydrographic Department must include oceanography in all its branches, including accurate observation of currents, tides and tidal streams, salinity and temperature of the ocean.

It was very largely due to the painstaking research work done in salinity and temperature by many stations and observers that by 1924 the need for accurate tables of the speed of sound arising from echo sounding in the layers of the ocean was met, which in turn led to new and important developments of echo sounding techniques and radio acoustic ranging in hydrography. Tables of the velocity of sound in sea water of the required precision were published by the U. S. Coast and Geodetic Survey in 1924, and by the British Admiralty in 1927.

Water, either fresh or salt, is the only liquid which permits of the direct measurement of the velocity of sound over appreciable distances. The first recorded observations are those of Colladon and Sturm in Lake Geneva. In these, a submerged bell was struck by a hammer, which simultaneously flashed a quantity of powder, thus indicating sonic and linear zeros to an observer on the other side of the lake, such being the instant of striking and site of the bell. A very good first result was obtained, the final value of the velocity being 1435 metres/sec. at 8°C., which is in good agreement with the calculated velocity of 1436.4 metres/sec. The French, German and American Governments all carried out similar observations for the velocity of sound, and the British Admiralty made experiments off Dover in 1920. These were carried out by Dr. A. B. Wood and Capt. H. E. Browne by means of hydrophones laid at intervals of about four miles on a line N. and S. to the eastward of the Goodwin Sands. The time interval was that measured from the instant of firing the charge, simultaneously indicated by the wireless signal, to the final arrival of the sound at the receiving hydrophones.

The results of the complete investigation are summarised in the following expression :

$$C = 4626 + 13.8t - 0.12t^2 + 3.73S \text{ feet/sec.}$$

or

$$C = 1410 + 4.21t - 0.037t^2 + 1.14S \text{ metres/sec.}$$

where t is the temperature within the range 6° — 17°C. and S is the salinity in parts per thousand (e. g. 35 at Dover). These figures agree remarkably with the tables published by Mr. D. H. Mathews in that there was no difference between theory and observation as great as one-tenth of a metre per second ; roughly, one part in fifteen thousand. Sir Isaac Newton first showed, reasoning from fundamentals, that the velocity of transmission of sound through any given medium is given by the equation

$$V = \sqrt{\frac{\text{elasticity of the medium}}{\text{density of the medium}}}$$

The velocity of transmission of sound through the layers of the ocean is given by the formula

$$V = \sqrt{\frac{dp}{de}}$$

where

V = velocity
p = pressure
e = density.

Before the numerical values of these quantities can be found it is necessary to know with regard to the water

(1) the temperature
(2) the salinity.

The accuracy of the Admiralty Tables depends upon the values of these quantities in Knudsen's Hydrographical Tables, 1901.

The errors of echo sounding devices in the first years of their use, whether for navigation or hydrography, were considerable, but in depths of 200 fathoms no corrections for temperature or salinity were applied except in exceptional areas such as the Red Sea, where the correction is considerable, amounting to about 5 % in some depths. Generally speaking, the mechanical error swamped all the others, and it was not until the improved machine came out in 1929-30 that serious value was attached to echo depths and surveyors were sufficiently confident of their accuracy to incorporate them in charted information. Hydrographers were still using the lead and depth wire as a check and discussing its undoubted curving and stretching ; also the various methods of sounding by such gadgets as the Plomb Poisson were advocated to obtain vertical checks against the echo sounder. But, practically speaking, hammer and hydrophones of improved types were hard at work in many parts of the world on chart making from 1927-1930. In 1927 the Thalassological Institute of Finland procured their first echo sounder, British Admiralty Type 752 with headphone listening type and the hammer and hydrophone were fitted in the ship "Nautilus".

A survey during 1927-1929 was carried out in Bothman Bay and the North Kvark and the table of working results shows the large number of soundings taken and the progressive improvement in area covered. Dr. Renquist, in his report of 1930, states :

« Naturally there arises some question as to the degrees of exactitude obtainable with Echo Sounder. The divergencies keep within limits which barely exceed one metre, and after a certain amount of practice can be reduced to one or two decimetres. One can depend on the echo sounding agreeing within a metre with depths obtained by means of sounding wires, and it is therefore *no longer possible to assert that soundings obtained with wires are more reliable.* »

The same shallow water type of echo sounder was installed in 1928 on the Survey Yacht "Giralda", of the Spanish Navy, and very successful trials were made at Ferrol. The installation was a good one owing to the sharp lines of the vessel, and there was no interference or aeration, with the result that the echo could be obtained with sharp definition and readings accurately determined up to 130 fathoms.

A deep water echo sounder, British Admiralty Type, was also installed in the Spanish Hydrographic Service, and finally in 1930 all the cruisers and submarines of the Spanish Navy were fitted with British Admiralty type Sonic Echo Sounders.

The progress of echo sounding in the Mediterranean was greatly accelerated by the general use of echo sounding in the Spanish Navy, and such generally good results helped to put echo sounding results on sea charts.

Very early in the record of echo sounding the surveying ships of the British Royal Navy were fitted with sonic echo sounders, seven in all by 1925 — the "Moresby" in Australia and, a little later, a ship in South Africa. All these ships were taking very exact echo soundings by listening, which was admitted by Dr. Harvey Hayes to be more exact than the flashing light device. Great efforts were made to obtain the best listening devices, i. e. the carbon button for hydrophones, and the regulation of the speed of the pick-up motor. The deep water gear was first fitted in H. M. S. "Ormonde" and about 1930 a trial was made off Ushant to pick up the 1000 fathom line. The echo soundings were clear, but for the first time on these slopes it was observed that echo could jump from 1200 - 1000 - 800 fathoms and back again in a few minutes, whilst the ship slowly moved on, and this was obviously due to the canyon excavation.

In about 1922 the Behm Echo Lot was being used with pistol discharge, quite accurate echo soundings being obtained in shallow water.

In 1925-1927 the German Exploration Ship "Meteor" made history in echo sounding by the establishment of 14 trans-oceanic profiles comprising more than 67,000 soundings taken at approximately 34,000 stations with two echo sounders, and in the same year the German cruiser "Emden" recorded by echo sounder the greatest known oceanic depth of 10,790 metres in the Mindanao Deep, using Fessenden oscillators. The Dutch ship "Snellius Willebrod" was fitted in 1931 with the Atlaswerke echo sounder and the British Admiralty deep water gear. The results of the Snellius Expedition led to a considerable discussion of slope correction for great depths and this has always to be considered in the early deep water sounding by wide beam oscillators.

In the American Navy great interest had been shown in sonic depth finding and, following the successful voyage of the destroyer U. S. S. "Stewart" in 1922 to Manila by way of Gibraltar, on which soundings were taken every 20 minutes and at times as often as one minute, the destroyers "Hull" and "Corry" were equipped with depth sounding apparatus and proceeded to make a survey of about 3,500 square miles of sea floor off the coast of California. This is the first successful contour map of a zone of deep sea soundings, and the chart represents the configuration of the ocean floor showing the submerged hills, valleys, cliffs and precipices.

By 1928 four ships of the U. S. Coast and Geodetic Survey were fitted with sonic depth finders, and this Office was receiving an enormous amount of reliable deep sea sounding data.

By 1931 fifteen ships of the Coast and Geodetic Survey were fitted with shallow water type fathometers.

That distinguished Hydrographer and Engineer, Mons. Marti, was largely responsible for the development of echo sounding in the French Navy. He carried out all the early trials by detonators, and as early as 1922 he had introduced his system of recording the soundings on smoked paper in the Hydrographic Service, from which many interesting records were obtained and some remarkable investigations made in echo sounding.

By 1920 Dr. Langevin had introduced his ultra-sonic appliance, which originated from the experiments made by Dr. Curie in the Piezo quartz effect.

Since that time the use of ultrasonics, or supersonics as it is now called, has rapidly spread into all the Hydrographic services, and it is universally recognised today that supersonic echo sounding is the most convenient and accurate method.

In 1926 the ultrasonic sounding machine, Langevin Florisson System, was fitted on board the "Ammiraglio Magnaghi", a surveying vessel of 2,500 tons of the Royal Italian Navy, and Captain Tonta, who was in command, reported that it gave magnificent results. At a subsequent date the "Citta di Milano" was fitted with the same gear and did work in northern waters. This vessel, when employed by the Pirelli Company, was fitted with the British Admiralty echo sounder, deep water type, in 1930, which was very successful in obtaining deep water soundings in the Bonifacio Straits up to 3,000 fathoms when laying the Rome to Malaga cable.

Two ships of the Swedish Navy were fitted with the Langevin ultrasonic machine in 1928, and Captain Renius, the Hydrographer, reported they were giving very accurate results in shallow water.

In 1928 the Canadian Survey Ship "Acadia" was fitted with Admiralty deep water echo sounder, and remarkably good results were obtained off the coast of Labrador. This led to the introduction of echo sounding into the Canadian Hydrographic Service.

Despite the early suspicions of echo sounding, which were shown by requests for the use of special depth figures on charts as symbols for echo soudings, and even a further distinction between sonic and supersonic soundings, the true value of this new method was fully appreciated by the Hydrographic Departments and a large number of extra soundings were incorporated in the charts of the world by 1930.

The echo sounder undoubtedly gave the Hydrographer an added sense of exploration because he could work much more rapidly and cover such a lot of ground. This had a great influence on the cost of hydrography, and from the records of the U. S. Coast and Geodetic Survey, these figures were arrived at in 1931 by F. S. Borden.

Intensity of Sounding : I = Linear miles per sq. mile = average spacing of parallel sounding lines in "lines to the square mile".

$$\text{Unit cost} = \frac{C}{I} = \frac{\text{cost per sq. mile}}{\text{Miles per sq. mile}} = \text{cost per mile.}$$

Reduction in cost since development of echo sounding and R. A. R. = 47 %.

For purposes of standardisation in the construction of machines the speed of sound for use in echo sounding was assumed to be 1500 metres per second in Metric models or 4800 feet per second in British models. This gave what was called Echo Time ; that is, the time to go to the bottom and back. Therefore, for one second a depth of 750 metres = 1 second of echo time, and a depth of 2400 feet— 1 second of echo time. As a consequence of this the scales of echo sounders were adjusted to the echo time ; thus

200 fathom scale was 1/2 second echo time
130 " " 1/3 " " "

and this relationship has been very generally adopted in echo sounding engineering for mechanical reasons and ease in computing scales. Although in the early stages it was considered extraordinary to sound at one pulse a minute, the widespread use of the echo sounder made it apparent that a complete mesh of soundings could be obtained at the rate of three pulses per second, thus giving 180 soundings per minute. A ship travelling at 10 knots covers roughly 17 feet per second, and in that time three soundings could be made.

Such possibilities in sounding frequency had a great influence on Harbour Surveyors in particular, many of whom were eager to use the advantages of echo sounding for increased coverage and greater intimacy in defining bottom profiles.

Many small ships were fitted with sonic gear in about 1930 ; notably the yacht "Katherine" in the Port of London, together with ships of other Harbour Boards. This led to greater precision in shallow water sounding and aroused considerable discussion about limits of accuracy attainable as compared with results obtained by the very experienced hand leadsmen employed. But Harbour Survey ultimately demands the highest accuracy at all working depths and speeds and the most precise sounding possible by careful hand lead sounding at slow speed could not compete with that possible in echo sounding. Echo sounding, even in its early stages, gave an accuracy to one foot with proper calibration, using sonic methods, and later developments in supersonics improved accuracy to $\pm$ 3" with bar-check.

In February 1930 the first trials of the magneto-striction oscillator were made by the British Admiralty Research Department in a survey boat at Sheerness. Good records of the contour of the sea bed were at once obtained with the motor boat running at full speed (8 knots) in a choppy sea. In these early experiments the transmitter and receiver were fitted in a frame on the gunwale of the boat and adjusted to a depth of 18" below the waterline. This temporary outboard mounting was later replaced by a more permanent inboard fitting. Two openings 8" square were cut in the bottom of the boat and wooden tanks constructed above them. The holes were subsequently covered with copper sheeting, through which the supersonic pulses passed.

The recorder used in these trials was the first short range type using starched iodide paper moistened by a wick as it unrolled. The width of the actual record for very shallow water was approximately 5" per 200 feet of depth, and the stylus or pen crossed the paper in 1/12th of a second approximately. Provision was made in subsequent recorders for a total range of depth of 0 - 420 fathoms. The recording stylus crossed the paper in a time corresponding to 70 fathoms, and by the instant of transmission in steps equivalent to 50 fathoms, the series of overlapping ranges 0-70, 50-120, 100-170... 350-420 fathoms is obtained. This is known as "phasing" and has since become an important feature for increasing the range of echo recording.

Further tests were made in the H. M. Survey Ship "Flinders" in 1932 on the west coast of Scotland, using ring type oscillator fitted with 12" diameter reflectors with pulses at 15 kilocycles per second. The high frequency sound impulse and the returning echo passed successfully through the steel hull of the ship, 3/8" thick. Good results were obtained with a speed of 10 knots and no interference from ships or water noise were experienced up to depths of 440 fathoms.

Finally, the trawler "Glen Kidston" was fitted in the same year with magneto-striction oscillator and recorder and very good records were obtained off the Norwegian coast near Bergen. Dr. H. B. Wood, who conducted the Admiralty trials, stated his views as follows :

"The magneto-striction system may have any degree of directionality required. At present it has been found satisfactory to use a conical beam of sound of semi-apical angle 20^{0} - 30^{0}. The comparative ease with which the receiver can be screened from the transmitter is due to the relatively short wave length (about 4") of the sound and the directional properties of the conical reflectors.

"Another advantage of the directional characteristic is that the soundings are taken directly beneath the ship and the receiver is therefore insensitive to echoes from submerged cliffs or banks. In this respect also the directional beam is more discriminative of detail than non-directional types and is less liable to miss a submerged rock or a wreck."

The immediate advantages that were envisaged from these trials were the portability and ease of fitting for small boats, and in the early days, 1932, experiments were made in fitting the Admiralty High Frequency Boat Type Echo Sounder in remote parts of the world.

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MODEL	Type	SCHEDULE OF TYPES & SCALE RANGES				
		Maximum Scale Range		Basic Scale		Phasing Shallow
		Shallow	Deep	Shallow	Deep	
MS 10	—	40 ft.	—	40 ft.	—	—
	—	480 ft.	—	40 ft.	—	15×30 ft.
	—	12 mtrs.	—	12 mtrs.	—	—
	—	150 mtrs.	—	12 mtrs.	—	10×14mtrs.
MS 12	—	60 ft.	120 ft.	60 ft.	120 ft.	—
	—	110 ft.	120 ft.	60 ft.	120 ft.	50 ft.
	—	60 ft.	220 ft.	60 ft.	120 ft.	—
	—	60 ft.	60 fms.	60 ft.	60 fms.	—
	—	100 ft.	60 fms.	60 ft.	60 fms.	40 ft.
	—	120 ft.	120 fms.	120 ft.	120 fms.	—
	—	220 ft.	120 fms.	120 ft.	120 fms.	100 ft.
	—	120 ft.	220 fms.	120 ft.	120 fms.	—
	—	70 fms.	350 fms.	70 fms.	350 fms.	—
	—	25 mtrs.	125 mtrs.	25 mtrs.	125 mtrs.	—
	—	45 mtrs.	125 mtrs.	25 mtrs.	125 mtrs.	20 mtrs.
	—	50 mtrs.	250 mtrs.	50 mtrs.	250 mtrs.	—
	—	90 mtrs.	250 mtrs.	50 mtrs.	250 mtrs.	40 mtrs.
	—	50 mtrs.	450 mtrs.	50 mtrs.	250 mtrs.	—
	—	125 mtrs.	625 mtrs.	125 mtrs.	625 mtrs.	—
	—	225 mtrs.	625 mtrs.	125 mtrs.	625 mtrs.	100 mtrs.
MS 16	—	120 ft.	120 fms.	120 ft.	120 fms.	—
	—			(Indicator	150 fms.)	
	—	—	120 fms.	—	120 fms.	—
				(Indicator	150 fms.)	
	—	93.75 mtrs.	468.75 mtrs	93.75 mtrs.	468.75 mtrs.	—
				(Indicator	450 mtrs.)	
MS 19	*A*	120 fms.	1,200 fms.	30 fms.	300 fms.	5×20 fms.
	B	180 mtrs.	1,800 mtrs.	45 mtrs.	450 mtrs.	5×30 mtrs.
	C	300 fms.	3,000 fms.	75 fms.	750 fms.	5×50 fms.
MS 20	—	—	360 fms.	—	80 fms.	—
	—	—	660 mtrs.	—	150 mtrs.	—
	—	Dual	360 fms.	—	80 fms.	—
	—	Scale	660 mtrs.	—	150 mtrs.	—
MS 21	*A*	270 ft.	540 ft.	45 ft.	90 ft.	8×30 ft.
	B	720 ft.	720 fms.	120 ft.	120 fms.	8×80 ft.
	C	—	540 fms.	—	90 fms.	—
	D	Dual	540 fms.	—	90 fms.	—
	—	Scale	990 mtrs.	—	165 mtrs.	—
	E	—	2,160 fms.	—	360 fms.	—
	F	90 mtrs.	180 mtrs.	15 mtrs.	30 mtrs.	8×10 mtrs.
	G	225 mtrs.	1,350 mtrs.	40 mtrs.	240 mtrs.	8×25 mtrs.
	H	—	4,050 mtrs.	—	700 mtrs.	—

Phasing Deep	No. OF SOUNDINGS per minute		PAPER SPEED (inches per minute)	
	Shallow	Deep	Shallow	Deep
—	300	—	1.6/0.8"	—
—	300	—	1.6/0.8"	—
—	300	—	40.6/20.3 mm.	—
—	300	—	40.6/20.3 mm.	—
—	533.3	266.6	1.16"	0.58"
—	533.3	266.6	1.16"	0.58"
100 ft.	533.3	266.6	1.16"	0.58"
—	533.3	88.8	1.16"	1.16"
—	533.3	88.8	1.16"	1.16"
—	266.6	44.4	0.58"	0.096"
—	266.6	44.4	0.58"	0.096"
100 fms.	266.6	44.4	0.58"	0.096"
—	80	16	0.7"	0.14"
—	400	80	22 mm.	4.4 mm.
—	400	80	22 mm.	4.4 mm.
—	200	40	11 mm.	2.2 mm.
—	200	40	11 mm.	2.2 mm.
200 mtrs.	200	40	11 mm.	2.2 mm.
—	80	16	17.5 mm.	3.5 mm.
—	80	16	17.5 mm.	3.5 mm.
—	266.6	44.4	0.58"	0.096"
—	—	44.4	—	0.096"
—	106.6	21.3	26 or 18 mm.	5.2 or 3.6 mm.
5×200 fms.	203.6	20.6	0.4" (Constant	0.04" 0. 2")
5×300 mtrs.	250	25	25 mm. (Constant	2.5 mm. 12.5 mm.)
5×500 fms.	82.6	8.266	1" (Constant	0.1" 0.5")
5×60 fms.	—	66.6	—	0.281"
5×110 mtrs.	—	66.6	—	7 mm.
5×60 fms.	—	66.6	—	
5×110 mtrs.	—	—	—	7 mm.
8×60 ft.	533.3	266.6	(Constant)	1"
8×80 fms.	200	33.3	(Constant)	0.5"
8×60 fms.	—	44.4	(Constant)	0.5"
8×60 fms.	—	—	—	0.5"
8×110 mtrs.	—	44.4	(Constant)	12.5 mm.
8×240 fms.	—	11.12	(Constant)	0.25"
8×20 mtrs.	500	250	(Constant)	25 mm.
8×150 mtrs.	200	33.3	(Constant)	12.5 mm.
8×450 mtrs.	—	11.12	(Constant)	6.25 mm.

Trials were made in the small motorships of the Admiralty and echo records were obtained off wrecks and sunken piles, etc. It was finally decided to redesign the recording gear, which in the early models used the feature known as straight line recording. The result was the rotating stylus recorder, which, whilst giving an arc trace on the paper, is free of errors due to acceleration and deceleration, can be governed very closely in speed, and in consequence can achieve an accuracy on larger scales than was possible with the original gear.

The recorder known as M. S. 12 was produced and scales for survey work on this instrument developed rapidly.

With straight line recorder the reciprocating motion for the mechanical reasons above indicated made accuracy very difficult beyond one sounding per second, but the revolving arm allowed the speed of sounding to be increased and consequently the range was adapted to produce a very open scale.

The number of scale ranges which can be produced in the Hughes recording echo sounder is shown on the diagram. Most of these are applicable to M. S. 12 and were developed in the early days when the Hydrographic Departments all over the world demanded scales to their own particular requirements.

THE HUGHES RECORDING ECHO SOUNDER.

Selection of scales. — Everyone is familiar with the term "scale" as applied to map and graph reading, and practical experience has pointed out the mistake of using a scale which is either too large or too small. Similar considerations apply in the selection of a scale for an echo sounder recorder, and to meet every condition in the most efficient manner possible an infinite variety of scales would be necessary. Unfortunately, however, the characteristics of the scale are determined by the ratios between a train of gear wheels, which, from the point of view of repetition and standardisation in production, obviously cannot be made and stocked in an infinite variety of sizes. Moreover, there are certain other practical limits governing the maximum and minimum number of depth units into which a scale of a given length may be divided. The speed of traverse of the recording stylus is inversely proportional to the number of depth units covered by any particular scale length ; hence, owing to recording difficulties at very high pen speeds, a limit is imposed on the *minimum* number of units usable. On the other hand, the *maximum* number is determined by the difficulty of reading fine, closely graduated divisions at a reasonable distance.

These considerations may be summed up by saying that the minimum scale found practicable for an M. S. 12 recorder is 60 feet, and for an MS. 10 recorder, 40 feet, while the maximum depth for an M. S. 12 type scale is considered to be 350 fathoms. These figures relate only to *scales*, and must not be confused with maximum sounding *ranges*, since by application of the usual phasing technique the total range of the instrument may be made equal to many times the scale range.

From the foregoing it is clear that some degree of standardisation in scale is essential. The appended series of scales has therefore been standardised after careful consideration and represents the best possible compromise between the twin ideals of operational perfection and efficient after-sales service.

PHASING.

Phasing is the system whereby the range of the recorder can be increased to sound depths very much greater than those covered by the lowest or basic calibrated scale. This basic scale embraces only the distance traversed by the stylus from one side of the recording paper to the other, but if the moment of transmission is advanced to occur a pre-determined interval *before* the scale zero, allowing time for the sounding to reach a greater depth, then the depth corresponding to that interval can be added to the scale to give an increase in range.

The extra phase or phases may be brought into operation by means of an electrical switch, or mechanically by a rotary dial calibrated in successive steps, *e. g.*, + 30, + 60 etc., while on "Multiphase" instruments the scale and phasing system are combined and rotary, an increase in scale reading taking place automatically with each increase in phase.

There are two types of magneto-striction oscillators. Roughly speaking, the cylindrical or roll type oscillator with reflector is used for boat work up to 100 fathoms and the pack oscillator with reflector for fitting in larger ships for survey work requiring sounding up to 1,000 fathoms. Since 1932 there has been great improvement in the efficiency of these oscillators, and whilst in the case of deep water work it is desirable to fit a thin stainless steel diaphragm under the oscillators, in general it may be said that the magneto-striction oscillator has the enormous advantage of operating through the metal hull of a ship whatever the thickness, and is not affected by very acute angles of fitting on the hull near the keel.

In the "Queen Mary" the plate thickness was over an inch and well-recorded soundings over 200 fathoms at 30 knots were obtained. In early fittings of destroyers, hull plating angles of 25° to 30° were experienced for fitting oscillators.

It was not long before a demand came for a very high speed echo sounder with the most open scale possible for use in very shallow water. This requirement was met by the design of the M. S. 10, which has a 9" stylus radius as compared with 5" in the M. S. 12.

Speed of sound in sea water is roughly taken at 4,800 feet per second ; therefore, an echo foot $= \frac{1}{2400}$ sec. To provide a scale, say 1/8 in. = 1 ft. on 0-40 ft. record means that the pen has to travel at a linear speed of 26 feet per second and this must be done rigidly and precisely. The essential features are, therefore, the motor governor and gears, which can be time checked and adjusted. The first machine of this type was produced for Dr. J. Van Veen to be used in the summer of 1934 in the Waterstaat surveying ship "Ocean" for investigating sand movements between Dover and Calais. The original model had a scale of 1 cm. = 1 metre, and could be altered by gear changes to 1 cm. = 4 metres.

In order to get the maximum amount of oil for the tankers using Maracaibo Bay, several M. S. 10 machines were fitted in launches belonging to the Anglo Saxon Petroleum Company. Such are today operating successfully to give accurate depth to 3". Harbour authorities in different parts of the world are using this gear and perhaps the most successful and important has been the Port of Southampton, where the constant stream of large ships entering and leaving the harbour demands great accuracy in survey. Rapid and accurate decisions on the basis of such depths and varying tidal levels are necessary to ascertain the clearances which can be guaranteed to a big liner of heavy draught entering the port from Southampton Water. Lieut. Comdr. D. A. MacMillan, R. N. R., Marine Surveyor of the Port of Southampton, has made a special study of the use of the M. S. 10 echo sounder for harbour work. He has published his results in 1935 under the title "Precision Echo Sounding and Surveying". This work is very well known and has been responsible for some important developments in Harbour Survey and the general use of the echo sounder in survey work. He describes the problem which confronts the harbour authorities dealing with transatlantic and other liners today. The most interesting feature of the first part of the book is the description of what is known today by all surveyors using echo sounders as the Bar Check Method. The Bar Check is the safest criterion for all depth measured below the water line of a survey launch at a given draught and trim at rest. Briefly, it consists in lowering directly under the oscillators an iron angle bar 3" in width ; the total weight of the bar is about 80 lbs and, by ingenious rigging, it can be lowered by calibrated depth wires under the oscillators until the required marks, say, 35 ft., are on the water line on the port and starboard sides, respectively, with lines "up and down". The sounding machine being switched on, the record of the top of the bar will appear on the paper. The glass scale should then be set to 35 ft. and the phasing can be tested at 5 ft. Similar records can be taken at 5 or 10 foot intervals of the scale. If all the steps are consistent and in agreement with direct and phase scale setting, timing phase relation and scale zero will all be correct to within $\pm$ 3" of depth provided the instrument is used near the site of the bar check and conditions of salinity and temperature have not materially altered.

Correction can be made by adjustment of the contactor over which moves the transmission line below the artificial zero to the actual vertical distance of the water-line above the effectual plane of the oscillators.

Normally, the bar check would be carried out before and after survey at the range of depths surveyed, and the True water-line zero for the survey would thus be determined from the depths "steps" which would be the absolute criteria for the zero of soundings deduced therefrom.

It is very interesting to note the great respect which is paid to the Bar Check by all Hydrographic Departments, and, indeed, it can be said that the most reliable method of obtaining accurate echo soundings to place on the chart is by Bar Check. It is referred to in the Admiralty Manual of Hydrography and in the Hydrographic Manual of the U. S. Coast and Geodetic Survey, and at the International Hydrographic Conference in 1947, when echo sounding was demonstrated in the Port of Monaco, it was clearly shown that all the Hydrographic Surveyors present appreciated the value of the Bar Check.

The history of echo sounding in the Canadian Hydrographic Service dates back to 1915 when experiments in connection with the travel of sound in sea-water were conducted aboard the Canadian hydrographic vessel "Cartier" in the lower St. Lawrence River. The apparatus used consisted simply of a submerged oscillator lowered overboard from the ship, and a telephone receiver suspended from a launch moored at various distances from the vessel.

One of the earliest and best records of practical hydrographic work which resulted from the invention of magneto-striction oscillators was the development that took place in Canada under the supervision of Captain F. Anderson, then Chief Hydrographer of the Canadian Hydrographic Service. In 1929 the surveying vessel "Acadia" was fitted with an Admiralty sounder for work on the Hudson Bay Route and the following year two other Canadian Hydrographic ships, the "Bayfield" on the St. Lawrence - Great Lakes Waterway, and the "Lillooet" on the Pacific coast, were equipped with these instruments. The latter vessel tested the new gear in very deep water 150 miles off the coast. Convinced, as a result of these trials, that in echo-sounding lay the means of greater efficiency and incomparably greater economy, Captain Anderson directed that echo-sounders be installed as regular surveying and navigational equipment on all hydrographic ships and surveying vessels. Subsequently, some 35 echo sounders were used by the Canadian Service.

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The year 1932 was a very interesting one for the development of deep water sounding by echo sounder with the recorder attached.

In June 1932 H. M. S. "Challenger" was ordered to proceed to Labrador and commence a survey of the coast between Indian Harbour and Cape Chidley on a scale of 1/75,000. On June 24 she sailed from Portsmouth and arrived at St. Johns, Newfoundland, on July 3, having carried out a series of oceanographical observations on passage. The British Admiralty deep water echo sounder was installed in the ship and continuous records were obtained across the Atlantic, and some very valuable data was collected on slope and gradient correction.

H. M. S. "Ormonde", which was already fitted with the same deep water Admiralty gear, made a trial off Ushant in October 1932 and revealed the extraordinary character of the continental slope which had been detected as early as 1930, but without an actual record being taken.

The first cruise of the "Challenger" was very successful in plotting the coast line of Labrador, and successive cruises in 1933 and 1934 have resulted in very excellent chartwork. The ship was commanded by Captain A. G. N. Wyatt, R. N., now Vice-Admiral Wyatt, K. B. E., C. B., Hydrographer to the Navy, and he carried out a very fine feat of seamanship and navigation in these difficult waters.

Thinking of large ships recalls that the Clyde Navigation Trust were very anxious in the beginning of 1936 about the 18 mile voyage down the Clyde to the open sea, which the world's largest liner "Queen Mary" had to make, and the river was carefully surveyed with an M. S. X. Recorder in the launch s. s. "Clyde". A complete survey of the channel was made, which showed how thoroughly and accurately the dredging operations had been carried out, and the "Queen Mary" reached the sea without mishap. The same records were used for the "Queen Elizabeth" later on, with complete success, although there were several anxious moments.

Echo sounding had definitely passed out of the experimental stage and become an exact science. Records were being made on a very large scale on all the important rivers and harbours, and some very interesting demonstrations took place in France. On the Vedette "Echo" in 1936 by request of Mr. Durepaire, of the Department of the Loire, an M. S. 12 machine with outboard oscillators was fitted and tried out. The demonstration took place between the Port of Donges and Paimbœuf in the vicinity of Des Brillantes, where it was known there were rock formations. On two successive days, runs of varying courses were made cross-sectioning a proposed new Channel, and the echo sounder recorded the depth to a proved accuracy of 10 centimetres, and at the same time indicated where there was rock strata underlying soft mud at several points. In the harbour basin at St. Nazaire it revealed a sunken boat lying on the bottom, the existence of which was not known to the authorities.

The Compagnie Nationale du Rhône, in order to make a reliable and accurate survey of the river from the Mediterranean to Lyons installed an M. S. X machine in one of their high speed launches. These survey boats are 20 metres long and are capable of a speed of 30 nautical miles per hour. The transmitter and receiver were fitted on either side of the centre line close to the keel, and on the run down the river at full speed, records were obtained without a break, giving a profile of the river bed accurate to within a few inches. It was a survey of their river which the engineer of the Compagnie du Rhône had never before seen, and each section was related to known distance marks on the bank by the fix marking switch.

The Port of Calcutta fitted a launch with echo sounder gear and made a record of the river Houghly in flood. The launch, steaming at 15 knots, approached the piers of the Harding Bridge and, nosing its way against a 14 knot current, recorded accurately the scour round the piers 50 feet deep, of which the bridge builders were aware but have never been able to measure.

Harbour Boards all over the world were by 1938 convinced of the accuracy and reliability of high speed echo sounding machines, and this had been established by the records obtained in their own waters by the Harbour Surveyors.

Cape Town, Demerara, Dublin, Freemantle, Greymouth N. Z., Melbourne, Mersey, London, Rio de Janeiro, Nantes, Bordeaux, Singapore, Beira and Basra, were some of the harbours being surveyed in 1938 by the M. S. 12 and M. S. 10 echo recorders.

It was by no means an easy task to arrange for the fitting of echo sounders in the various types of launches, and where the vessels were not easily fitted inboard, the solution was found in the outboard or streamline casing which began with a very heavy and clumsy "fish", but has now been finally established in a very light and convenient assembly which can be fitted by one man. In the war these outboard oscillators were of the greatest use, especially off the coasts of France before D-day.