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# DETERMINATION OF LIMIT ADMISSIBLE *A*-WEIGHTED NOISE EMISSION VALUES OF MACHINERY AND EQUIPMENT

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## ABSTRACT

The problem of technical standardization of noise emission values of machinery and equipment is considered as a problem of how to determine limit admissible values of sound power levels of machines by satisfactoring of which it is ensured the fulfillment of noise sanitary norms at operators stations when the scheme of machinery disposition in the room is specified. The system of linear algebraic equations for the limit admissible *A*-weighted sound power values of machines is derived. Some equations for the mean sound absorption coefficient $\alpha$ of a room where machines operate are proposed, which can be used when dealing with *A*-weighted quantities. The comparison of the $\alpha$ values calculated is done using the recommendations of ISO 3744 too, and the most suitable equation is found. As an example the limit admissible A-weighted sound power levels of curds production workshop equipment are calculated.

## INTRODUCTION

In the paper [1] a method for standardization of noise emission values of machinery and equipment is offered which is based on the solution of a reverse acoustic problem: to calculate the admissible values of sound power $P^{(ad)}$ of noise sources from the described normative values of sound intensity at operator station $I_{ad} = I_0{*}10^{0.1L_{ad}}$ ($L_{ad}$ is the noise standard value of sound pressure level, dB; $I_0$ is the reference value equal $10^{-12}$ W/m$^2$) taking into account a typical operating conditions of sound sources in a workshop (operation of a groupe of different equipment in a room at a time, a typical scheme of machines and operator stations location indicated in a workshop project, acoustic characteristics of a room). The method allows to determine the admissible noise emission limits (ANEL) of machines the meeting of which ensures the fulfillness of the noise sanitary norms in rooms of enterprises, needing no additional measures for reduction of noise affecting the operators.

One performs the calculations in octave frequency bands in which the admissible noise immission levels at operator places and the acoustic characteristics of a room are prescribed [2]. The problem is reduced to the solution of the system of linear algebraic equations

$$\sum_{i=1}^{n} a_{ji} P_i^{(ad)} = I_j = I_{ad}, \qquad j = 1,2,\ldots,n_W, \tag{1}$$

where $P_i^{(ad)}$ is the admissible sound power desired for the $i$-th noise source, $W$; $I_j$ is the sound intensity corresponding to the total noise at the $j$-th operator location, W/m$^2$; $n$ is the number of the noise sources operating at a time; $n_W$ is the number of operator stations in a room; $a_{ji}$ are the matrix system elements which consist of two components

$$a_{ji} = a_{ji}^{(dir)} + a_{ji}^{(ref)}, \tag{2}$$

first of them describes the contribution of the direct sound radiated by the $i$-th sound source at the $j$-th operator location, the second — the corresponding contribution of a reflected sound. Expressions for the components in Eq.(2) take into account the mutual disposition of the noise sources and the operator locations as well as room acoustic characteristics and are determined by adopted model of sound spreading in the room (upon the energy approach they are given, for example, in the reference book [2]).

The avalability of a priori information about the actual sound power values of noise sources makes it possible to determine their ANEL values more precisely and to optimize the $P_i^{(ad)}$. An idea and procedures of optimization are proposed in the papers [1,3]. It is required for their realization to know the noise emission data of the noise sources in octave frequency bands. In accordance with the International Standard ISO 4871 [4] a preffered noise emisson characteristic values of which shall be declared by manufactures or suppliers of machines is the $A$-weighted sound power level. In such a case, it is needed for performing the optimization procedures to have a system of equations similar to system (1) in $A$-weighted sound power $P_A^{(ad)}$ of noise sources as well as a mathematical expression for determination of the mean sound absorption coefficient $\alpha_A$ of a room, which allows to operate directly with $A$-weighted quantities when the reflected sound contribution is considered. These questions are settled in this paper.

## DERIVATION OF SYSTEM OF EQUATIONS FOR $A$-WEIGHTED SOUND POWER

The $A$-weighted sound power $P_A$ may be determined using the sound power values $P_k$ in the octave frequency bands by the equation

$$\sum_{k=1}^{N} A_k P_k, \quad A_k = 10^{0,1K_{Ak}} \tag{3}$$

where $K_{Ak}$ is the $A$-weighting characteristic of sound level meter, dB, [5]; N is the number of the octave bands summerized (for the range normalized N=8).

Let us multiple the two parts of the equations of system (1) described for all eight octave frequency bands by the $A_k$ values which correspond to the each octave frequency band, and sum over $k$. As the result we obtain the system

$$\sum_{i=1}^{n} a_{ji} P_{Ai}^{(ad)} = I_{Aad}, \quad j = 1, 2, \ldots, n_W, \tag{4}$$

where $I_{Aad}$ is the $A$-weighted sound intensity calculated from $I_{adk}$ values in octave frequency bands,using the equation similar to Eq.(3); $a_{ji}$ are given by Eq.(2) in which the second component is determined by equation

$$a_{ji}^{(ref)} = \frac{\sum_{k=1}^{8} a_{jik}^{(ref)} A_k P_{ik}^{(ad)}}{P_{Ai}^{(ad)}}, \tag{5}$$

and the $a_{jik}^{(ref)}$ values depend on the sizes and the shape of a room as well as on the values of mean sound absorption coefficient in octave frequency bands [2].

When the room is a commensurate room the $a_{jik}^{(ref)}$ values do not depend on the locations of operator stations and sound sources in the room and Eq.(5) can be rewritten as

$$a_{ji}^{(ref)} = \frac{\sum_{k=1}^{8} a_{k}^{(ref)} A_k \sum_{i=1}^{n} P_{ik}^{(ad)}}{\sum_{i=1}^{n} P_{Ai}^{(ad)}}, \tag{6}$$

Using Eqs.(5) and (6) one can deal with system (5) similar to system (1) and perform the optimization of the $A$-weighted sound power values of noise sources by the algorithms described in the papers [1*], 3]. One can use as $I_{ad}$ not only the sum of the admissible $A$-weighted values of sound intensities in octave frequency bands but also the admissible $A$-weighted sound intensity equal $10^{0,1L_{Aad}}$ which is less by factor 1,5 (1,8 dB).

## DETERMINATION OF THE MEAN SOUND ABSORPTION COEFFICIENT

The mean sound absorption coefficient $\alpha$ is the one of the acoustic characteristics of a room which are used when calculating the reflected sound contribution in the room.

In a case of a commensurate room $a^{(ref)} = 4(1 - \alpha)/(\alpha\ S_V)$($S_V$ is the total area of the enclosed surfaces of the room, m$^2$) [2] and one can obtain from Eq.(6) the expression for mean sound absorption coefficient $\alpha_A$ which allows to perform the calculation with the $A$-weighted quantities directly

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*)The misprint is made in Eq.(9) of the paper [1]: $I_{j_{q+1}}^{(M)} / a_{j_{q+1}q+1}$ will be insteed $I_{j_{q+1}}^{(M)}$.

$$\alpha_A = \frac{1}{1 + \sum_{k=1}^{8} \frac{1-\alpha_k}{\alpha_k} A_k \sum_{i=1}^{n} P_{ik}^{(ad)} / \sum_{i=1}^{n} P_{Ai}^{(ad)}}, \qquad (7)$$

where $\alpha_k$ is the mean sound adsorption coefficient in a room in the $k$-th octave frequency band.

For a source of the pink noise, which is recommended in ISO 3382 [6] when measuring the reverberation time in a room, one can obtain from Eq.(5) the following expression

$$\alpha_A = \frac{1}{1 + \sum_{k=1}^{8} \frac{1-\alpha_k}{\alpha_k} A_k / \sum_{k=1}^{8} A_k}, \qquad (8)$$

At last, directly from system (4) the equation identical Eq.(7) can be derived

$$\alpha_A = \frac{1}{1 + 0{,}25 S_V (I_{Aad} - \sum_{i=1}^{n} a_{ji}^{(dir)} P_{Ai}^{(ad)}) / \sum_{i=1}^{n} P_{Ai}^{(ad)}}. \qquad (9)$$

Eq.(8) conforms to the common practice of the sound absorption determination in a room [6]. The mean sound absorption coefficient value calculated by it characterizes the own acoustic properties of a room and does not depend on the noise emission data of noise sources operating in it. Use of Eq.(7) or Eq.(9) can however give more precise ANEL values since they are, to a sertain extent, taking into account a spectrum character of the noise which the noise sources create in a room. Nevetheless, the differences in $\alpha_A$ values calculated by Eq.(7) and Eq.(8) should be insignificant when a number of noise sources operate in a room, since a spectrum of the total noise is similar to the spectrum of pink noise by reason of statistical independence and different spectra of noise sources.

To illustrate this consideration we compare the results of $\alpha_A$ calculations by Eq.(7) and Eq.(8) for a curds production workshop [7] considered as an example below. The composition and disposition of the noise sources in the room are shown in Fig.1. The $\alpha_A$ value calculated by Eq.(7) is 0,093 and by Eq.(8) — 0,105. The dufference is 13% only. When using the ISO 3744 recomendations [8] $\alpha_A = 0{,}15$ and differs from the value calculated by means of Eq.(7) by 61%. It is therefore best to apply more simply Eq.(8) to practical use.

## ANEL CALCULATION EXAMPLE

As an example we calculate the limit admissible sound power levels of the equipment for curds production [7] mounted in a room of the right-angled shape 14,5*14,0*6,0 m as it is showed in Fig.1. The sound sources are numbered sequentially. There is one operator station near the control desk in the room.

The calculation is made by means of the updated version of the program PDHX [9] which allows to calculate both the limit admissible sound power levels in octave frequency bands and the $A$-weighted values. The results are presented as a diagramme in Fig.2.

The comparison of the $A$-weighted sound power levels calculated (columns 2 in Fig.2) with the actual (measured [7]) values (columns 1) shows that the actual sound power levels of twelve machines exceed their ANEL values abtained as the solution of system (5) and these machines should be accepted as noisy dangerous ones in the operating conditions considered (the corresponding notion is introduced in the draft of new edition of GOST 27409 [10]). The noise reduction required is from 1 dB (for machine 2) to 23 dB (for machine 8). The attempts to apply the optimization procedures [1] and to increase the ANEL values by transfering the operator station to the region with the lowerest value of the sound level in the room in according with the algorithm described in the paper [11] does not better the situation. The ANEL values obtained with the new location of the operator station (position a′ in Fig.1) increase from 0,3 to 2,4 dB only. The reason of a such phenomenon is in a high liveness of the room and a great portion of the reflected sound in the shop because of its small dimensions and high reflecting abilities of surrounding surfaces [9], that is confirmed by the small value of the mean sound absorption coefficient calculated in the previous clause.

The best plan to be followed in this case to modify the acoustic environment by lowering of the extent of the reverberation sound field in the room. The results of the repeated calculation of the ANEL values of machines under conditions when the ceiling and a part of the walls (the total area is 448 $m^2$) would be covered by the sound absorption lining are presented in Fig.2. The lining consists from the superthin glasfibre 50 mm thick with density 15 $kg/m^2$, the glascloth of the type Э3-100 and cutstretched skinplat 2 mm thick and 74% perforated. The values of sound absorption coefficient of this lining are given in the guide [12]. The $\alpha_A$ value in the shop rises under this covering by more than six times and is 0,631 when using Eq.(7) and 0,684 when using Eq.(8).

Under the new operating conditions the ANEL values rise from 3 dB (machine 4) to 9 dB (machines 13 and 14) in the case of the initial position of the operator station (position a in Fig.1). After transfering the operator station in the position a′ (the oprimum position in the region with the lowerest value of sound level) we obtain the additional increasing from 2 dB (machines 13, 14) to 10 dB (machine 4). As the result the ANEL values are in excess of the actual sound power levels only for four machines (number 6, 8, 14 and 15 — compare the columns 1 and 4 in Fig.2). Performing the optimization procedure makes it possible to exclude the 6-th, 14-th and 15-th machines of the list of noisy dangerous ones, and it is required to reduce the noise of separator 8 by 6 dB only.

In closing we emphasize that the $L_{WA}^{(ad)}$ value calculated for the most power 8-th noise source is 99,2 dB(A) when using Eq.(7) or 100,1 dB(A) when using Eq.(8) and is practically coincident with the value 99,8 dB(A) which is obtained by the energy summation of the admissible $A$-weighted sound power levels in octave frequency bands. This result supports to the conclusion made in the previous clause of the possibility to use Eq.(8) for the mean sound absorption coefficient calculation.

## CONCLUSIONS

The approach considered makes it possible to calculate the admissible $A$-weighted noise emission limits of machinery and equipment using the optimization procedures described in the paper [1] if it is available the actual values of the $A$-weighted sound power levels only.

The equations proposed for mean sound absorption calculation allows one to obtain the *A*-weighted acoustic characteristics of a room directly. Eq.(8) may be recomended as the more simplier for practice use. The *A*-weighted ANEL values may be calculated by using of this equation with a sifficient accuracy.

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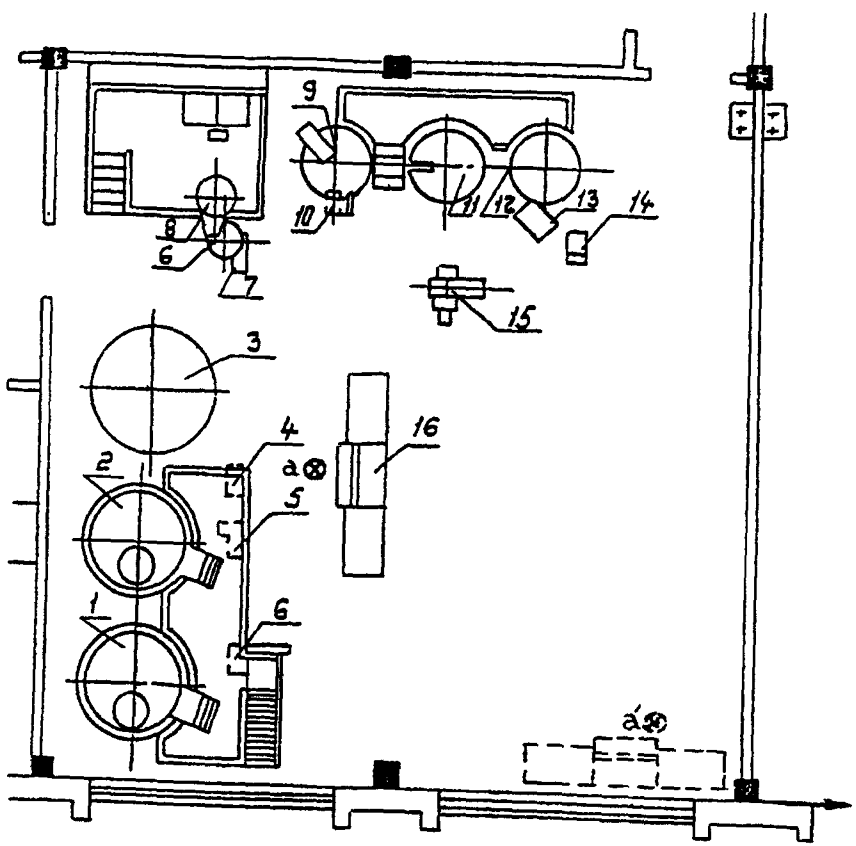


**Fig.1. Scheme of curds production equipment disposition in a workshop.**
1, 2 — aseptic reservoir B6-OKM/1; 3 — reservoir A1-OMC/1; 4, 10 — pump 36-3C-3,5-10; 5 — pump P8-ONB; 6, 14 — pump 50-3C-7,1-20; 7, 13 — pump for curds P8-OND; 8 — separator for curds A1-ODB/3; 9 — pool for cream B6-ODB/10; 11, 12 — reservoir for curds B6-ODB/6; 15 —mixer B6-ODB/5; 16 — control desc; a — operator station initial position; a' — operator station optimum position.

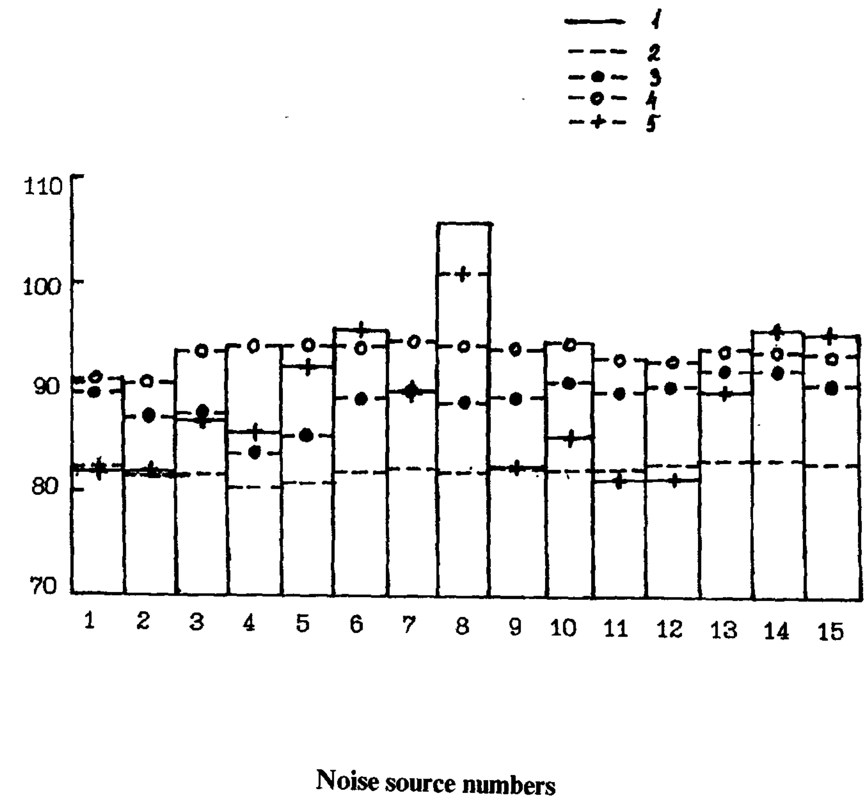


**Fig.2.** Actual (1) and limit admissible (2-5) *A*-weighted sound power levels of curds production equipment; 2 — with unlined ducts; 3 — with sound absorbing lining and initial position of operator station; 4 — the same as 3 after operator station transfering; 5 — the same as 4 after optimization procedure performing.