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ON FORMATION OF CARDIOID-LIKE DIRECTIVITY PATTERN USING AN ASYMMETRICAL UNDERWATER PRESSURE GRADIENT SENSOR

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Consideration is given to the possibilities of forming the unidirectional cardioid-like directivity pattern (DP) by underwater "asymmetrical" pressure gradient sensor in the form of a laminated piezoceramic transducer, which is set on the end of a hollow cylindrical acoustically rigid baffle. The purpose is to minimize the amplitude of DP back lobe. The prototype has been prepared. The experimentally measured DP has 23% of frontal maximum as the back lobe amplitude. We obtained a theoretical expression for the relative quantity of DP back lobe depending upon the wave dimensions and the diameter of cylindrical baffle. The back lobe amplitude predicted theoretically is consistent with the one measured by experiment with the use of prototype. A possibility to decrease the back lobe amplitude up to 13-14%, when the size of baffle and piezoceramic transducer is technically feasible, is demonstrated in theory.

The problem of unidirectional DP formation for point underwater receivers is of high priority in many practical applications of ocean acoustics [1]. One of the ways for solving this problem to provide cardioid DP is combining the signals of sound pressure and pressure gradient sensors together [2]. There is, however, a more simple solution in constructional plan, related to the use of the «asymmetrical» pressure gradient sensor [3] in the form of the plate transducer placed on the end of a hollow cylindrical baffle. In this case, according to [3], the DP of supercardioide-hypercardioide class, having quite a considerable back lobe, is formed and not the ideal cardioid.

The paper sought to estimate the possibility for reducing the DP back lobe amplitude of this type underwater receivers.

Let us consider the acoustic receiver of length L, containing a bimorph bender of R as radius and an acoustically rigid hollow cylindrical baffle. With the supposition of L smallness as against the wave length in medium λ, the receiver response to the signal in the form of a plane sound wave from the direction of the peak of DP frontal lobe [3] takes the form:

$$U(0^o) = -2i\,\nu_p \sin[k(L+R/2-h_1-h_2/2)]\exp[ik(L+R/2-h_1-h_2/2)], \quad (1)$$

where h_1 – the depth of setting the piezoceramic transducer in cylindrical baffle, h_2 – the thickness of the piezoceramic transducer, and ν_p – the sound pressure sensitivity of the bimorph piezoceramic transducer (screened in the rear by air gap). The response of the receiver to a plane sound wave from the direction of the DP back lobe peak is evaluated [3] as

$$U(180^o) = 2i\,\nu_p \sin[k(R/2+h_1+h_2/2)]\exp[ik(R/2+h_1+h_2/2)]. \quad (2)$$

Thus, the relative amplitude of DP back lobe may be written

$$N = U(180^o)/U(0^o) = -\sin[k(R/2+h_1+h_2/2)]/\sin[k(L+R/2-h_1-h_2/2)]. \quad (3)$$

In the event that $R/\lambda<<1$, $h_1/\lambda<<1$, $h_2/\lambda<<1$, the expression (3) is simplified:

$$N \approx -[\pi(R+2h_1+h_2)/\lambda]/\sin[\pi(2L+R-2h_1-h_2)/\lambda]. \quad (4)$$

On the other hand, in so far as from [3] it follows that the discussed receiver realizes DP of the form

$$R(\theta)= (1 + C\cos\theta)/(1 +C), \quad (5)$$

the back lobe relative amplitude may be written as $N=(1 - C)/(1 + C)$. (6)

Combining expressions (6) and (4) we have:

$$C=\{1+[\pi(R+2h_1+h_2)/\lambda]/\sin[\pi(2L+R-2h_1-h_2)/\lambda)]\}/\{1-[\pi(R+2h_1+h_2)/\lambda]/\sin[\pi(2L+R-2h_1-h_2)/\lambda)]\}. \quad (7)$$

The receiver prototype, tested for the wave dimensions:
$L/\lambda = 0.12$, $R/\lambda = 0.043$; $h_1/\lambda = h_2/\lambda = 0.004$, was made. The directivity was determined in the hydroacoustic tank. The random mean-square error of measuring the DP amplitude readings was 10%.

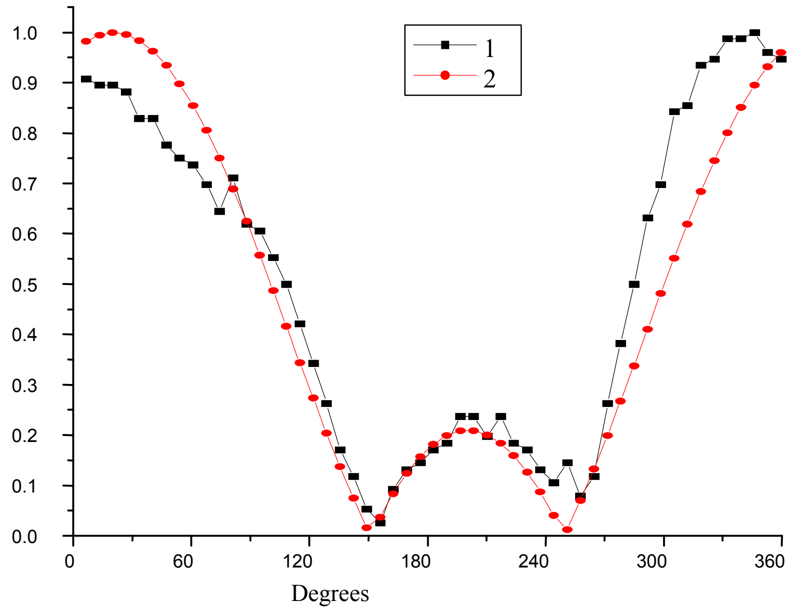

Figure 1. The directivity pattern of the prototype: 1-experiment, 2- theory.

Illustrated in Figure 1 are the DPs obtained by experiment - 1 and those computed - 2 from the

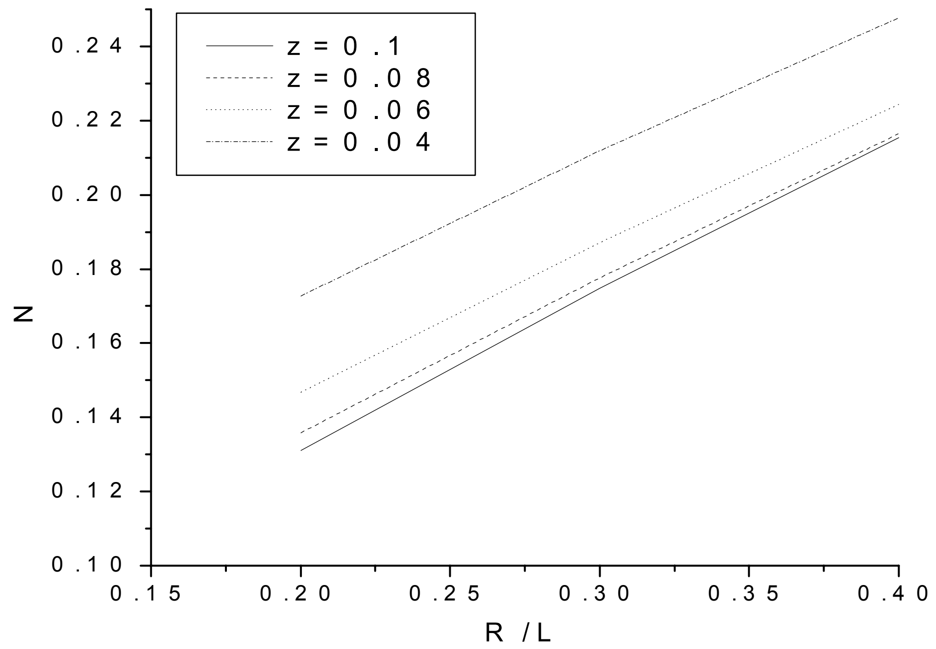

Figure 2. Diagram N(R/L): z = L/λ (the notations are in the text).

formula (5) for the coefficient C calculated by expression (7). The back lobe quantity of the experimental DP constitutes 23%, which is quite acceptable for practical purposes. The experimental and theoretical DPs are similar, particularly in the field of DP back lobes, both in amplitude and angular opening. The major lobe of the experimental DP is slightly wider than theoretical one, which appears to be involved the finiteness of value L/λ. Since the quantity L/λ defines the frontal responsivity of the receiver it is due to be maximum possible. Judging by the obtained experimental results, the value L/λ=0.12 is near the limit wherein the major lobe of DP is not yet perturbed very significantly. The frontal responsivity of the receiver therewith comes to $0.75\nu_p$. With decreasing the wave dimension of receiver the frontal sensitivity, as it is typical of gradient sensors, falls off having a slope on the order of 6dB/octave. Alternatively, the smaller the ratio R/L, the lower the amplitude of back lobe N. As a consequence of the proximity of our theoretical calculations to the experimental data (рис.1), the limits of reducing the back lobe amplitude in accordance with the decrease of value R (if L being fixed) may be estimated analytically by application of formula (7). Figure 2 displays an assumption diagram of dependence N(R/L) at given parameter L/λ. It follows from the figure that in the range of technically implemented values L/λ и R/L the back lobe amplitude may well be decreased to 13% - 14% on retention of a reasonably high frontal responsiveness (of the $0.5\nu_p$ order).

Notice that compared to solutions [1,2], the unlimited depths and the independence of DP mode from dip depth are evident advantages of the considered receiver, deriving from the fact that bimorph piezoceramic transducer is balanced to the action of hydrostatic pressure.

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