Experience in using regulations when performing acoustic designs in graduate qualification work

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Abstract. This work is devoted to the problems of acoustic design that a future specialist may face in the field of labor protection. The article provides a review of existing noise protection regulations, including those that have lost their force due to the emergence of a new set of rules (Sanitary Regulations) but contain useful information. Using the example of the acoustic design of a machine shop (within the framework of the graduate qualification work (GQW), the article discusses the difficulties of using existing literature and regulations, as well as the inconsistencies and contradictions between them. The material of the article can be used in the development of methodological training materials for technical specialists in the field of technosphere safety.

Knowledge of the expected sound pressure levels (or sound level) at the starting point, occurring in the work area and the environment during some technological processes [17,18,23], is necessary even at the design stage of production processes to prevent exceeding the standard values, and to develop measures to reduce noise. For this purpose, an acoustic design is carried out for specific industrial premises in which the technological equipment is located [1, 2, 3, 4].

In the absence of experience in carrying out such designs, the problem of finding a method of acoustic design may arise, since there is no separate regulation or guidelines that would cover all stages of its implementation. A large number of textbooks and articles on acoustic design, as a rule, are based on the design experience of the authors of the works and may contain inaccuracies or assumptions. In particular, the problem of finding the necessary literature arises during the performance of the graduate qualification work GQW), performed by future specialists in the field of labor protection.

Noise protection regulations

Currently, the need and the procedure for conducting acoustic designs to assess the noise regime in industrial premises of buildings is regulated in sufficient detail by Sanitary Regulations (SR) 51.13330.2011 “Noise protection. The updated edition of Building Codes and Regulations 23-03-2003 (with Amendment No. 1) ”, as well as the reference book by E.Ya. Yudin and in a series of contributions [2, 5]. But after reading these sources, the question arises: where can we get the necessary calculation formulas to determine the sound pressure levels or sound level? The fact is that SR 51.13330.2011 [1], according to its abbreviation (SR is a set of rules), contains only a list of rules and recommendations that must be taken into account when calculating, and its mathematical
description is missing. This is due to the world's tendency to simplify the noise rationing process. For this purpose, integral standard values are increasingly used in new regulations, such as sound level $L_{PA}$, dBA, equivalent sound level $L_{PA}^{eq}$, dBA, corrected sound power level $L_{wA}$, dBA, (as a standard characteristic of a sound generation source). At the same time, spectral normalization is not recommended for use, or a reference is given that it is auxiliary. It makes rationing easier.

However, for technical specialists, a significant task is not only to answer the question: does the noise correspond to the norm at the control point, but also to make an acoustic design, to develop protection measures against noise, to link the parameters of the working process of the noise source with the emission of noise, etc. These problems cannot be solved without knowing the spectral characteristics. Moreover, it is very important to solve the problem of linking the spectral characteristics of the design with the standard integral parameters of modern regulations.

The experience of solving the above tasks is discussed in this article. Acoustic design, according to [1], has several stages: identification of noise sources and determination of their noise characteristics; selection of calculated points; determination of expected noise levels at starting points; determination of the required noise reduction based on the comparison of the expected noise levels with the permissible noise levels; development of measures to ensure the required reduction of noise levels.

But SR 51.13330.2011 does not help to carry out all of the above calculation stages. To determine the expected noise levels and the required reduction of noise levels, it is necessary to use an invalid document, however, containing the necessary information for the calculation - Building Codes and Regulations 23-03-2003 "Noise protection", the updated edition of which is SR 51.13330.2011. Building Codes and Regulations 23-03-2003 [6] contains not only recommendations for the calculation, but also its mathematical description (how to determine the expected noise levels at the starting point and their required reduction). That is why, when fulfilling the requirements specified in SR 51.13330.2011, we relied on calculations according to Building Codes and Regulations 23-03-2003.

The acoustic design is carried out for each of the octave bands that are significant from the point of view of the radiated noise, with the corresponding geometric mean frequencies. In our case, the calculation was carried out at frequencies of 63, 125, 250, 500, 1000, 2000, 4000, 8000 Hz.

**Example: Acoustic design of a machine shop in GQW**

To illustrate other difficulties arising in the course of the calculation, we will perform an acoustic design of the machine shop. The room has the following dimensions: 40×16×4. It has 8 machine tools (2 lathes, 2 millings, 2 surface grinders, 1 circular grinder, and 1 sharpening machine), which are the main sources of noise in the machine shop under consideration.

To estimate the expected noise levels in the machine shop, we will select a starting point in the center of the room at a height of 1.5 m from the floor. Figure 1 shows the machine shop plan with the designation of the starting point and the distances to it from each noise source. The $r_i$ values will be given in the calculation itself.

![Figure 1. Scheme of placement of workplaces with the designation of the starting point](image-url)
To determine the noise characteristics of machines, we will use the "Catalog of the noise characteristics of technological equipment" [7], which is a guide to the invalid Building Codes and Regulations II-12-77 "Noise protection" (this document is the "predecessor" of the document [6]). The noise characteristics of more modern machines must be looked at in their passport.

In [7], the octave band sound power levels are indicated for each machine model. As an example, Table 1 shows the noise characteristics of a lathe.

| Equipment, model (dimensions) | Octave band sound power levels $L_{wp}$, dB, with geometric mean frequencies, Hz |
|------------------------------|---------------------------------------------------------------------------------|
| Lathe, 1M10A (1460×870×1450) | 90 95 100 102 104 101 94 89                                                |

Next, we need to determine the permissible sound pressure levels for this room (machine shop). The regulations are based on the principle of the limitary spectrum (LS). The noise limit is a set of standard sound pressure values at the following standard geometric mean frequencies: 63, 125, 250, 500, 1000, 2000, 4000, and 8000 Hz. The number of the limitary spectrum is numerically equal to the octave band sound pressure level with a geometric mean frequency of 1000 Hz (for example, LS-75) [8].

Here there are contradictions between the values in the documents SR 51.13330.2011 [1] and Sanitary Norms 2.2.4/2.1.8.562-96 [9], and both standards are valid. Permissible sound pressure levels according to these documents are shown in Table 2.

| Type of labor activity, workplace | Octave band sound pressure level $L_s$, dB, with geometric mean frequencies, Hz |
|----------------------------------|---------------------------------------------------------------------------------|
| Premises with permanent workplaces of production facilities, areas of enterprises with permanent workplaces (according to [1]) Performance of all types of work at permanent workplaces in the production facilities and on the territory of enterprises (according to [9]) | 63 125 250 500 1000 2000 4000 8000 |
|                                  | 90 82 77 73 70 68 66 64                                                        |
|                                  | 95 87 82 78 75 73 71 69                                                        |

This contradiction leads to the following conclusion: the comparison of the calculated values with the standard is a check of the compliance of the values with a certain current document, and not specifically with existing norms. It turns out that the choice of standard values depends on the person making the calculation. Consequently, in the report on the acoustic design, it is not possible simply to make an unambiguous conclusion about whether or not the sound pressure levels (or sound level) comply with the standards: it is necessary to clarify which document corresponds to the standard values or not.

Since both [1] and [9] are valid documents, we can choose values according to any of these standards. But more often, when designing production facilities, ones are guided by the regulations from Sanitary Norms 2.2.4/2.1.8.562-96 (where LS-75 is used), therefore, the values will then be compared with the second row of Table 2.

So, let us look at the main stages of the calculation.

The expected octave sound pressure levels $L_p$, dB, at the starting point of the machine shop when operating one noise source should be determined by the formula:
\[ L_p = L_w + 10 \log \left( \frac{\chi \Phi}{\Omega r^2} + \frac{4}{kB} \right), \]  

where \( L_w \) – is the octave sound power level, dB;
\( \chi \) – is a coefficient that takes into account the effect of the near field in cases where the distance \( r \) is less than twice the maximum size of the source: \( r < 2l_{\text{max}} \) (this ratio is less than 2 for surface grinding and milling machines in the center of the machine shop, since for them it is equal to 1.4, then according to [1] from the table: \( \chi = 1.37 \));
\( \Phi \) – is the directivity factor of the noise source (for sources without radiation directivity \( \Phi = 1 \)), for more details on the directivity factor, see [10];
\( \Omega \) – is the spatial angle of source radiation, rad (we accept \( 2\pi \) since the source is on the floor and radiates into the hemisphere); hemisphere is the source on the floor);
\( r \) – is the distance from the acoustic center of the noise source to the starting point, m (determined by Figure 1);
\( k \) – is the coefficient that takes into account the violation of the diffuseness of the sound field in the room (taken according to [1], depending on the average coefficient of sound absorption \( \alpha_{\text{av}} \));
\( B \) – is the acoustic constant of the room, \( m^2 \), which is determined by the formula:
\[
B = \frac{A}{1 - \alpha_{\text{av}}},
\]  

where \( A \) – is the equivalent sound absorption area, \( m^2 \);
\( \alpha_{\text{av}} \) – is the average sound absorption coefficient.
In turn, the equivalent sound absorption area is determined by the formula:
\[
A = \sum_{i=1}^{n} \alpha_i S_i + \sum_{j=1}^{m} A_j n_j,
\]  

where \( \alpha_i \) – is the sound absorption coefficient of the \( i \)-th surface;
\( S_i \) – is the area of the \( i \)-th surface, m\(^2\);
\( A_j \) – is the equivalent sound absorption area of the \( j \)-th piece absorber, m\(^2\);
\( n_j \) – is the number of \( j \)-piece absorbers, pcs.
Since there are no piece absorbers in the considered machine shop, formula (3) will take the form:
\[
A = \sum_{i=1}^{n} \alpha_i S_i.
\]  

The average sound absorption coefficient is determined by the formula:
\[
\alpha_{\text{av}} = \frac{A}{S_{\text{en}}},
\]  

where \( S_{\text{en}} \) – is the total area of the enclosing surfaces of the room (the area of the walls, ceiling, and floor for a given machine shop: \( S_{\text{en}} = 1728 \text{ m}^2 \)).
The values of the sound absorption coefficients \( \alpha_i \) are determined depending on the materials of the surfaces of the room. The \( \alpha \) values can be determined, for example, from the catalog of manufacturers of sound-absorbing materials. The coefficients selected according to [11] are given in Table 3.

| Material                                    | Sound absorption coefficient \( \alpha_i \) in octave bands with geometric mean frequencies, Hz |
|---------------------------------------------|------------------------------------------------------------------------------------------|
|                                             | 63  | 125 | 250 | 500  | 1000 | 2000 | 4000 | 8000 |
| Brick wall plastered and painted with oil paint (walls) | 0,01 | 0,01 | 0,01 | 0,02 | 0,02 | 0,03 | 0,03 | 0,03 |
| Concrete (floor)                            | 0,01 | 0,01 | 0,01 | 0,02 | 0,02 | 0,04 | 0,04 | 0,04 |
| Rough lime plaster (ceiling)                | 0,025 | 0,025 | 0,045 | 0,060 | 0,085 | 0,043 | 0,058 | 0,058 |
Having calculated all the missing parameters for formula (1) by formulas (4), (5), and (2), it is possible to determine the octave sound pressure levels \( L \) at the starting point of the machine shop. For example, Table 4 shows the obtained values for a lathe.

**Table 4. Sound pressure levels \( L \) from each noise source at the starting point.**

| Workplace       | Octave band sound pressure level \( L \), dB, with geometric mean frequencies, Hz |
|-----------------|-----------------------------------------------------------------------------------|
| Lathe \((r_1=6.3 \, \text{m})\) | 63 125 250 500 1000 2000 4000 8000                                               |

The octave sound pressure levels at the starting point of a room with multiple noise sources are determined by the formula:

\[
L_{p\, \text{sum}} = 10 \log \sum_{i=1}^{n} 10^{\frac{L_{pi}}{10}},
\]  

(6)

where \( L_{pi} \) – are the sound pressure level generated by each sound source (machine tool) at the investigated point in space, dB.

The required reduction in octave sound pressure levels \( \Delta L_{\text{req}} \) at the starting point of the machine shop from each noise source should be determined by the formula:

\[
\Delta L_{\text{req}} = L_{p\, \text{sum}} - L_{p\, \text{per}},
\]  

(7)

where \( L_{p\, \text{sum}} \) – are octave sound pressure levels, dB; \( L_{p\, \text{per}} \) – is the permissible octave sound pressure level, dB (table 2).

The sound pressure levels \( L_{p\, \text{sum}} \) at the starting point and the required noise reduction \( \Delta L_{\text{req}} \), calculated by formulas (6) and (7), respectively, for all considered noise sources are presented in Table 5.

**Table 5. Sound pressure levels at the starting point.**

| Octave bands with geometric mean frequencies, Hz | 63 | 125 | 250 | 500 | 1000 | 2000 | 4000 | 8000 |
|-------------------------------------------------|----|-----|-----|-----|------|------|------|------|
| \( L_{\text{sum}} \), dB                       | 85 | 90  | 94  | 94  | 95   | 92   | 85   | 80   |
| Permissible sound pressure levels \( L_{\text{per}} \) according to [9], dB | 95 | 87  | 82  | 78  | 75   | 73   | 71   | 69   |
| \( \Delta L_{\text{req}} \), dB                 | -  | 3   | 12  | 16  | 20   | 19   | 14   | 11   |

Thus, as a result of this spectral calculation, as can be seen from Table 5, it is necessary to take appropriate measures to reduce noise at frequencies in the range of 125 ... 8000 Hz.

Let us proceed following the requirements of [1, 12, 19, 21, 22] to the normalization of noise by integral parameters, which is based on the measurement of sound levels on the "A" scale of the sound level meter (in dBA). "A" frequency response simulates the sensitivity curve of the human ear, which is characterized by reduced sensitivity at low frequencies. When measuring the noise level, a weighting filter is used, which makes it possible to take into account the different sensitivity of a person's hearing to noise at different frequencies.

Determination of the sound level at known sound levels in octave frequency bands will be sought [6] by the formula:

\[
L_{PA} \equiv 10 \log \left( \sum_{i=1}^{n} 10^{0.1(L_{pi} - \Delta L_i)} \right),
\]  

(8)

where \( L_{pi} \) – is the sound pressure level, dB; \( \Delta L_i \) – is the A-weighting, dB (values are given in [6]).
The necessity to introduce A-weighting is due to the discrepancy between the loudness levels perceived by the human ear and the sound pressure levels at frequencies other than perception at the standard frequency of 1000 Hz [13, 14, 15, 16].

Let us determine the sound level at the starting point of the machine shop. The resulting value is shown in Table 6.

| Value                        | Octave bands with geometric mean frequencies, Hz | Sound level, dBA |
|------------------------------|-------------------------------------------------|------------------|
| Sound pressure level, dB     | 63  125  250  500  1000  2000  4000  8000 - | 85  90  94  94  95  92  85  80 - |
| A-adjusted sound level, dBA  | -  -  -  -  -  -  -  -   99 |

According to [9], the sound level norm when performing all types of work at permanent workplaces in industrial premises and on the territory of enterprises is 80 dBA. Since the calculated value of the sound level is 99 dBA, this confirms the above conclusion with the spectral approach that the noise in the machine shop does not meet sanitary requirements and it is necessary to give recommendations for its reduction.

For a machine shop, the most suitable noise reduction methods are:

- sound insulation of the noise source;
- acoustic treatment of the room, that is, cladding of the enclosing surfaces of the room (ceiling and part of the walls) with sound-absorbing materials.

Sound insulation has become quite widespread among the methods of noise reduction. It is the use of soundproofing barriers in the form of walls, partitions, screens, casings, cabins, and so on. The physical essence of such barriers is that most of the energy falling on the fence is reflected from specially made massive fences made of dense materials (metal, wood, plastic, concrete, etc.) and only a small part penetrates through the fence.

Similarly to the acoustic design of a room, the requirements and recommendations for the calculation of soundproof structures are given in [1, 20], and in [9, 19] the stages of its implementation are indicated with a mathematical description. The required values of the sound insulation of materials and the sound absorption coefficients of the cladding can be found, for example, in [9] or in the catalogs of manufacturers of sound-absorbing and sound-insulating materials. The corresponding recommendations were developed in the next section of the GQW and are not included in this article.

For a technician, in addition to modern SR, it is necessary to use the experience already accumulated in the previous technical and sanitary documentation, which significantly more fully illuminates the physical processes of generation and distribution of noise, and also contains more detailed recommendations for its reduction. It should also be noted that to develop such recommendations, it is necessary to know (or be able to calculate) precisely the spectral characteristics of noise sources at the corresponding starting points. On the other hand, since modern standards provide for integral regulation, the relationship between the integral and spectral parameters of noise is important, one of the variants of which is considered in this work. We believe that our experience can be useful in solving acoustic problems in GQW for students of technical universities.

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