# FIRE AND INDUSTRIAL SAFETY (CIVIL ENGINEERING)

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## THE METHOD OF SOUND DESIGNING OF A SINGLE VOICE FIRE ALARM

**Statement of the problem.** Experts in the field of fire safety suffer a number of difficulties arising in the process of designing voice announcement system in the event of a fire. It is connected with the lack of criteria system to the parameters of the sound field premises created by the sirens in conjunction with other sources. The purpose of the work is to develop the methods of designing a single acoustic voice fire alarm.

**Results.** According to the fire safety regulations and literary sources the influence of background noise on the comprehension of the speech signal from the alarm warning and evacuation system in the event of a fire was analyzed. An algorithm of acoustic design of a single alarm taking into consideration its acoustic power, sound-absorbing and sound-reflecting characteristics of structures and background noise as well was developed.

**Conclusions**. According to the study a technique of designing a single alarm using the reverberation noise method to evaluate the comprehension of the signal was developed. The presented technique allows one to provide the most rational position of the voice alarm in the premises, to improve the comprehension of the speech message that will help to make the evacuation of people in the case of fire more effective.

**Keywords:** fire, system of alarm, evacuation of people, speech message, background noise, sound-absorbing properties, single voice fire alarm.

## Introduction

A fire alarm sounder (FAS for further reference) is designed to give people verbal instructions in the event of a fire about evacuation paths and other activities to be undertaken to provide the safety and preventing panic from happening. One of the priorities is to ensure instructions to be clearly heard at any point of the premises. For a better-quality design of FSAs a system of criteria should be in place for the sound field parameters generated by the alarms together with other sources of sound. The requirements for fire alarm sounders are detailed in Set of Rules (СП) 3.13130.2009 and 133.13330.2012. The essential ones apply to a general sound level generated by sounders and other sources of sounds at any point of the premises should be no less than 75 but no more than 120 dB; general sound level generated by sounders and other sources of sounds should be no more than 15 dB higher than a level of background noise.

Distinction of verbal warnings depends on the useful signal-background noise ratio, reverberation and the overall noise reflection pattern especially earlier ones. A high-quality alarm sounder is a result of special calculations that can be performed in a number of ways. We see the method of reverberation noise as the best since it makes allowances for a space and time structure of a reflected field generated in the premises.

For fire alarm sounders syllable distinction of over 56 % is recommended which is a characteristics of a clear, distinct speech (according to Set of Rules (СП) 23-104-2004).

**1. Acoustic design of a single fire alarm sounder** as a block scheme is in Fig. 1.

*Step 1.* Designing process starts with the collection of the initial data in order to come up with a list of requirements, information is gained on geometric and acoustic parameters of the premises and an appropriate type of a fire alarm sounder is selected. Of particular importance are the parameters of local sound sources, background noise level from the distributed internal noise sources and the noises coming from the exterior sources. Further in the paper the noises from all sources of noise except that of fire alarm sounders will be referred to as background noises $L_{ф}$.

The guideline literature (СП 3.13130.2009, СП 133.13330.2012) background noises (constant noises) is recommended to be as much as the acceptable one. This means that before designing fire alarm sounders there should be a list of activities in place to reduce a noise level down to the acceptable level.

For a large group of premises the noise regulations provide for the acceptable levels of the exterior noises which include the outside noises coming through the windows, ventilation system noises and noises from the adjacent premises. The outside noises are generally lower than the inside ones, e.g. noises of educational institutions especially during a break are higher than the noise outside. Low outside noises certainly cannot be used in designing fire alarm sounders otherwise they would result in being a lot less powerful. Background noises from the inside sources of noise should be defined based on the measurements of noise levels in similar premises. Reverberation time will need to be measured as well as the noise absorption coefficient of the premises and acoustic power of the distributed sources of noise. This data allows for the dependence of background noise on acoustic cladding of the premises and enable the design of a sufficiently accurate fire alarm sounder. Therefore fire alarm sounders need to be designed based on the acoustic power levels of the interior sources of noise and/or background noise levels as well as acoustic parameters of the premises where noises were measured.

*Step 2:* calculation of a minimum acceptable coefficient of noise absorption of the premises $\alpha_{min}$. Noise absorption properties of the enclosures have an immediate impact on the clearness of the signal. In small noise absorption coefficients and greater reverberation times respectively, a sound alarm will show an insufficient clearness performance even if there are no more obstacles. Later reflections will take a lot more to absorb the useful part of the signal, while a greater acoustic power will have no effect on the performance of a fire alarm. As acoustic power of a fire alarm increases proportionally as well as the useful signal and later reflections which are obstacles. Therefore an actual noise absorption coefficient exceeding αmin is crucial for a good performance of a fire alarm. In order to calculate αmin we can assume there is no background noise Lф = 0, which will make the calculation a lot more simple.

## 2. Calculation of a minimum noise absorption coefficient based on the reverberation obstacle method

For a distinct signal with a syllable distinction of > 60 % the factor *Q*" should be over 1.1. Therefore a minimum average coefficient of noise absorption of the premises should be given by the expression

$$Q'' = K_L T Q = 1{,}1\,, \tag{1}$$

where *T* is the reverberation time for the premises. In the assumption a diffusion sound field dampening of an average density of the reflected energy is $м\varepsilon_{on}^{50}$ which comes into the design point within 50 msec after the straight one comes in; $\varepsilon_0$ is a threshold density of the sound energy.

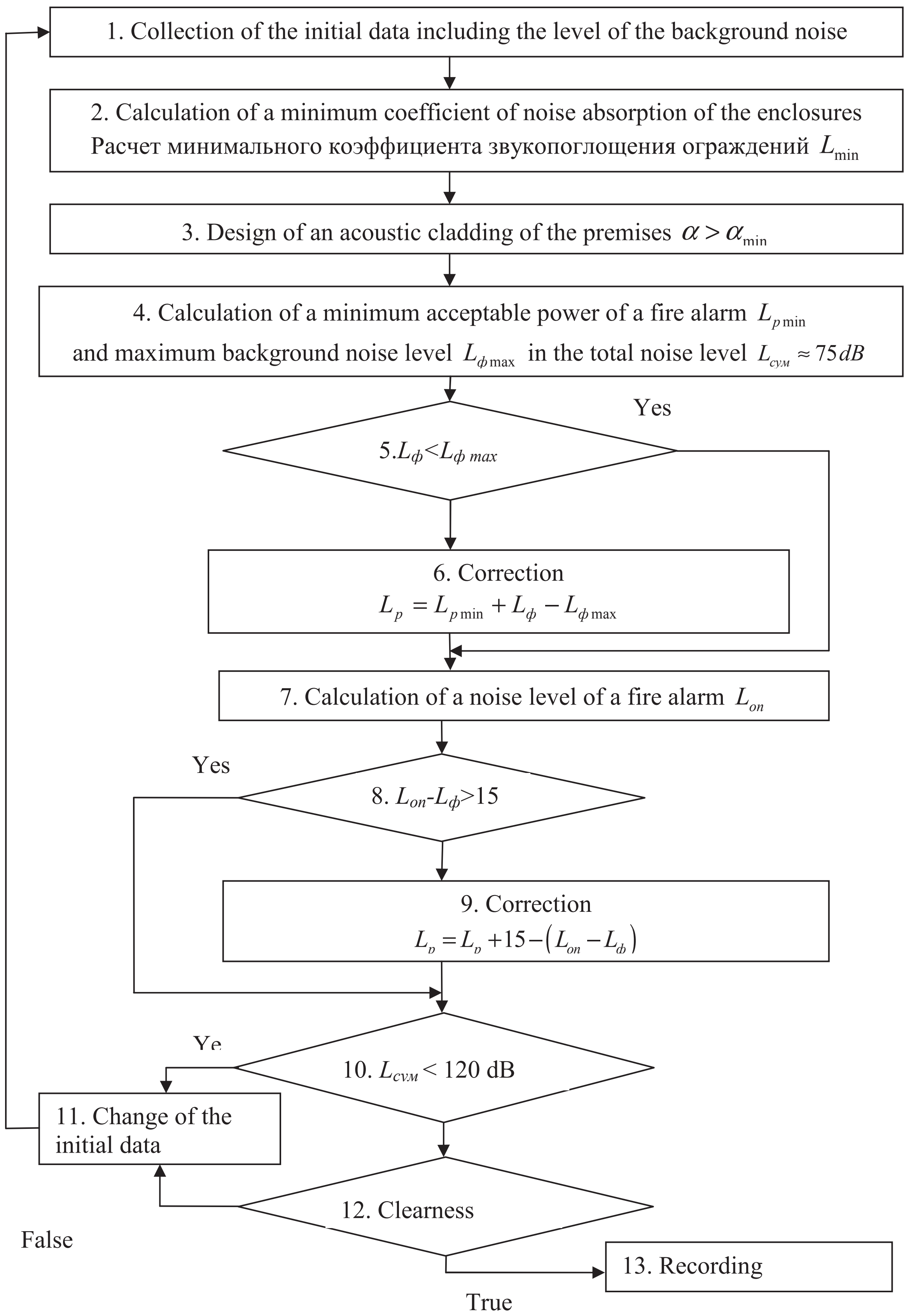


**Fig. 1.** Block diagram of the design of the parameters of a single fire alarmer

The factor of reverberation obstacles is the ratio

$$Q = \frac{\varepsilon_{np} + \varepsilon_{on}^{50}}{\varepsilon_{on}^{>50} + \varepsilon_{\phi}}. \tag{2}$$

In the numerator (2) there is the density of the energy of a useful signal and in the denominator there is the energy of the obstacles which is made up of the background noise level of the premises with the energy density $\varepsilon_{\phi}$ and energy of the later reflections of a fire alarm that come over 50 msec later than the direct sound $\varepsilon_{on}^{>50}$.

In the assumption of the diffusion reflected field of a fire alarm the expression for the components of the expressions (1) and (2):

– density of the direct sound of a fire alarm is

$$\varepsilon_{np} = \frac{\Phi}{\Omega C r^2} \text{ or } \varepsilon_{np} = \frac{\Phi \Omega_o}{4\pi C r^2}; \tag{3}$$

where $\Phi$ is a directivity factor or the square of the directivity coefficient; $\Omega_0$ is a coefficient of axial concentration; $\Omega$ is a spatial angle of the radiation of a noise source; $r$ is a distance between a fire alarm and the calculation point; $C$ is a speed of a sound in the air;

– density and energy level of the earlier reflections of a fire alarm within $t = 50$ msec $= 0.05$ sec:

$$\varepsilon_{50} = \frac{4P(1-\alpha)}{\alpha S}\left(1 - e^{\frac{\ln(1-\alpha)ct}{l_{cp}}}\right); \quad L_{on}^{50} = L_p + 10\lg\left[\frac{4(1-\alpha)}{\alpha S}\left(1 - e^{\frac{\ln(\alpha-1)ct}{l_{cp}}}\right)\right]; \tag{4}$$

– density of the energy and level of the sound of the later reflections of a fire alarm coming into the calculation point within over $t = 0.05$ sec after the direct signal:

$$\varepsilon_{on}^{>50} = \frac{4P(1-\alpha)}{\alpha S c} e^{\frac{\ln(\alpha-1)ct}{l_{cp}}}; \quad L_{on}^{>50} = L_p + 10\lg\left[\frac{4(1-\alpha)}{\alpha S} e^{\frac{\ln(\alpha-1)ct}{l_{cp}}}\right]. \tag{5}$$

If there are no background noises, the factor $Q''$ can be given by an approximated formula at $K_L \approx 1$:

$$Q'' \approx \left[ T + \frac{13,8\Omega_0 V}{4\pi C r^2} \right] e^{0,69/T} - T, \qquad (6)$$

where $\Omega_0$ is a coefficient of axial concentration; $V$ is the area of the premises; $r$ is a distance between an acoustic axis of a fire alarm and the sounded surface; $C$ is a speed of a sound.

The exact $\alpha_{min}$ can be determined based on the numerical solution for the equation (1). An approximate minimum noise absorption of the enclosures can be calculated based on the following simplifications. At the point most remote from a fire alarm where the energy of a direct sound is minimum $\varepsilon_{np} \to$ min, there are generally the worst conditions for the clearness of a signal. At $\varepsilon_{np} \approx 0$ a minimum (exceeded) coefficient of noise absorption of the enclosures of the premises is

$$\alpha_{\min} = 0,0526 \ell_{\text{cp}} . \qquad (7)$$

If an average coefficient of noise absorption of the premises is minimum and there is no background noise, the ratio of the energies (4) will make $Q''$ identical for any acoustic power of a source. If there is background noise $Q'' < 1.1$, there will be insufficient clearness performance for any power of a fire alarm.

*Step 3*: design of acoustic cladding of the premises. It has to be made sure that an average coefficinet of noise absorption of the enclosures of the protected premises is over the minimum. If this is not the case, noise absorbing cladding of the enclosures of the necessary area has to be used.

The problem of choosing an optimal noise absorbing cladding, its performance and area is of a lot of concern and affects economics decision-making and requires an in-depth optimization study. As noise absorbing structures become more efficient, there is more direct sound and useful signal and there is also increasing clearness, all of which requires a more acoustically powerful fire alarm.

*Step 4*: calculation of a minimum acoustic power of a fire alarm and maximum background noise. Important characteristics for the design of fire alarms are a minimum acoustic power of fire alarms and maximum background noise when the total level of noise in the worst calculation point will be 75 dB with the sound staying sufficiently clear $Q'' = 1.1$.

Based on the diffusion field method, a connection can be identified between a background noise level and acoustic power of a fire alarm for a noise level $L_{сум} \approx 75$dB as set out in the regulations

$$L_p = 10\lg\left(10^{7,5} - 10^{0,1L_\phi}\right) - 10\lg\left(\frac{\Phi}{\Omega r^2} + \frac{4(1-\alpha)}{\alpha S}\right). \qquad (8)$$

A good clearness performance also puts restrictions on the ratio of a background noise level and the sound of a fire alarm considering the equations (1)—(5) of the method of reverberation obstacles

$$L_\phi = 10\lg\left(\frac{TK_L(\varepsilon_{пр} + \varepsilon_{оп}^{50})/1{,}1 - \varepsilon_{оп}^{>50}}{\varepsilon_0}\right). \qquad (9)$$

Therefore the equations (8) and (9) make up a system of two equations with two unknowns; based on their solution, a maximum level of background noise $L_{\phi\,\max}$ and a minimum acoustic power of a fire alarm $L_{p\,\min}$ can be obtained.

Th equation (8) with the condition (1) can be solved using a numerical method as well.

It should be noted that at an average noise absorption coefficient for the premises of less than $\alpha_{\min}$ the numerator in (9) becomes negative and the system of the equations (8) and (9) has no solutions.

*Step 5.* Checking the inequality $L_\phi < L_{\phi\,\max}$.

A maximum level of background noise and a minimum acoustic power of a fire alarm provide a sound of 75 dB at the worst point. At a background noise level of less than $L_{\phi\,\max}$ background noise is not a considerable obstacle.

*Step 6.* If a level of background noise is over $L_{\phi\,\max}$, background noise becomes a consideravle obstacle for a signal and an acoustic power of a fire alarm should be over a minimum $L_{p\,\min}$. As background noise should be maintained proportional for a useful signal and obstacles (see expression (2)), acoustic power of a fire alarm should be increased to

$$L_p = L_{p\min} + L_\phi - L_{\phi\max}. \qquad (10)$$

*Step 7.* Calculation of a level of sound at the calculation point from a fire alarm according to the expressions (3)—(5).

*Step 8.* The fire safety regulations provide for a level of sound generated by a fire alarm should be 15 dB over a background noise level, i.e.

$$L_{on} - L_{\phi} > 15. \tag{11}$$

We assume this condition is excessive. If a sound of a fire alarm includes a direct and reflected components, this requirement applies for most cases.

*Step 9.* If the condition (6) does not hold true, the acoustic power of a source should be increased

$$L_p = L_p + 15 - \left(L_{on} - L_{\phi}\right). \tag{12}$$

*Step 10.* The following condition is checked

$$L_{on} - L_{\phi} > 15. \tag{13}$$

If this does not hold true, this means that at some points of the premises a total level of noises generated by a fire alarm nod background reach a threshold.

*Step 11.* If at some point of the premises, a total level of background noise and fire alarm noises is over 120 dB, there should be an analysis, some actions should be in place to reduce a level of noise followed by change in the initial data and design of the location of a fire alarm.

*Step 12.* A final check of the clearness of a signal using the expressions (1)—(5).

*Step 13.* If a signal is not sufficiently clear, an analysis has to be performed followed by changes in the initial data and a fire alarm design afterwards.

*Step 14.* The design guidelines are finally put together.

**Conclusions**

1. A method of designing a single fire alarm using a reverberation obstacle method for assessing the clearness of a signal.

2. The calculation of the parameters of a sound field of a fire alarm is performed using a diffusion field method of the statistical theory.

3. The choice of the method is due to a high accuracy of a diffusion model of a sound field in equally dimensional premises and possible simple analytical expressions.

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