A Note on Wideband Sonar Trials

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1.0 Introduction

1.1 History

This project was initiated by Professor Tucker in about 1957 with a study of arrays with a constant beamwidth over a wide range of frequency, for example up to a ratio of up to ten to one. This work led to an array in the shape of a hyperbolic paraboloid (1), which can be formed from a series of straight lines; this is the basis of the twisted array now used on reception. The transmitting array presented a greater problem, but fundamental research into non-linear acoustics in this department has resulted in a solution which meets the requirements of constant beamwidth, although it is relatively inefficient in power. A sonar using these arrays has been developed, which works over a 10:1 range of frequency; early trials were carried out in 1967 (2) and 1968 (3), and an improved system has recently been tested at sea. This note describes the results of measurements in the laboratory and at sea.

1.2 Specification of the present system

It was envisaged that a Wide Band Sonar would have applications in fisheries, so a range of frequencies from 6 to 60 kHz was chosen. This is compatible with commercial fish-finding sonars working on 30 or 50 kHz, and it was thought after the trials in 1967 that frequencies well below these would be more useful than those much above, The system can be used in two modes, firstly as a simple sonar, but with the special facility that the carrier frequency can be changed quickly to any frequency in the range 6 to 60 kHz, and secondly in the "chirp" or swept mode, in which a long pulse is transmitted, during which the carrier frequency is swept linearly over the full range, and the signals from a selected range are analysed to give an immediate record of amplitude against frequency. However the response of the receiving array is too irregular at present for satisfactory results in the "chirp" mode, which was not used in the latest trials. The beamwidths of the transmitting and receiving arrays were designed to be about 15° as a compromise between ease of handling and discrimination against unwanted targets and noise.

2.0 The equipment

2.1 The transmitting system

This makes use of the non-linear interaction in the water of two acoustic signals at high frequencies to produce the wanted low difference frequency. The primary frequencies are about 500 kHz, and hence the maximum relative bandwidth is only about 12% for the 10:1 sweep at the difference frequency. The transmitting array consists of 91 individual elements; each is a piezo-electric disc 25 mm in diameter and resonant in thickness at 500 kHz, which is bonded to an aluminium disc nominally half a wavelength thick, but the thickness is adjusted to set the exact resonant frequency. The discs are set at 33 mm centres in a hexagonal pattern over a surface which is part of a sphere with a radius of curvature of 1.25 m., the diameter of the array being about 35 cm. The large size is necessary to handle without cavitation the high power required for a sufficient source level at the difference frequency, and the curvature is to broaden the beamwidth to 15°.

The power amplifier can give a maximum output of 2½ kW, i.e. about 600 W at each primary frequency, these having been mixed electrically and fed to every element in the array. The alternative scheme of feeding the two frequencies to separate groups of elements and relying on acoustic mixing was found to be much less effective. The pressure levels at the difference frequency build up with increasing distance from the surface of the array in the near-field interaction zone before showing the usual inverse square law spreading; because it was not possible to make measurements directly in the far field, measurements were made at various ranges in the near field and the asymptotic square-law spreading levels estimated which could be extrapolated back to 1 m. from the centre of the curvature of the array surface to give the equivalent source level. The results are shown in fig. 2.1, together with those from measurements in the far field via a reflection with uncertain loss from the concrete wall of the tank. The half-power beamwidths shown in fig. 2.2 were estimated from directional patterns measured at 6.3 m. from the array; the variation with frequency is small and the average value is close to the design figure of 15°.

2.2 The receiving array

This consists of 169 short piezo-electric tubes, resonant at 80 kHz, mounted in 13 rows, each of 13 elements, each row being skewed by 1½° relative to its neighbours, so that opposite edges of the 33 cm. square array are twisted by 18° relative to each other. The beamwidths are shown in fig.2.4, both calculated and measured; at low frequencies, the beamwidth is set by the overall size, the twist having little effect, and at high frequencies it is set by the total twist. However in the intermediate region there is a fall to a minimum of about two thirds of the twist angle, and this seems to be characteristic of this type of array. The receiving sensitivity was calibrated for signals arriving on the axis, as shown in fig.2.3, which also shows the theoretical variation due to the twist. The difference between the curves gives the variation in sensitivity of an individual element; the sharp dip at 17 kHz and the broad peak around 23 kHz are probably due to a resonance in part of the mounting of each element, and the broad peak around 53 kHz may be due to an overtone of this.

3.0 Trials at sea

3.1 Narrative

The Fisheries Laboratory of the M.A.F.F. at Lowestoft generously made time and space available on the R.V.Cirolana from the 10th to the 16th November 1975 for some preliminary trials under more realistic conditions than those available in and around Birmingham. The tests were aimed at proving the basic operation of the system by measuring the target strengths of various objects under controlled conditions. Unfortunately it was not possible in the limited time to measure the source level, and the results of the tests in the tank at Birmingham had to be used. The trials were carried out in the western English Channel, while the ship was engaged on a survey of pelagic fish. The transducers were simply hung over the side of the ship, which had to be stopped for the purpose, as no arrangements for towing them were available. The weather was generally unfavourable, and gales blew up which were rough enough even to curtail the survey work, so work with the Wide Band Sonar was possible on two days only.

3.2 Measurements on targets

The pulsed mode was used, with 2 msec pulses and a bandwidth of 1 kHz in the receiver. Considerable fluctuations were noted in the amplitude of the received signals, and the maxima over periods of about a quarter to half a minute were noted. These fluctuations are due to relative motion between the target and the arrays, and also to the changing aspect of the target; these movements are unavoidable with the simple arrangements used for suspension from a freely floating ship, but this situation does give freedom from unwanted echoes.

The first measurements were of the reflections from the sea bed, which was probably sand, at a depth of about 38 m. The reflection loss at vertical incidence is shown in fig.3.1; a single measurement with the

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M.A.F.F. survey equipment at 30 kHz gave a loss of 20 dB compared with the Wide Band figure of 16½ dB. There is little variation with frequency, in accordance with published figures (5), and the average loss is of the expected order, but there is a general trend towards a higher loss at higher frequencies.

Measurements were done on a hollow plastic net float 20 cm. in diameter and on a dead Pollack 51 cm. long; the target strengths are shown in figure.3.2, together with that for the fish calculated from the "all species" expression recommended by Goddard and Welsby (4):

$$\text{Target strength} = 25.8 \log L - 5.8 \log \lambda - 35 \text{ dB.},$$

where L is the length and λ the wavelength, both in metres. A single test on a dead mackerel 34 cm. long gave a target strength at 22 kHz of 45½ dB.; the expected value from the "all species" expression reduced by 3 dB to allow for the absence of a swim bladder is -43½ dB. Again there is a general trend towards a lower target strength at higher frequencies, particularly noticeable if practice and theory for the Pollack are compared, and this suggests a systematic error in the basis calibration of the system, increasing towards the high frequencies. The average calibration is probably correct; the average target strength of the net float is -27 dB compared with the theoretical value of ±26 dB (excluding the possibility of resonance effects), and that for the fish agrees with theory well enough at low frequencies. The errors are most probably caused by changes in the source level of the transmitter.

4.0 Acknowledgements

Grateful thanks are due to the M.A.F.F. Fisheries Laboratory at Lowestoft for their support in providing facilities on board the R.V. Cirolana and to the N.E.R.C. who financed the building of the power amplifier.

5.0 References

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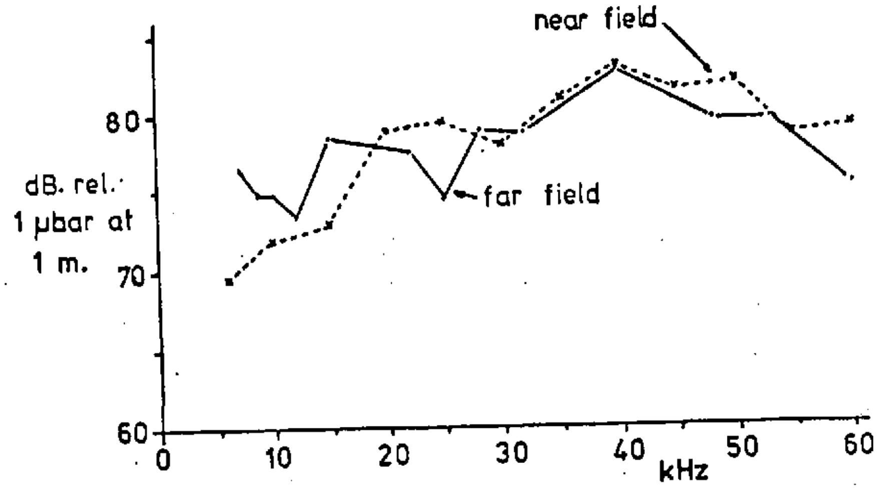

Fig. 2·1 Source level

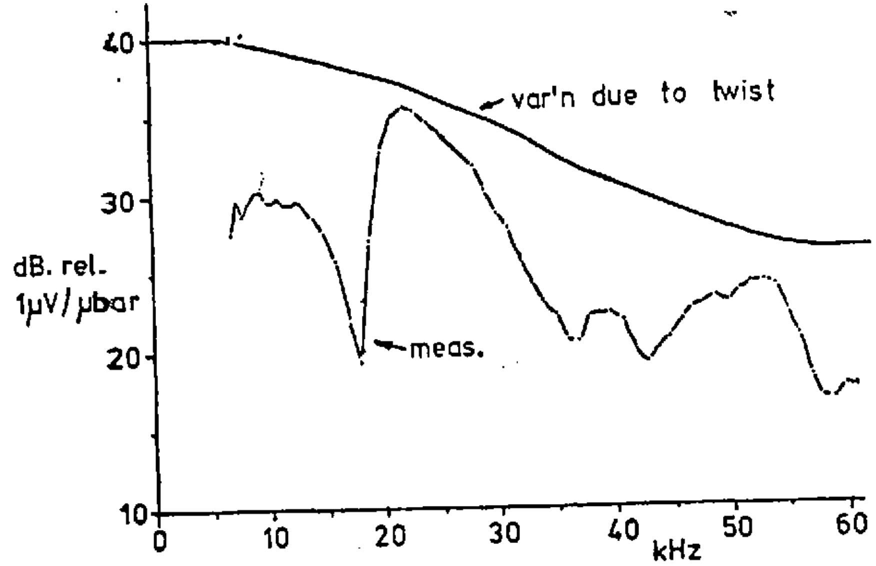

Fig. 2·3 Sensitivity of twisted array

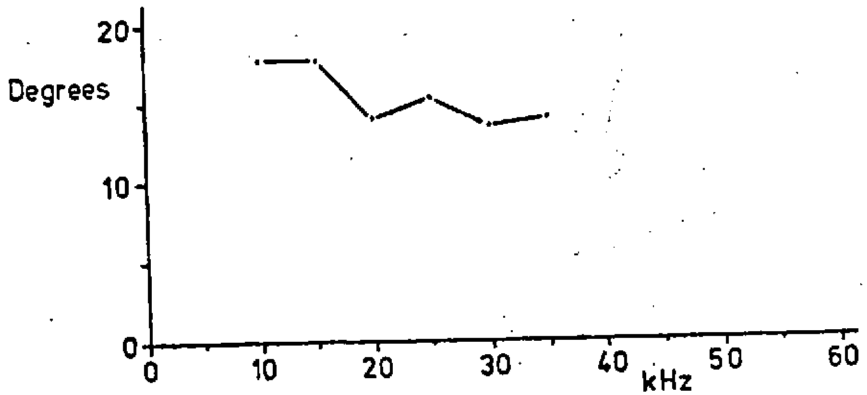

Fig. 2·2 Beamwidth of non-linear source

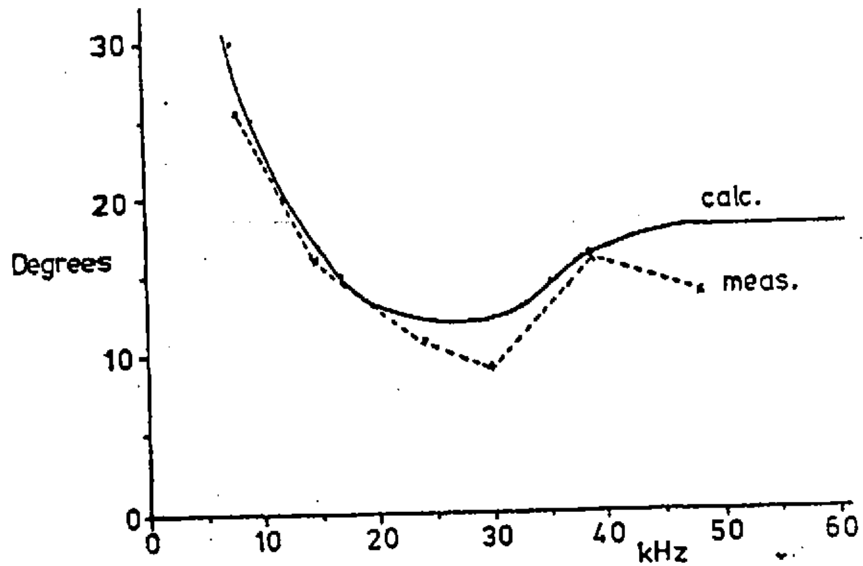

Fig. 2·4 Beamwidth of twisted array

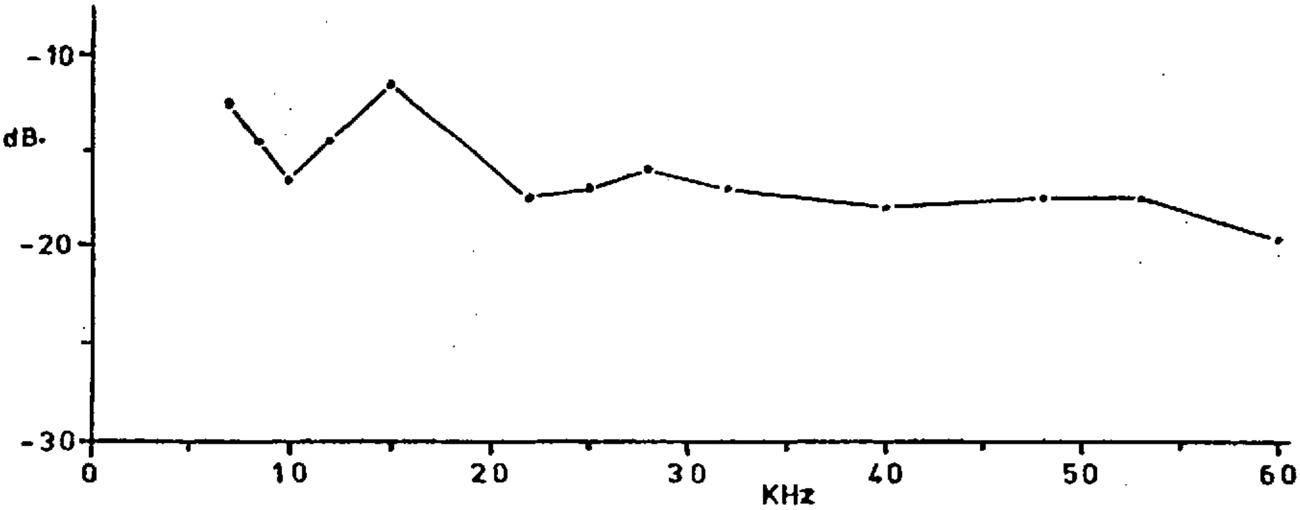

Fig. 3.1 Reflection coefficient of sea bed

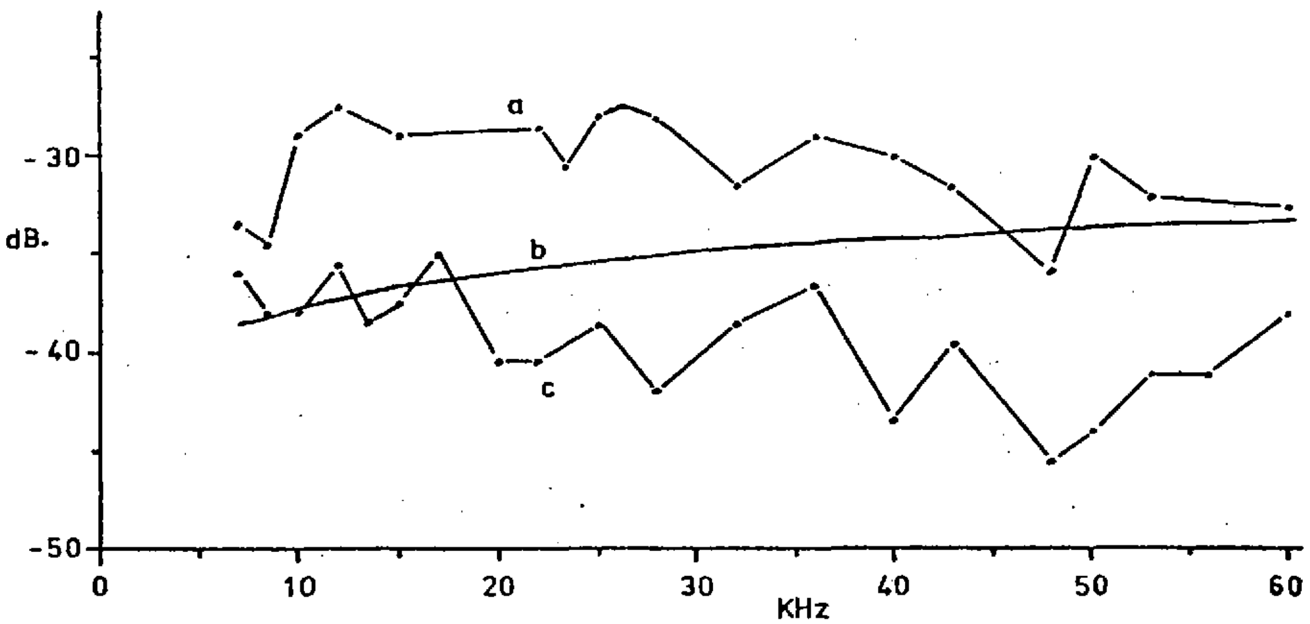

Fig. 3.2 Target strengths

a: 20 cm. hollow plastic netfloat
b: 51 " fish, calculated ('all species' average)
c: " " Pollack, measured