Speech as Noise Interference During a Mass Event

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Annotation. Participants of mass events are noise sources for surrounding area and perception of information. To rate the intelligibility of the signals of sound amplification systems and to design the instruments of the noise insolation, the methods of calculating the propagation of sound energy from distributed noise sources such as people are developed. Methods take into account features of the emission of sound energy by such sources. The features include time-varying acoustic and spatial characteristics of noise sources. They are associated with the random nature of the position and direction of noise emission from event visitors. The method of calculating the energy parameters of direct sound depends on the parameters of the noise source. The low density of people location implies to use the method of mathematical modeling, including the random position, orientation and duration of speech of noise sources. The increase in the mass character of events and the increase in the density of point noise sources are rational to use the integral calculation method. The numerical solution of the integral equation is implemented in a computer program and used for calculating the noise from fans of a football match at the stadium and adjacent urban development. The methods for calculating direct sound from distributed sources in the form of a circle, a circular sector and a rectangle are suggested on the basis of an analytical solution of integral expressions. Comparison of calculation results by developed methods and experimental data is performed. The discrepancy between the results in the most difficult situations doesn't exceed ± 3 dB.

1 Introduction

There are within urban development a large number of places with a mass staying of people. These include stadiums, open hockey and other sports grounds, school and kindergarten grounds, places for city events with a plenty of people, etc. The sound energy emitted by people, which are located in these venues and territories, spreads over long distances and creates increased noise levels in urban environment [1, 2]. The noise regime around these objects often exceeds permissible values. Noise from people in the stadium stands and at other events can make high noise background, which interferes with the perception and recognition of information emitted by sound amplification systems in voice alerts [3, 4].

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The methods of calculating the direct sound from people are also important for rating speech intelligibility in public places with a mass staing of people and also for the design of voice fire alarms [5, 6]. Features of the formation and distribution of direct sound from people make influences at the formation of the reflected sound field in the premises [7, 8, 9]. The parameters of the reflected sound field determine mostly the acoustic qualities of the halls and auditoriums with a mass staying of people [10, 11, 12]. For these reasons, it is necessary to make sufficiently accurate calculations of direct sound from people as distributed noise sources with different characteristics of the sound energy emitted by them.

2 Methods

The mass events visitors as sources of noise have a number of features [13, 14]. Their position, orientation or direction of speech are unknown probabilistic quantities. Also random quantities are the duration of the speaker's speech and the number of speaking at the same time people.

The places of mass staying of people, which are a relatively small number of noise sources in the form of talking visitors (usually less than 1000 people) implies to use the method of computer modeling of the acoustic process for the calculation of direct sound exactly.

The essence of the method is as follows. Supposing, N people occupy a some area of any space. All visitors in this area of space are placed a certain number of times M_0 randomly proportional to the distribution of the density of people. The angle between the direction of speech and the direction to the calculated point, which determines sound pressure level, is also set randomly [15].

Sound pressure levels at the calculated point are calculated at a result of computer modeling with subsequent averaging, based on the expression

$$L_{dir} = L_w + 10\,lg\left[\frac{1}{M_0}\sum_{M_0}\sum_{i=1}^{N}\frac{K_{od}F_{(\theta)}}{4\pi r_i^2}\right], \qquad (1)$$

where $F_{(\theta)}$ – the speech directivity factor; r_i - the distance from the talking person to the calculated point; L_W - the level of acoustic power of a mass event visitors; K_{od} - the part of talking event visitors at the same time.

It should be noted that when the program calculating of direct sound levels doesn't include the contribution of noise sources located closer than 1 m from the calculated point.

To getting reliable statistical validity of the calculation, the number of arrangements or the direction speech of people M0 should be sufficiently. The value of M_0 should be in proportion to the area of location the mass event visitors.

The computer modeling method has independent practical application for calculating direct sound from distributed noise sources, and can also be used to rate the accuracy of other calculation methods.

Simpler methods for calculating direct sound are obtained by using the principle of "smearing" of local point sources of noise along the plane in the calculation method. This is based on replacing the system of local point sources with a flat source with the relevant energy characteristics of acoustic power and directivity of emitting. This calculation method is suitable for conditions where subsequent calculation of reflected noise is required. [16, 17, 18]. The value of the surface acoustic power of this distributed sound source is

$$W = \frac{W_0 NK_{od}10^{0.1L_W}}{S_0}, \qquad (2)$$

where N – the number of people in the area S_0; NK_{od} – the number of signal sources (speakers); S_0 – location area of N visitors; w_o – the limited value of acoustic power.

In this case, the density of sound energy at the calculated point (excluding the reflection of sound from the floor surface) will be determined with base of the integration of the expression

$$\varepsilon_{dir} = \int_{S_0} \frac{WF}{4\pi r^2 c} dS = \frac{W}{4\pi c} \int_{S_0} \frac{F}{r^2} dS, \tag{3}$$

where r – the distance from the element dS to the calculated point; c – the speed of sound in the air.

For randomly orientation of speaking visitors, equal probability of sound energy emitting should be taken in all directions, that is, $F = 1$. For noise sources such as sports stands, where all fans are oriented within a known spatial sector, the speech directivity factor can be used. It is determined by the expression [16].

In the general case the calculation of the integral in (3) should be performed with numerical method. For some special cases of the arrangement of noise emitters analytical expressions of the sound energy density of direct sound can be recieved.

Flat sources of noise with circular symmetry (circle, circular sector, etc.) are found during open air concerts. This form of sources allows finding of analytical expressions for calculating direct sound parameters, including sources with big sizes - "infinitely long."

In a spherical coordinate system (see Figure 1, a), the expression for the energy density of direct sound from a noise source as a circular sector is

$$\varepsilon_{dir} = \frac{1}{4\pi c} \int_{\varphi_1}^{\varphi_2} d\varphi \int_{r1}^{r2} \frac{W_{(r)} r}{r^2 + h^2} dr, \tag{4}$$

where φ_1, φ_2, r_1, r_2 – are the limits of integration.

The density of the arrangement of people near the stage is usually maximal and it decreases gradually on distance from stage. In this case, the acoustic power of the noise sources from the conversation of the audience can be considered linear and determined according to the expression

$$W_{(r)} = W\left[1 - \frac{r - r_1}{r_2 - r_1}(1 - m)\right], \tag{5}$$

where m – the coefficient of variation of the acoustic power of noise sources, $m \geq 0$.

It supposed to every section of a flat sound source emits noise evenly into the surrounding half-space $F = 1$. Integration of expression (4) for the calculated point on the axis of symmetry of the noise source brings the result

$$\varepsilon_{dir} = \frac{W(\varphi_2 - \varphi_1)}{8\pi c}\left\{\left[1 + \frac{r_1(1-m)}{r_2 - r_1}\right]\left[ln(r_2^2 + h^2) - ln(r_1^2 + h^2)\right] - \frac{2h(1-m)}{r_2 - r_1}\left[arctg\left(\frac{r_2}{h}\right) - arctg\left(\frac{r_1}{h}\right)\right]\right\}. \tag{6}$$

This work[19] has a formula for calculating direct sound from a circular noise source for a random position of the calculated point (see Figure 1b). In this case the value of the density of sound energy at the calculated point will be determined by the expression

$$\varepsilon = \frac{W}{4c} ln \frac{r^2 + h^2 - A^2 + \sqrt{(r^2 + h^2 - A^2)^2 + 4A^2 h^2}}{h^2 - A^2 + \sqrt{(h^2 - A^2)^2 + 4A^2 h^2}}. \tag{7}$$

In some cases, the directivity factor of noise emitters can be considered as the dependence of the cosine $F = 2cos(\theta)$. In the case of a constant surface density of the acoustic power of the noise source, the integral (2) will expressed as simpler form [20]

$$\varepsilon_{dir} = \frac{W\Theta}{2\pi c}. \tag{8}$$

where θ – contracting the radiating surface of S_i the solid angle is defined in spherical coordinates as

$$\Theta = \int_{S_i} sin\,\theta\, d\phi d\theta. \tag{9}$$

The value of the solid angle of a triangular element of a noise-emitting surface can be calculated conveniently by the Liouille theorem with the flat angles of a trihedral angles γ_a, γ_b, γ_c at the apex

$$\Theta = 4 arctg\left(\sqrt{tg\frac{\gamma_s}{2} tg\frac{\gamma_s - \gamma_a}{2} tg\frac{\gamma_s - \gamma_b}{2} tg\frac{\gamma_s - \gamma_c}{2}}\right), \tag{10}$$

where $\gamma_c = 0.5(\gamma_a + \gamma_b + \gamma_c)$ – the half-perimeter.

a)   *b)*
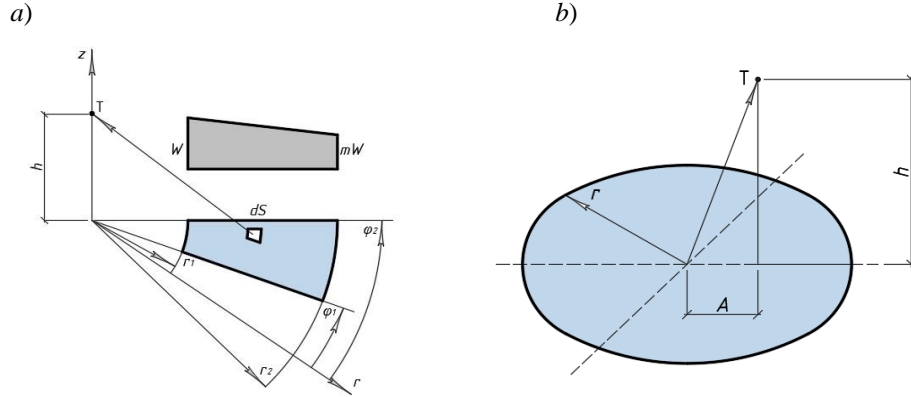
Fig. 1. The calculation scheme in a spherical coordinate system for a flat source of circular form

Using the numerical method, the initial plane with evenly distributed sound sources is divided by a grid with K elements of equal area with the subsequent summation of the energy emitted from each element as a point source of sound.

The solution to the problem is implemented at computer program by a numerical method. The value of the density of sound energy is determined with the summation of a number

$$\varepsilon = \sum_{i=1}^{K} \frac{NK_{od}W_0 F 10^{0.1 L_W}}{4\pi r_i^2 cK}.\qquad(11)$$

Accordingly for calculation of the direct sound that spreads from objects with a mass staying of people, computer methods have been proposed to make it possible for calculation of the noise regime in open space and indoors with different acoustic and spatial characteristics of sources of this type. The developed computer program is designed to rate the noise situation, to develop noise protection measures, and it can also be used in the design of speech intelligibility in sound reinforcement systems.

3 Results and discussion

To assess the posibility and the accuracy of the proposed methods, measurements and calculations of the spread of noise from fans during a football match were made at the Spartak stadium in Tambov and in the surrounding area. The scheme of the stadium, the location of the stands and noise measurement points are shown in Figure 2, a. The incision through the main covered stand near the measurement points T3 – T5 is shown in Figure 2, b. The match was attended by about 1,500 fans, who were mainly located on the covered stand. The visor of the covered stand formed a sound reflector, which created high noise levels in the stadium and in the surrounding area together with the direct sound. A diagram of the formation of an imaginary noise source is shown in section 2, b.

Sound pressure levels were measured at the characteristic points of the stadium during a football match. To account for fluctuations in noise levels in time, measurements were performed by two sound level meters with a control point of T0. Equivalent levels of sound pressure, adjusted for the time-varying noise of the stands, are shown in Table 1.

a)
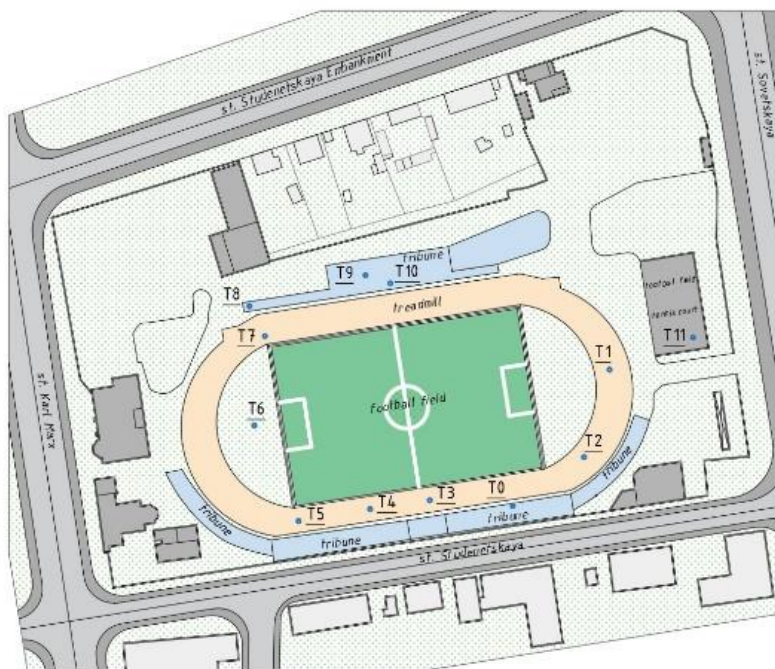
b)
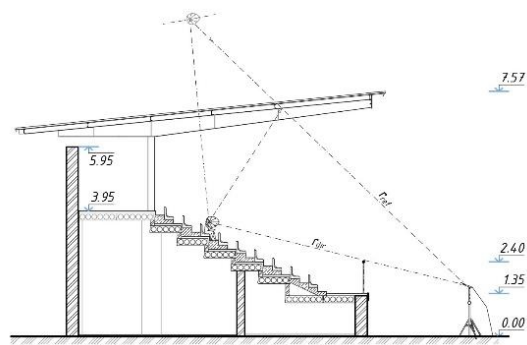
Fig. 2. The position of the points of measurement of noise (a) and the incision of the main covered stand (b)

The calculation of sound pressure levels was made using a computer program, in which the surface densities of the acoustic power of noise sources were calculated with expression (2). The average equivalent acoustic power levels of a separate person at the main stand and a fan at the fan sector with using noise instruments are given in Table 2. Power levels are calculated on the base of the measured noise levels on the stadium stands.

Comparison of the spectra of the noise source and the acceptable noise levels in the area directly adjacent to residential buildings showed that the most unfavorable range is an octave with an average geometric frequency of 1000 Hz. The noise map of the stadium in this octave band is shown in Figure 3.

Table 1. – Comparison of measured and calculated sound pressure levels

Measuring point	Levels, dB at an octave frequency of 500 Hz			Levels, dB at an octave frequency of 1000 Hz		
	L_{met}	L_{cal}	ΔL	L_{met}	L_{cal}	ΔL
T1	70.5	72.8	-2.3	69.4	72.3	-2.9
T2	73.4	74.5	-1.1	74.2	74.7	-0.5
T3	75.1	72.7	2.4	78.0	76.8	1.2
T4	72.5	72.5	0	74.8	76.1	-1.3
T5	65.3	67.8	-2.5	69.3	72.2	-2.9
T6	66.3	63.2	3.1	67.9	66.2	1.7
T7	63.3	61.7	0.6	62.6	64.0	-1.4
T8	64.0	60.8	3.2	66.0	63.1	2.9
T9	67.5	67.0	0.5	71.4	71.3	0.1
T10	68.5	68.4	0.1	69.2	71.5	-2.3
T11	89.0	88.7	0.3	87.7	87.7	0

Table 2. – Equivalent acoustic power levels of fans during a football match

Noise source	Acoustic power levels, L_{WP}, dB in octave bands, with an average geometric frequency, Hz					
	125	250	500	1000	2000	4000
Person at the main stand	68	63.8	73.6	77.6	70.3	63.1
Fan witn noise device	96	95	94	93	80	73
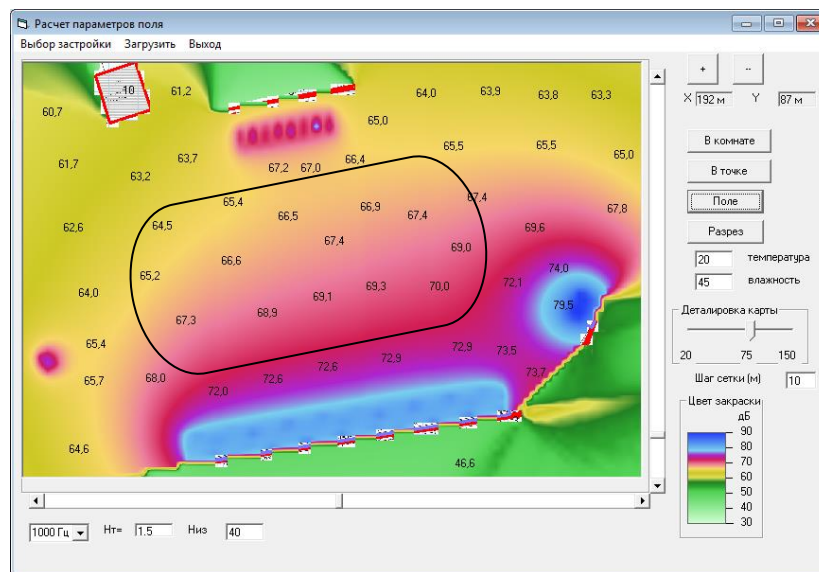
Fig. 3. The noise map of the stadium at an average geometric frequency of 1000 Hz

Analysis of the calculation results indicates the maximum sound pressure levels near the fan sector on the stands. In this sector fans used different objects emitting a lot of noise. Because of he drums, noise at low frequencies (up to 500 Hz) in this sector exceeds the noise of the main stand by 20-25 dB. The noise map shows that the noise from the fan sector dominates in a relatively small part of the stadium, because the number of fans in this sector of the stands is not large (51 people).

Near the stadium, in the area directly adjacent to residential buildings, the noise during the match is 54-57 dB. Noise exceeds the allowable level of 50 dB at a frequency of 1000 Hz. To protect the adjacent area from such noise, it is necessary to arrange sound protect screens.

Comparison of calculated and experimental data shows that the computer program as a whole adequately reflects the distribution of sound energy. The discrepancy between the measured and calculated sound pressure levels does not exceed ± 3 dB.

4 Conclusions

The following results are presented in the work:
- two calculation models are given for calculation of noise from people in places of mass events: a model based on computer modeling of noise influences from every person with their subsequent energy summation; a model based on view of people as a flat emitting sound energy surface;
- analytical and numerical methods for calculation of noise based on these models are offered, and a computer program for their implementation is developed;
- an example of using a computer program to analyze a specific noise situation during a football match at the stadium and the adjacent area is given, and the calculated and measured noise levels are compared. The calculation and comparison results are in good matching.

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