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ABOUT ONE VOLUME REVERBERATION MODEL OF ACOUSTIC IMPULSES OF PARAMETRIC SOURCES

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In work the model of a volume reverberation of a parametrical impulse source in which "nonlinear" component the interaction of primary waves in current sounding medium volume a is taken into account is offered. The analytical expression permitting to calculate an average level of reverberation created by Poisson model of scattering objects radiated by a parametric narrow-band sound impulses source is obtained.

The sound waves, scattered in the inverse direction, contain an information about properties of hydrophysical heterogeneities. This information also can be used for inverses problems solution, such, as restoring of sound's temperature or velocity structure along a way of propagation and others. Therefore, the specifying of reverberation models, in particular of broadband parametrical sources, is an actual problem.

The parametrical source creates a volume reverberation, which theoretically can be represented, at least, by two components: "linear" and "nonlinear" reverberations. Where linear reverberation is understood as scattered sound waves, which were created before dispersing impulse volume in the result of nonlinear interaction of initial (primary) waves. And the sound waves – products of nonlinear interaction of primary waves scattered in the inverse direction, are implied by a nonlinear reverberation.

The sound waves, being propagated in a "real" medium, are subjected to scattering. If scattering objects are small on a comparison with a wavelength and do not create explicitly expressed boundary surfaces or big gradients in distribution, the scattered acoustic field does not contain a coherent component [1]. At not enough high density of scattering objects, the secondary scattering is neglected [2]. At such model scattering objects it is possible to consider, that there is no correlation connection between scattered waves of a parametrical source. In this case the average value of quadrate of the common sound pressure module in a scattered in the inverse direction wave of difference frequency, can be found:

$$<|P_-|^2> = <|P_{-1}|^2> + <|P_{-2}|^2>, \qquad (1)$$

where P_{-1} – sound pressure of scattered by "sounding" medium volume wave of difference frequency, in a current time; P_{-2} – sound pressure in a difference frequency wave, created by interaction of scattered by the same "sounding" medium volume high-frequency pump waves. By_"sounding" volume here we shall consider the occupied by sound impulse medium volume. For a determination of $<|P_{-1}|^2>$ And $<|P_{-2}|^2>$ values, let's accept a obtained in the result of a solution of the KZK equation [3] model of a parametrical antenna with a circle primary waves_radiator with Gaussian amplitudes distribution. Herewith considered, that the sound waves, scattered in direct direction, do not bring the essential contribution in to sound pressure of waves scattered in the inverse direction.

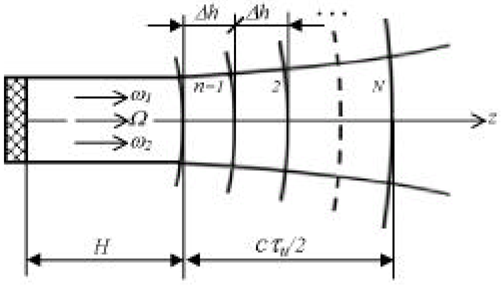

Fig.1. Geometry of parametric antenna's "active" impulse volume.

For a parametric antenna it is distinctive that primary waves interaction happens while they are propagating, therefore each elementary layer of sounding volume will disperse sound waves with amplitudes, varying because of nonlinear interaction. Considering, that these varying of amplitudes are insignificant on a path Δh, equal to one difference frequency wavelength l_- (i.e. $\Delta h = l_-$), let's present a current sounding medium layer $\Delta H = c\tau_è/2$ as a sum of partial dispersing layers Δh, as is it indicated in Fig.1. Each such layer disperses waves independent from each other and gives the contribution to common sound reverberation pressure. Let's name such model of sounded volume an “active” impulse volume of a parametrical source.

Thus, for magnitude $<|P_{-1}|^2>$ we can write:

$<|P_{-1}|^2> = \sum_{n=1}^{N} \left\langle |P_{-1n}(\Omega)|^2 \right\rangle$, where $N = \Delta H / \Delta h$ – amount of partial layers in “sounding” volume; $P_{-1n}(\Omega)$ – sound pressure of a scattered by n's partial layer of sounded from a distance $z_n = H + \Delta h(n-1)$ volume difference frequency wave. Magnitude $\left\langle |P_{-1n}(\Omega)|^2 \right\rangle$ let's find, supposing, that scattered in the inverse direction wave of difference frequency keeps a Gaussian profile. Then:

$\left\langle |P_{-1n}(\Omega)|^2 \right\rangle = \left\langle s(\Omega) \right\rangle |P'_{-1n}(\Omega)|^2 /(1 + z_n^2 / 4L_d^2)$, where $\left\langle s(\Omega) \right\rangle = \left\langle a_- \right\rangle \Delta h$ – specific backscattering section of a medium layer with thickness Δh; $\left\langle a_- \right\rangle$ – average value of volume backscattering coefficient [m^{-1}] on difference frequency; $L_d = a^2 \Omega / 4c_o$ – length of secondary bundle diffraction zone; $P'_{-1n}(\Omega)$ – sound pressure in a acting on a partial layer wave. Neglecting an attenuation of a difference frequency wave on a path, equal to l_-, we shall get:

$$\left\langle |P_{-1}|^2 \right\rangle = \frac{\left\langle a_- \right\rangle l_- p_{01}^2 p_{02}^2 e^2 \Omega^2}{(2 r_o c_o^3)^2} \sum_{n=1}^{N} \frac{\exp(-4 b_- z_n)}{1 + z_n^2 / L_d^2} \cdot |I_1(z_n)|^2 , \qquad (2)$$

where, $I_1(z_n) = \int_0^{z_n} \frac{\exp(-b \cdot y)dy}{1 - j(z_n - y)/L_d + y(2jL_d + z_n)/L}$; $b = b_1 + b_2 - b_-$; b_-, b_1, b_2 – attenuation coefficients of waves with frequencies Ω, w_1, w_2, accordingly; $L = l_{d1} l_{d2}$; $l_{d1,2} = a^2 w_{1,2} / 2c_o$; r_o, c_o – density and sound velocity of a medium at a lack of acting; P_{01}, P_{02} – amplitudes of primary waves sound pressure on a surface of pump antenna; ε – nonlinearity parameter; à – radius of pump antenna.

Average module quadrate of sound pressure $\left\langle |P_{-2}|^2 \right\rangle$ presents a “nonlinear” part of a reverberation. For it determination we shall define sound pressure of regular component of primary waves acting a partial layer of dispersing volume:

$P_{1,2}^{i} = \frac{p_{01,02}}{1 - jz'_n / l_{d1,2}} \exp(-b_{1,2} z'_n - \frac{r^2}{a^2} \frac{1}{1 - jz'_n / l_{d1,2}})$, where $z'_n = H + n\, l_-$. Sound pressure in pump waves, scattered in the inverse direction by partial layer with thickness $\Delta h = l_-$ of sounded volume, we shall represent as: $P_{1,2}^{S} = P_{1,2}^{i} \left\langle á_{1,2} \right\rangle ë_-$. Using a solution for Gaussian sound bundles, we can find a “nonlinear” component of reverberation:

$$\left\langle |P_{-2}|^2 \right\rangle = \frac{\left\langle a_1 \right\rangle^2 \left\langle a_2 \right\rangle^2 l_-^4 p_{01}^2 p_{02}^2 e^2 \Omega^2}{(2 r_o c_o^3)^2} \sum_{n=1}^{N} \left| \frac{\exp(-b' \cdot z)}{(1 - jz \;\; / l_{d1}) \cdot (1 + jz \;\; / l_{d2})} I_2(z) \right|^2 , \qquad (3)$$

where

$I_2(z) = \int_0^{z} \frac{\exp(-b \cdot y)dy}{(1 - jy / l'_{d1})(1 + jy / l'_{d2}) - j2(z-y)[(1 - jy / l'_{d1})/a_2^2 + (1 + jy / l'_{d2})/a_1^2]/k_-}$; $k_- = \Omega / c_o$

$l'_{d1} = w_1 a_1^2 / 2c_o$; $l'_{d2} = w_2 a_2^2 / 2c_o$; $a_{1,2}^2 = a^2(1 \mp jz'_n / l_{d1,2})$; $b' = b_1 + b_2 + b_-$.

In case of scattered waves receiving in the place of pump transducer's position, the distance z is numerically equal to magnitude z'_n.

The obtained expressions for a “linear” and “nonlinear” components of reverberation allow to calculate average value of parametric antennas reverberation envelope, and also to carry out the analysis of the reverberation’s components contribution in a sum level, in dependence on frequency properties of scattering objects. The volume backscattering coefficients are depend on a scattering objects type, concentration and can vary in a broad band of values._Especially great sound scattering happens on gas bubbles on its resonance and close to resonance frequencies. And, in dependence on exterior hydrostatic pressure and bubbles sizes, the resonance frequencies are observed in a range from units up to hundreds kilohertz. Therefore the effective sound scattering can be observed simultaneously in broad frequency band, for example on primary frequencies waves and on waves of difference frequency.

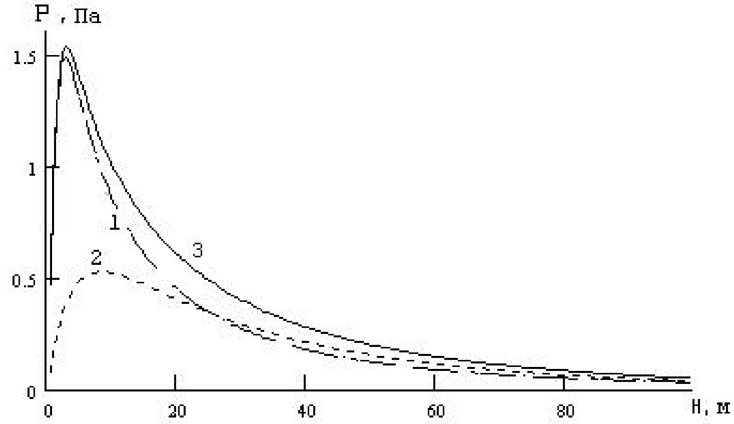

Fig.2. Sound reverberation pressures of a parametrical source: 1 - “linear”, 2 - “nonlinear” component, 3-sum sound pressure of reverberation.

The calculations show, that at identical volume backscattering coefficients on pump frequencies and on difference frequency, the contribution of “nonlinear” reverberation component is negligible. In case, when the scattering coefficient on frequencies of pump waves_is on several orders more than the scattering coefficient on difference frequency, “nonlinear” reverberation component will gives the significant contribution (as it shown in Fig.2.) to a sum reverberation level of a parametric source. Shown in Fig.2 the calculated curves of average sound pressure reverberation values, are obtained at the following input data:

$a_1 = a_2 = 10^{-4}; a_- = 2 \cdot 10^{-8}; b_1 = b_2 = 0.009\ Np/m; b_- = 0.00045\ Np/m; f_1 = 180\ kHz;$

$f_2 = 210\ kHz; R = 0.25\ m; P_{01} = P_{02} = 3 \cdot 10^5\ Pa; t_{è} = 1 ms.$

In summary we shall mark, that the given model of a reverberation with “active” impulse volume, when the interaction of primary waves in current sounded medium volume is taken into account, can be used for evaluation of reverberation levels on sum frequencies, harmonics, at combinative scattering, i.e., for all cases, when during waves propagation the nonlinear effects are observed.

R E F E R E N C E S

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