CALIBRATION OF ACOUSTIC EMITTERS IN A BOUNDED SPACE

N. N. Nefedov

Vestnik Moskovskogo Universiteta. Fizika,
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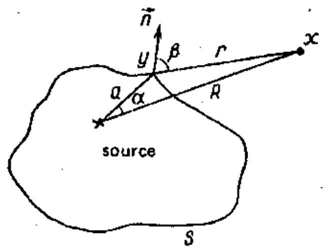
A method for calculating the directivity pattern of the far field of an emitter from the measurement of the pressure and its normal derivative in the near field of the emitter when the condition of free space is not satisfied, i.e., when the boundaries of a homogeneous acoustic domain affect the field produced by the emitter, is suggested.

The directivity pattern is one of the principal characteristics of acoustic sources. Lately a great deal of attention is paid to developing methods for calculating these diagrams from near-field measurements, which involves experimental difficulties of calibration in the far field and its low accuracy. These methods are based on Helmholtz's integral theorem (see papers by Baker [1], Schenk [2] and Rimskii-Korsakov with Tsukernikov [3]). We note that these methods were developed for free-field conditions. However, when measurements are performed at low frequencies, the provision of free-field conditions involves serious difficulties. This applies to hydroacoustic measurements, when it is convenient to perform work in closeby storage ponds or test flumes, i.e., in bounded bodies of water, as well as to measurements in air, in acoustically closed chambers, the metrological performance of which deteriorates steeply at low frequencies.

When calibrating emitters in bounded spaces allowance must be made for the effect of the boundaries on the operation of the emitter proper, as well as on the acoustic field produced in it. Allowances for the effect of the field reflected from the boundaries on the operation of the emitter is a rather complex problem on its own. However, for a wide class of emitters (emitters with large internal resistance, for example, magnetostriction units) it is possible to neglect the effect of boundaries on the emitter operation. We shall consider precisely such emitters. They were investigated previously by Brekhovskikh with his coworkers [5, 6]; here the effect of reflections from the boundaries on the field of the monopole was taken into account as for the case of deep sea and a layer with ideal boundaries. Brontvei et al. [4] determined the capacity of a monopole in a layer with a nonlinear lower boundary, the acoustic characteristics of which were measured.

The present paper suggests a method for calibrating emitters in a bounded space, based on analysis of the vector-phase structure of the near field of a source employing Helmholtz's integral theorem, which makes it possible to eliminate the effect of the boundaries, and to obtain calibration data as if it were performed in the free space.

If an emitter is calibrated in a bounded space, then the resultant field is complex - in addition to the direct signal, we have a signal reflected from the



boundaries of the homogeneous acoustic domain. The potential $\varphi(y)$ (actually the acoustic pressure) and its normal derivative $\frac{\partial\varphi}{\partial n}$ $(y \in S)$ at a sufficiently smooth surface S, within which the emitter is situated, and which separates it from the boundaries, can be determined experimentally. The reflected field can be represented on surface S as the field of imaginary sources lying outside of S.

We shall assume that the conditions are such that diffraction of the reflected field on the emitter can be neglected. This is so, for example, when it is required to determine the capacity of nondirected sources [4-6], the acoustic model of which - the monopole - is an extensively used model of acoustic sources at low frequencies, when the dimensions of the emitter are small as compared with the wavelength.

Under such conditions the field on surface S is a superposition of the direct field of the emitter and the field of imaginary sources, i.e.,

$$\varphi(y) = \varphi_d(y) + \varphi_{im}(y), \quad \frac{\partial\varphi(y)}{\partial n} = \frac{\partial\varphi_d(y)}{\partial n} + \frac{\partial\varphi_{im}(y)}{\partial n}$$

(subscript "d" pertains to the direct, and "im" to the imaginary sources).

We write the Helmholtz integral theorem, assuming that φ and $\frac{\partial\varphi}{\partial n}$ are specified on surface S in the case when the point under computation is external relative to the surface (Figure).

$$L(\varphi(y)) \equiv \frac{1}{4\pi}\oint_S \left\{\varphi(y)\frac{\partial}{\partial n}(\exp(ikr)/r) - \frac{\partial\varphi}{\partial n}\exp(ikr)/r\right\} ds = \qquad (1)$$

$$= L(\varphi_d(y)) + L(\varphi_{im}(y)) = L(\varphi_d(y)) = \varphi_d(x),$$

where $r = |x - y|$, whereas $\frac{\partial}{\partial n}$ is a derivative to a normal, external to S, and $L(\varphi_{im}(y)) = 0$, since point x and the imaginary sources lie in a region external to surface S.

If x is a point of the far field, then Eq. (1) yields

$$\varphi_d(x) = -\frac{e^{ikR}}{4\pi R}\oint_S \left(\varphi ik\cos\beta + \frac{\partial\varphi}{\partial n}\right)\exp(-ika\cos\alpha)\Big\} ds. \qquad (2)$$

This means, that if the capacity of the monopole is determined from measurements in a bounded space, then, since the potential of the monopole in the free space is

$$\varphi = \frac{Q}{4\pi R}e^{ikR}, \qquad (3)$$

and equating Eqs. (3) and (2), we obtain

$$Q = -\oint_S \left(\varphi ik\cos\beta + \frac{\partial\varphi}{\partial n}\right)\exp(-ika\cos\alpha)\, ds. \qquad (4)$$

If the source is not a monopole, then, evaluating the potential of the direct field from Eq. (2) for points x, belonging to the sphere, we obtain $Q=Q(\theta,\varphi)$, which is the directivity pattern.

This means that the values of the potential and of its normal derivative, measured on surface S, can be used, for example, by numerical integration by computer, for determining the emitter directivity pattern. Here, as follows from Eq. (1), the procedure of measurements and calculations will be precisely the same, as when using the method of direct measurement of the pressure gradient for calculating directivity patterns from measurements in the near field under free-field conditions.

We note that the measuring technique differs very little from that employed by Brontvei et al. [4]. It should also be emphasized that it is unnecessary to determine the acoustic characteristics of the reflecting objects, which significantly simplifies both the measuring procedure and the calculations.

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Acoustics Department