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Underwater Acoustic Test Facilities
and Measurements.

AN ACOUSTIC TANK FOR HEARING STUDIES ON FISH

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Introduction

The principal difficulty which has been experienced in investigating the hearing abilities of fish has been the lack of a suitable laboratory test facility for presenting fish with sounds. Aquarium tanks are not adequate for this purpose, since they are completely surrounded by pressure release boundaries, which reflect and distort sounds. So far, the most suitable solution to the problem of providing an appropriate acoustic environment has been to perform the experiments on an acoustic range in the sea, with the fish, hydrophones, and sound projectors mounted in midwater, well away from reflecting boundaries. This approach presents many technical and biological difficulties, however, and is not entirely satisfactory. Difficulties are experienced in presenting low frequency sounds under these conditions, since the experiments must be done at considerable depths to ensure immunity from the effects of the sea surface.

This paper describes an acoustic tank which has been constructed to provide a suitable acoustic field in the laboratory. The tank is intended for an investigation of the ability of fish to detect low frequency sounds, and in particular to test the suggestion that at low frequencies fish are sensitive to particle velocity, rather than sound pressure.

The acoustic tank

Parvulescu (1964) first suggested that a suitable acoustic tank for hearing studies could be constructed from a sealed water-filled tube, with a sound projector at each end. He pointed out that by introducing a phase shift between the 2 opposing sound projectors, it was possible to vary the ratio of sound pressure to particle velocity at the centre of the tube.

Our version of Parvulescu's tank is a steel tube 80 cm in length and 25 cm in internal diameter, with 5 cm thick walls. It is capped by heavy conical end pieces, each incorporating a rubber diaphragm 15 cm in diameter. Each diaphragm is driven by a vibrator (Derritron, type VPM 2). A row of 5 calibrated hydrophones are spaced along the centre of the tube, 15 cm apart, with electrical connections passing to the exterior via waterproofed connectors. The tank is filled by total immersion in a large container of de-gassed sea water (to avoid bubble formation). A slow flow of water (sufficient to keep a fish alive) is maintained by way of entry and exit valves at each end, and is fed by a constant head device.

The vibrators are driven from a single oscillator, feeding two power amplifiers via attenuators and a phase shift network. The outputs of the 5 pressure sensitive hydrophones are fed to pre-amplifiers incorporating appropriate filter networks, and are displayed on an oscilloscope and vacuum tube voltmeter.

Principles of operation

Though the distance between the 2 opposing diaphragms is 110 cm, the effective length of the tube consists of the distance between the 2 most extreme hydrophones, i.e. the 60 cm in the middle of the tubular portion. In considering only this region we eliminate end effects at the diaphragms, and in the region of the access ports in the conical end pieces.

The equations presented below have been derived using one-dimensional acoustic wave theory. This should be adequate for describing sound pressure and particle velocity relationships near the tank centre-line (which forms an axis of symmetry) particularly since the tank has been designed to minimise radial movements in the water. The performance of the tank at higher frequencies can be expected to depart from the ideal, firstly, because the wave-length of the sound approaches the length of the tank, and, secondly, because there will be a complex interaction between sound waves generated inside the steel casing, and those generated in the water mass. We have so far limited our observations to frequencies below 150 Hz.

Let the sound pressures at the 2 extreme hydrophones be represented respectively by:-

$$P_1 = P(1 + \Sigma) \exp(i\varphi) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

and $$P_2 = P(1 - \Sigma) \exp(-i\varphi) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Where Σ is a measure of the imbalance between the two pressures and 2φ is the phase difference between them (radians).

If p and v are the sound pressure and particle velocity at the centre of the tube, then :-

$$p = P(\cos\varphi + i\Sigma\sin\varphi)/\cos K \quad \ldots\ldots\ldots\ldots\ldots \quad (3)$$

$$v = -P(\sin\varphi + i\Sigma\cos\varphi)/(Z\sin K) \quad \ldots\ldots\ldots \quad (4)$$

Where Z is the acoustic impedance of the contained water, and K is the number of wavelengths between each of the extreme hydrophone positions and the tank centre.

Since the pressure waveforms from the 2 extreme hydrophones can be examined to determine values of P, Σ , and φ, then the particle velocity at the tank centre can be calculated using (4).

The tank is normally used in 2 extreme modes. In the first, the phase difference between the two diaphragms (φ) is zero, and the amplitudes are adjusted to provide a pressure maximum at the centre hydrophone. In this case the fish (which is adjacent to the centre hydrophone) experiences a stimulus consisting primarily of sound pressure. In the second mode, the phase difference between the 2 diaphragms (φ) is adjusted to achieve a situation where the particle velocity is a maximum, and sound pressure a minimum. This is normally done by carefully adjusting the phase and amplitudes of the diaphragms to minimise p. ($\varphi \simeq \pi/2$).

In practice, by varying φ, it is possible to vary the quantity $|p/Zv|$ within wide limits.

The use of the tank in hearing studies

Two main techniques are being used to study the hearing of fish inside the tank. In one, the fish is trained to respond to the onset of a stimulus, and a minimum detectable stimulus level determined. In the other, the very small electrical potentials generated within the ear are detected, and their amplitudes compared under different stimulus conditions. It is clear from preliminary studies that at low frequencies particle velocity and not sound pressure is the relevant stimulus parameter.

Reference

Parvulescu, A., (1964). Problems of Propagation and Processing, in Marine Bioacoustics, Vol. 1, edited by W.N. Tavolga. Pergamon Press, New York 1.