PRELIMINARY EXPERIMENTS ON THE DETERMINATION OF THE ACOUSTIC SIGNATURE OF SHIPS

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ABSTRACT

A method has been developed at the Naval Physical Laboratory, Cochin for recording and analysing the acoustic signature of a ship. The equipment consists of a magneto-striction transducer, a panoramic spectrum analyser, a frequency analyser and other accessories carried on board INS Cauvery, kept anchored 15 miles due west of Cochin. The hydrophone is lowered to a depth of 40 feet and kept at a distance of 200 feet from this ship. The Ship, INS Ranjit whose acoustic signature is being studied passes as close to the hydrophone as possible. The spectrum of noise, as recorded on the "panoramic" analyser is photographed for various positions of the ship. These observations are repeated several times and for different speeds of the ship. This experiment is later repeated with the functions of the two ships reversed so that the acoustic output of Cauvery also is obtained in a similar manner.

Introduction

The study of the frequency spectrum and intensity of the noise produced by a ship and transmitted into the sea is very important from the point of view of the design of acoustic mines. The acoustic mines can be made sensitive to a narrow band of frequencies correponding to the most intense part of the spectrum of the ship's noise. Also knowing the intensity of the noise emitted by the ship, the sensitivity of the hydrophone can be made just sufficient to enable it to respond to the ship's noise and not to the background ambient noise in the sea. Thus by operating the acoustic device of the mine in a narrow band and also by limiting its sensitivity to the minimum possible value, operation of the mine due to the ambient noise in the sea can be eliminated.

The acoustic signature of ships varies from one class of ship to another and even in the same class there will be certain variations from one ship to another. Also with the same ship, the acoustic signature will vary with speed and also for a given speed it might vary depending upon the alterations in the vibrations of machinery etc. It is therefore essential that the signatures of various ships of each class have to be studied and the average spectrum worked out in each case. In addition to this, the data for all the different classes should also be studied, in order to arrive at the optimum data for the design of acoustic mine to suit all classes of ships.

During the last war, the German and Japanese Navies made considerable use of listening hydrophones. If similar technique is to be used in future, it would be useful to have an idea of the acoustic signature of the various classes of ships based on tonnage of the ship, the nature and h.p. of the engine. Such data will be useful in categorising the nature of the ship from the observed acoustic signature.

A third possible use of the study of acoustic signature of ships is that if the signatures of various ships of the same class be studied accurately and if one of them exhibits an abnormal spectrum different from the rest, the cause of this could be investigated and any defects in the ship, which have not been noticed otherwise, can be detected. Also the signature of the same ship taken from time to time may reveal any defects that might be developing.

Equipment Needed for the Experiment

There are different types of instruments which can analyse any acoustic noise into the various bands and give the value of noise in each band. Most of them operate on the principle that the applied electrical input from the microphone is mixed with the output of a local oscillator and converted into a suitable high frequency such as 100 kc/s and applied to a crystal filter of very narrow pass band. As the local oscillator frequency is varied, different parts of the input spectrum come within the pass band of the filter and the output of the filter is measured by means of a vacuum tube voltmeter. This method though suitable for a static observation (where the wave form to be analysed is constant in amplitude and structure w.r.t. time) is not very suitable for the analysis of ship's noise. A more suitable instrument is the Panoramic Sonic Analyser. This is a scanning heterodyne instrument which automatically provides graphic indications of frequency versus amplitude components in complex waves. This feature eliminates the tuning of individual components by hand and thus enables observations on a source, the amplitude of whose noise output would change with time, as in the case of a moving ship. A block diagram of this instrument is given in figure 1. The diagram is self explanatory. The signal to be analysed is amplified and applied to a balanced mixer. The local oscillator which feeds the balanced mixer is frequency modulated by a linear sawtooth voltage of 1 second period. The reactance modulator is adjusted so that the local oscillator scans at a logarithmic rate, those frequency components appearing at the balanced mixer. The oscillator output and spurious cross modulation products are balanced out at the output of the balanced mixer leaving only the sum and difference terms of the input and oscillator frequencies. The sum frequency component is selected by a sharply tuned filter and amplified. This is proportional to the amplitude of the component in the input. It is rectified and applied to the vertical deflection plate of a c.r.t. to whose horizontal plates the linear sawtooth voltage is applied. The scanning rate is one per second and the c.r.t. has large after glow characteristics. The range covered by the instrument is 40 c/s to 20,000 c/s. The frequency resolution (*i.e.* separation of two signals of equal amplitude the deflections of which intersect 0·5 down from their peak amplitude) is 50 c/s at 100 c/s, 140 c/s at 1000 c/s, and 550 c/s at 10,000 c/s, 1000 c/s at 20,000 c/s.

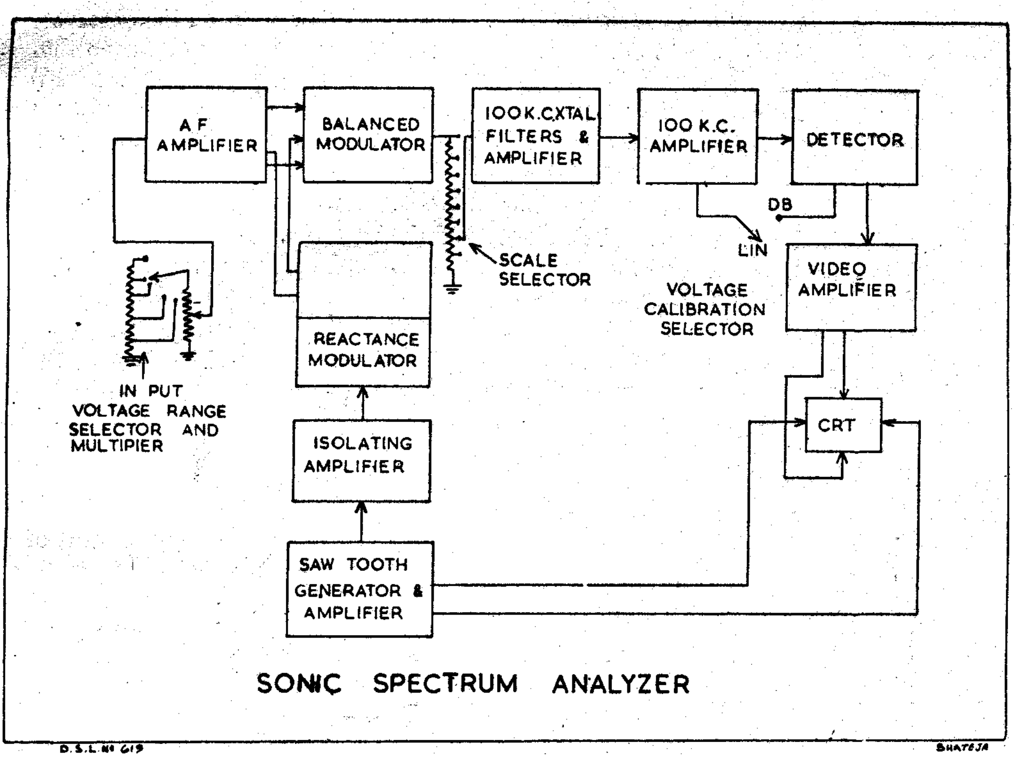

FIG. 1.

A proper choice of the hydrophone to be used is very important in this experiment. A scroll type of magnetostriction hydrophone was found suitable as it had flat frequency—response characteristics in the audio band and also as it had a low impedance, of the order of 10 ohms. The latter feature was found very beneficial, as, with a source of low impedance, the electrical pick up by the long cable used for connection to the instruments was a minimum. The hydrophone was found to be practically non-directional which is very essential.

Choice of Site

In order to minimise the effect of reflection from the bottom of the sea, it is essential that the site chosen should be as deep as possible and also the reverberation characteristics and the background ambient noise of the site should be studied as a preliminary step to ensure that these factors do not affect the observed noise of a ship. As there was not enough time available for these, a site at a depth of 100 ft. was chosen. The sea bottom in this locality was of soft mud having a good sound absorption characteristic.

Experimental Details

(*a*) For best results it is essential that with each ship and for each set up, several observations are taken to eliminate errors and to see if consistent results are obtained.

(*b*) The moving ship should pass at exactly the same distance from the hydrophone during all the observations.

(c) The hydrophone should be as far away as possible from the observational ship to eliminate the pick up from this and as close to the experimental ship as possible to obtain a large pick up voltage. In order to satisfy these requirements, it is essential some method should be found whereby the ship can be made to move accurately along a set course at all speeds.

For the present experiment the following arrangement was used—

The hydrophone was tied to a buoy and the latter was anchored to the sea bottom as shown in figure 2. The output of the hydrophone was taken to the recording apparatus by means of a shielded cable which was fastened to the steel rope connecting the buoy to the ship A. The distance between the ship A and hydrophone was kept about 100 yards to reduce the pick up of the

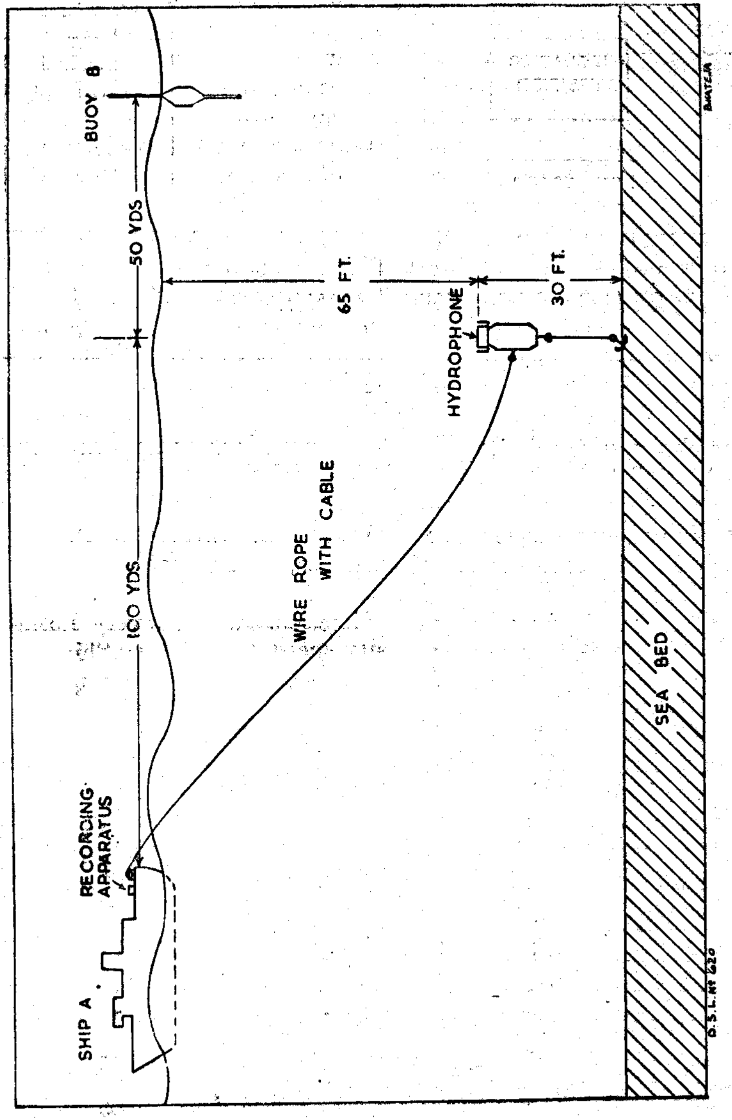

FIG. 2

noise of ship A. A marker buoy B was placed 50 yards away on the line joining the ship A to the hydrophone. The ship (C) whose acoustic signature was being studied was asked to proceed close to the hydrophone along a course at right angles to the direction joining the ship A to the buoy B. Several runs were taken for each speed of the ship C. During all these runs, care was taken to see that the ship C moved along practically the same course. This precaution was essential to ensure the distance between the ship C and hydrophone was the same for all the runs.

Results

The spectrum observed on the Sonic Analyser was photographed using an oscilloscope camera. The spectrum for different speeds of the ship may be seen from the attached photographs (figures 3, 4, 5, 6, 7). The several photographs in each figure show the spectrum obtained for different positions of the ship as it moved past the hydrophone. In figure 3, the photograph (*a*) was obtained with the ship about 300 yards away from the hydrophone and (*g*) was obtained with the ship just above the hydrophone, the photographs (3)(*b*) to 3(*e*) were obtained or the intermediate positions of the ship. Photographs 8(*a*) and (*b*) were obtained when 600 c/s and 1000 c/s square waves were applied respectively to the analyser. These were used for checking the frequency calibration of the Sonic Analyser.

Enlarged photographs of the spectrum obtained when the ship was just above the hydrophone are shown in figure 9. Photographs 9(*a*), 9(*b*), 9(*c*) will give an idea of how the intensity and spectrum of the ship's noise vary as the speed is increased. The average intensity of the noise in the various audio frequency bands are given in table 1, and table 2 gives the predominant frequencies. It is seen that the noise energy at low frequencies does not change appreciably with speed. But in the band above 1 kc/s, noise energy increases considerably with speed. Also at the economic speed, most of the noise energy is concentrated in the band 1·5 to 7 kc/s.

TABLE I

Table showing average Intensities of Noise in the various Bands.
(Intensities are in arbitrary units)

Frequency band Kcs/Sec.	Average Intensity Economic speed	Average Intensity speed 7 knots	Average Intensity Ship gliding
·01— ·1	·1	·15	·1
·1— ·2	·1	·15	·1
·2— ·3	·075	·15	·1
·3— ·4	·15	·2	·1
·4— ·6	·175	·2	·1
·6— ·8	·175	·1	·05
·8— 1·0	·175	·15	·05
1·0— 2·0	·5	·3	·1
2·0— 3·0	·55	·3	·2
3·0— 4·0	·35	·15	·1
4·0— 5·0	·55	·1	·1
5·0— 7·0	·4	·05	·05
7·0— 9·0	·15	·05	·05
9·0—11·0	·1	·05	·05

TABLE 2

Predominant Frequencies

	Frequency kc/sec	Intensity
Ship Gliding	2·8	[illegible]
	4·8	·2
Speed 7 knots	0·8	·25
	1·3	·55
	2·1	·45
Economic speed 11·5 knots	1·1	·55
	1·5	1
	2·3	·9
	4·5	·6
	6·5	·4

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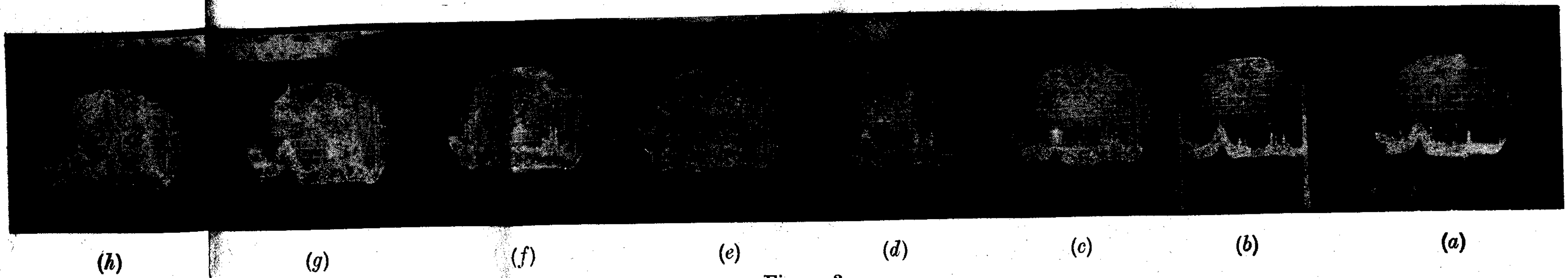


Figure 3

Acoustic Signature of ships proceeding at 11·5 knots (Linear amplitude scale)

Photograph (*a*) Ship 300 yards from the hydrophone.

Photograph (*g*) Ship just above the hydrophone.

Photographs (*b*) to (*f*) Intermediate positions of the ship.

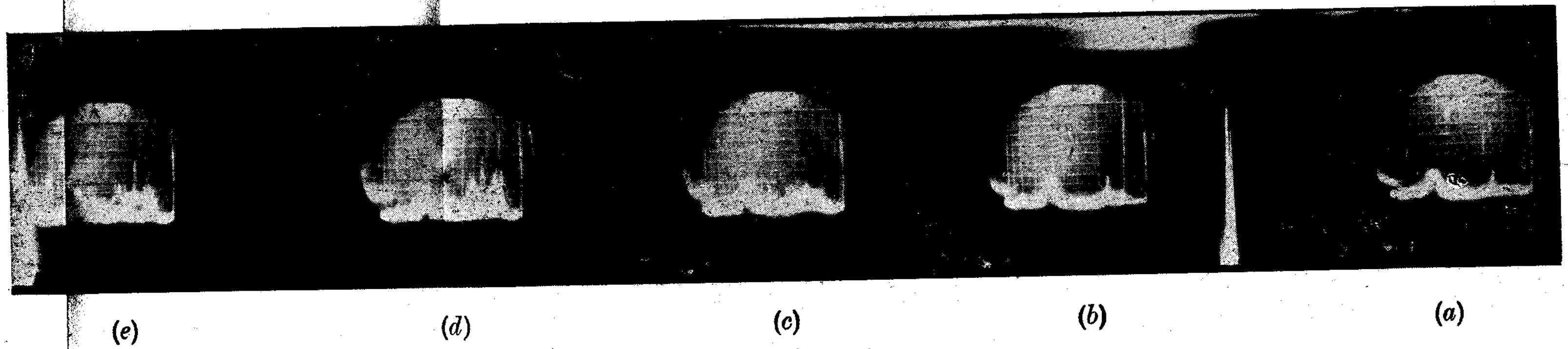


Figure 4

Acoustic Signature of ship proceeding at 11·5 knots (Decibel amplitude scale)

Photograph (*a*) Ship 300 yards from hydrophone.

Photograph (*e*) Ship just above hydrophone.

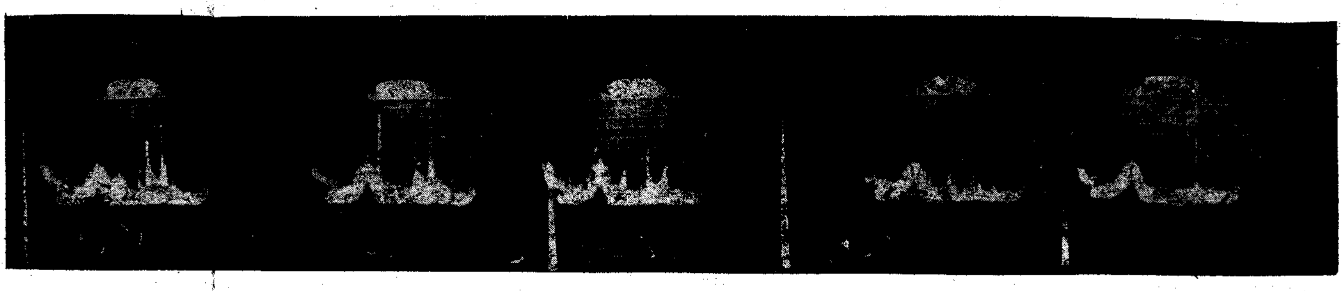


FIG. 5—*Ship proceeding at 7 knots (Linear Amplitude scale)*

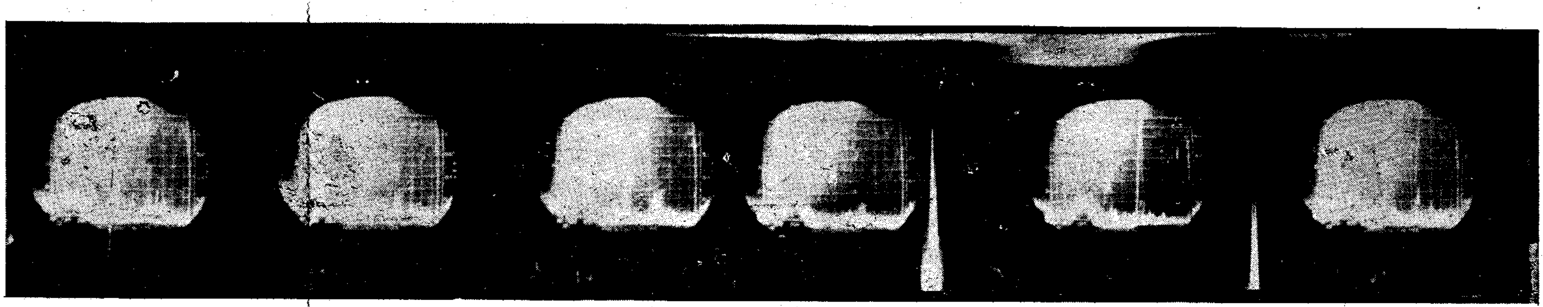


FIG. 6—*Ship Proceeding at 7 knots (Decibel Amplitude Scale)*

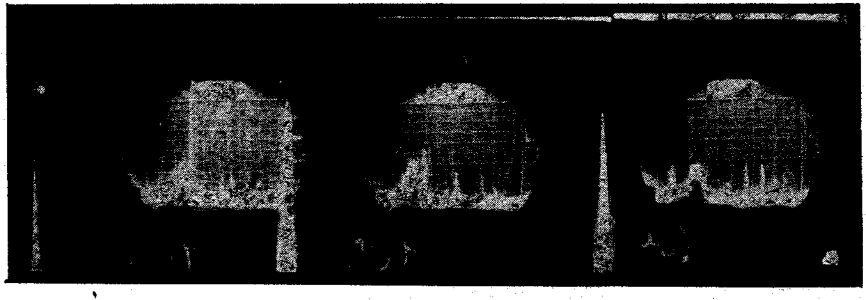
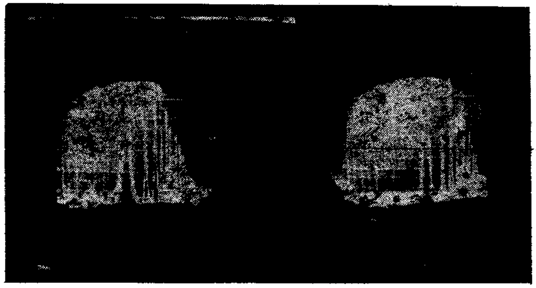


FIG. 7—*Ship gliding past the hydrophone (Linear Amplitude scale)*



(*a*) (*b*)

FIG. 8—*Calibration by Square waves of—(a) 600 c/s. (b) 1000 c/s.*

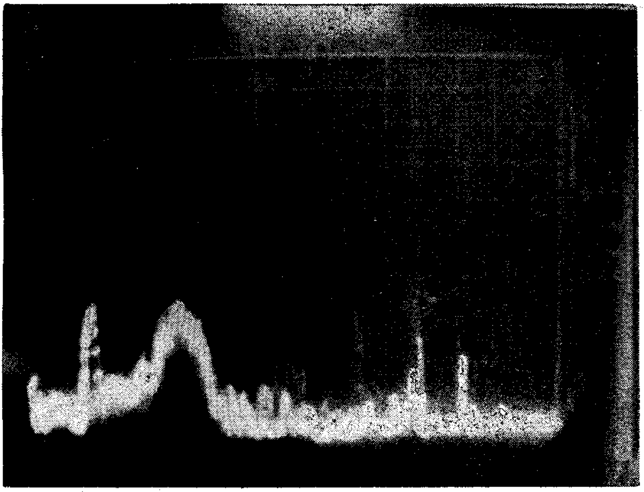


FIG. 9(*a*)—*Ship Gliding*

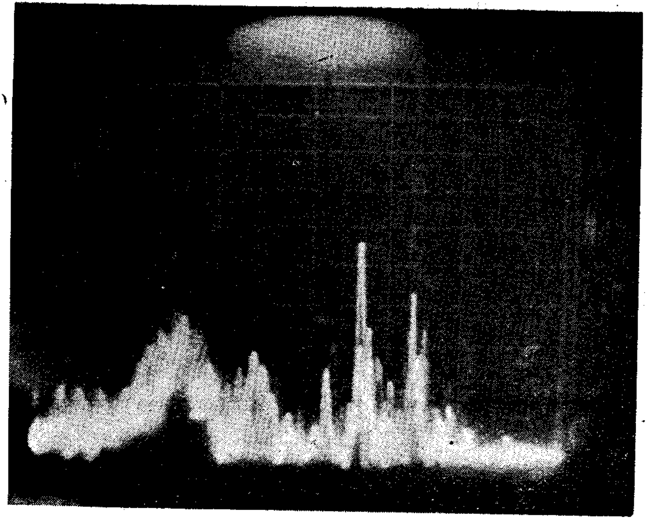


FIG. 9(*b*)—*Ship proceeding at 7 knots*

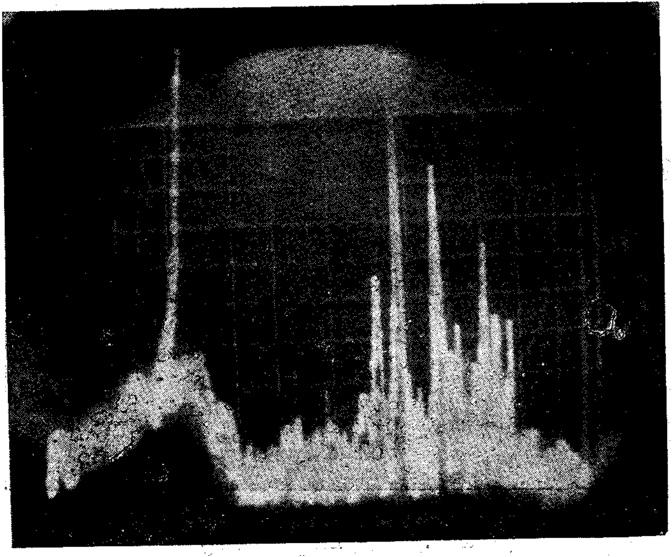


FIG. 9(*c*)—*Ship proceeding at 11·5 knots*