УДК 699.34:534.84

STATISTICAL ENERGY METHODS OF REFLECTED NOISE FIELDS CALCULATION IN HALLS

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Key words and phrases: energy balance method; quasi-diffusion field; method of variables division; noise level; pictures method; statistic energy model.

Abstract: Distribution of reflected sound energy indoors depends on proportion of room size and sound absorption features of enclosure and tends to decrease when moving away from the sound source. There is some connection between sound strength flow and density gradient of reflected energy in the form of transfer coefficient, describing physical indoor characteristics from the point of forming reflected sound field. On this basis calculation model for density distribution of reflected sound energy indoors is developed. The model is implemented by analogue, analytical and numerical methods.

Sound field creation indoors depends on direct and reflected components of sound strength, spreading over in closed volume. As a rule, calculation of the first one has no difficulties. The components of reflected energy distribution are more complex, taking into account physical indoor characteristics such as form and size, sound absorbing ability of certain surfaces, etc. Due to sound absorption in the media and at boundaries, reflected sound energy fields tend to decrease when moving away from the sound source and get a quasi-diffusible character, which is caused by resultant current of reflected sound energy, thus, keeping the formal feature of isotrope diffusion with angular directed elementary currents [1] at every volume point.

In quasi-diffiisible reflected sound fields there is some connection between sound strength current q and density gradient of reflected energy ε. The above mentioned relation can be formulated in the form of

$$q = -\eta \operatorname{grad} \varepsilon . \qquad (1)$$

Here η is coefficient of reflected sound energy transfer in a quasi-diffiisible field. It describes physical characteristics of closed volume from the point of the process of reflected sound field creation, which takes place in it. On the basis of conducted experiments, it was determined that the coefficient η may be considered constant and equal for almost all practically important cases

$$\eta = 0{,}5 c l_m , \qquad (2)$$

where – l_m means free path of reflected sound waves indoors; c is sound velocity in the air.

Generally speaking, when sound damps in the air the equation of reflected sound energy distribution in stationary conditions has the form of

$$\eta\nabla^2\varepsilon - cm_a\varepsilon = 0\,, \qquad (3)$$

where m_a is spatial coefficient of acoustic absorption in the air.

The equation has the only solution which is determined by setting boundary conditions of enclosures in the form of

$$\left.\frac{\partial\varepsilon}{\partial n}\right|_s = -\left.\frac{\alpha_s\varepsilon}{(2-\alpha_s)l_m}\right|_s\,, \qquad (4)$$

where α_s is coefficient of sound absorption of surface.

According to some frequency part of analysis, the equation (3) with boundary conditions (4) presents the calculation model of density distribution of reflected sound energy volume with stationary stimulation. The model has a structural and-functional character. On the one hand, it has similar to the object structure, and on the other hand the response of the model to the stimulation given, that numerically corresponds to the object response becomes possible without any imitation of wave action.

If non-stationary stimulation received, the equation of reflected sound energy distribution has the form of

$$\eta\nabla^2\varepsilon - \frac{\partial\varepsilon}{\partial t} - cm_a\varepsilon = 0\,. \qquad (5)$$

To carry it out, except boundary conditions (4) some information concerning initial distribution of reflected sound energy indoors is required

$$\left.\varepsilon\right|_{t=t_0} = f(x_1, x_2, x_3)\,. \qquad (6)$$

We developed analogue, analytical and numerical methods to put the mentioned model into practice.

Analysing the dependences of reflected energy distribution it is reasonable to use analogue modeling methods when carrying out calculation model in case of complex boundary and sixe conditions. For this purpose, an electrical volumetric combined model from electro-conductive paper [2] was designed.

Dealing with the equation for a rectangular-shaped hall (3), the pictures method is used. While working out the calculation method, we use the formal device of changing the energy absorption at volume boundaries for the absorption in environment in part, that is equal to the distance of sound free path between reflections,

$$m'_a = m_a - \ln(1-\alpha_m)/l_m\,, \qquad (7)$$

where α_m is an average coefficient of sound absorption of enclosure surfaces.

In this case, the equation (3) may be presented in the form of enclosure surfaces. In this case, the equation (3) may be presented in the form of

$$\nabla^2\varepsilon - \gamma^2\varepsilon = 0\,, \qquad (8)$$

and boundary conditions as

$$\left.\frac{\partial\varepsilon}{\partial n}\right|_s = 0\,. \qquad (9)$$

Here $\gamma = \sqrt{cm'_a/\eta}$ is the quantity, characterising sound energy damping in volume space and at its boundaries.

Reflected energy density for a rectangular-shaped hall is defined by the equation

$$\varepsilon = \frac{P\left(1-\bar{\alpha}\right)}{4\pi\eta} \sum_{m=-\infty}^{\infty} \sum_{n=-\infty}^{\infty} \sum_{q=-\infty}^{\infty} \frac{\exp\left(-\gamma\, r_{mnq}\right)}{r_{mnq}}, \tag{10}$$

where r_{mnq} is the distance between the calculation point and the picture; *m, n, q* is the combination of intergers, except $m = n = q = 0$; P is acoustic source strength.

The method of variables division is more suitable for carrying out the calculation model both in stationary and non-stationary conditions. The formula of time distribution for reflected sound energy field created by the source of acoustic power variable, is shown below. The coordinates of the calculation pointer $\left(x_1, x_2, x_3\right)$ and the source $\left(x_1^0, x_2^0, x_3^0\right)$ are constant

$$\varepsilon_t = \left(1-\alpha\right) \sum_m \sum_n \sum_q \frac{\varphi_m\, \varphi_n\, \varphi_q\, \varphi_m^0\, \varphi_n^0\, \varphi_q^0}{B_m B_n B_q} \int_{\tau_2}^{\tau_1} P\left(\tau\right) \mathrm{e}^{-U_{mnq}\left(T-\tau\right)} d\tau, \tag{11}$$

where *T* is time of energy impulse observation; $\varphi_m, \varphi_n, \varphi_q$ is the system of orthogonal trigonometrical eigenfunctions; $\varphi_m^0, \varphi_n^0, \varphi_q^0$ is the value of eigenfunctions in the source point; U_{mnq} is coefficient of time damping of particular solution amplitudes; $i = m, n, q$ is rating cofactors defined from the equation

$$B_i = \int_0^{l_j} \left[\varphi_i\right]^2 dx_j\,. \tag{12}$$

The numbers are selected so that φ_i functions could correspond to boundary conditions (4).

The distribution of the sound energy impulse indoors immediately after its radiation τ is taken as initial condition

$$\begin{cases} \varepsilon = \dfrac{P\left(1-\alpha\right) d\tau}{\int\limits_{V_{oc}} dV}; x_j \in V_{oc}; \\ \varepsilon_i = 0; x_j \notin V_{oc}, \end{cases} \tag{13}$$

where V_{oc} is sufficiently small range of the original impulse distribution as compared with hall volume.

On the basis of (11) a wide range of problems of industrial acoustics both in non-stationary and stationary conditions can be solved.

In case of stationary problem, the distribution of reflected sound energy density is defined as

$$\varepsilon = \left(1-\alpha\right) P \sum_m \sum_n \sum_q \frac{\varphi_m\, \varphi_n\, \varphi_q\, \varphi_m^0\, \varphi_n^0\, \varphi_q^0}{B_m B_n B_q U_{mnq}} \mathrm{e}^{-U_{mnq} r/c}, \tag{14}$$

where r is the distance between the source and the point of analysis.

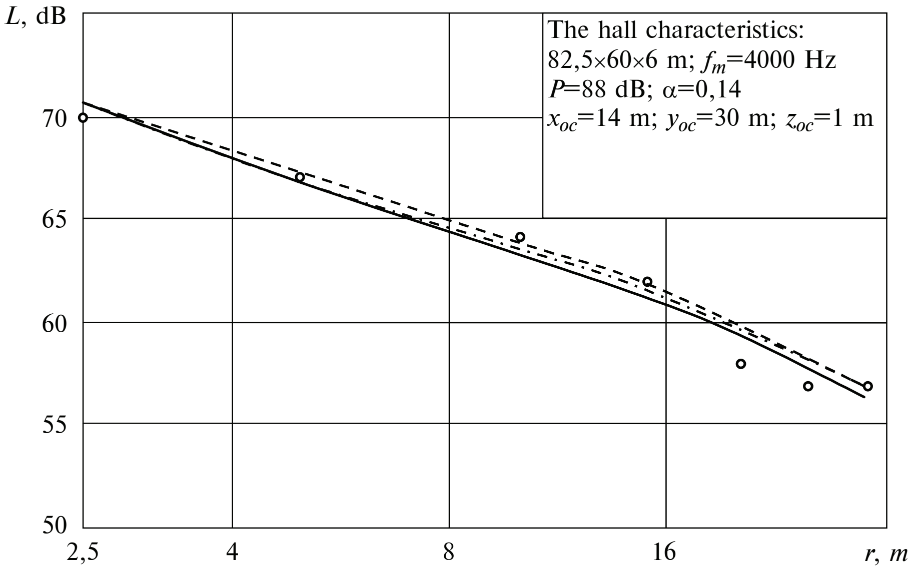

Fig. The results of noise level calculation by the following methods:
(———) the energy balance method; (– – – – .) the method of pictures;
(– · – · –) the method of separation of variables; (o) experimental data

The pictures methods and method of variables division can be used for a hall of simple geometrical shape. In the halls of complex form, the calculation relations can be received with higher accuracy carrying out the calculation model using the energy balance method. The method used is based on separating the hall volume into series of elementary ones of simple geometrical form. Within the limits of the volumes, the character of reflected energy density may be taken as linear and an equation is made for each elementary volume. Energy distribution is defined from equation system solution. The general form of reflected energy balance for each elementary volume is formulated in the form of

$$\sum_{j=1}^{N}\left(q_{ji}-q_{ij}\right)S_{ij}+\sum_{k=1}^{6-N}\left(q\left(w\right)_{ik}-q\left(\alpha\right)_{ik}\right)S_{ik}=0, \qquad (15)$$

where q_{ji} and q_{ij} are energy currents, circulating from j -volume into i -volume, and, vice a versa, from i -volume into j -volume through the surface S_{ij}, $q(w)_{ik}$, $q(\alpha)_{ik}$ are energy currents, accordingly, brought into i -volume after the first sound reflection, and absorbed by k-surface of i-volume, being enclosure surface S_{ik}; N is the number of j -volumes, getting in contact with i -volume.

The developed methods give sufficiently accurate results in the noise-preventing activity. In more complex cases the deviations of the calculated and experimental data do not exceed ±3 dB. Calculation of noise levels using mentioned methods is shown on the figure.

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Статистические энергетические методы расчета отраженных шумовых полей помещений

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Ключевые слова и фразы: квазидиффузное поле; метод изображений; метод разделения переменных; метод энергетических балансов; статистическая энергетическая модель; уровень шума.

Аннотация: Распределение отраженной звуковой энергии в помещениях зависит от соотношения размеров помещений и звукопоглощающих характеристик ограждений и имеет явно выраженные спады в направлении удаления от источника шума. Между потоком звуковой мощности и градиентом плотности отраженной энергии существует связь в виде коэффициента переноса, характеризующего физические свойства помещения с позиции формирования отраженного звукового поля. Основываясь на этом, разработана расчетная модель распределения в объеме помещения плотности отраженной звуковой энергии. Модель реализуется аналоговыми, аналитическими и численными методами.

Statistische energetische Methoden der Berechnung der reflektierten Lärmfelder in den Räumen

Zusammenfassung: Die Verteilung der reflektierten Schallenergie in den Räumen hängt von der Korrelation zwischen den Raumgrößen und den schallabsorbierenden Charakteristiken der Umzäunungen ab und hat scharf ausgeprägte Rückgänge in der Richtung der Entfernung von der Lärmquelle. Zwischen dem Strom der Schalleistung und dem Gradienten der Dichte der reflektierten Energie gibt es einen Zusammenhang in der Form des Übertragungskoeffizienten, der die physikalischen Eigenschaften des Raumes vom Standpunkt der Formierung des reflektierten Schallfeldes charakterisiert. Auf diesem Grund ist es das Berechnungsmodell der Verteilung der Dichte der reflektierten Schallenergie im Rauminhalt erarbeitet. Das Modell wird durch analogischen, analytischen und numerischen Methoden realisiert.

Méthodes énergétiques statistiques du calcul des champs de bruit réfléchis des locaux

Résumé: La répartition de l'énergie sonore dans les locaux dépend de la corrélation des dimensions des locaux et des catractéristiques de l'absorption phonique des protections et comprend des baisses évidentes dans la direction de l'éloignement du bruit. Entre le flot de la puissance sonore et le gradient de la densité de l'énergie réfléchie il existe un lien en forme du coefficient du transfert caractérisant les propriétés physiques du local du point de vue de la formation du champ de bruit réfléchi. En se fondant sur ce fait on a élaboré le modèle de calcul de la répartition de la densité de l'énergie sonore réfléchie. Ce modèle est réalisé par les méthodes analogiques, analytiques et nimériques.