Statistical analysis of acoustic noise in the industrial and living areas

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Abstract. In this article the algorithm of statistical analysis was considered providing the representation of the results of the measurement figures on the acoustic noise in the industrial zones and adjacent living areas in the form of time in percentage for the course of which the sound level was exceeded at some frequency at different time moments. The explanation of the analysis principle was mentioned. On the basis of the experimental data on the character of the acoustic noise in the area of the city of Murom curves were obtained reflecting the distribution of the noise levels by the action time.

1. Introduction
Among the hazards of the developed machine-building production, not the least is the acoustic noise that is present typically in indoor areas with active process of mechanical production. However, depending on the intensity of work of the enterprise, the vastitude of the territory and the availability of open areas with active construction and traffic, the acoustic noise may be a very influencing factor on open spaces too. If the enterprise is located in urban realm and not equipped with good protection against the propagation of noise into the urban area, this can be a problem for the entire urban agglomeration. Thus, from the problem of worker safety and health within the enterprise, the noise may become an environmental problem of a big urban land.

Of late acoustic noise has become one of the main problems of the modern urbanized space occupying the third place by its importance among all the city pollutants [1]. So the tasks of protecting a man within the frame of industrial or residential zones are becoming more and more important [1,2]. Thereby the demands of creating the systems of monitoring of acoustic and noise pollution in such areas become more and more important. Due to it the necessity to create the systems of acoustic and noise monitoring systems in such areas increases, which will give an opportunity to create the noise map of the city, to forecast the distribution of noise in the residential areas and to take effective managerial decisions to protect the population from noise [3].

Together with it because of the fact that acoustic noise in the industrial or residential area does not belong to stationary processes there is a problem of the reliability of the formed noise map, the correspondence of the obtained data not to instant but to relatively constant manifestations of acoustic and noise pollution. It is evident that it is impossible to perform the monitoring without any statistical treatment of the results with the purpose of developing prediction estimates with respect to the prediction estimates of this noise distribution in the residential areas. The solution of this task can be performed by using the abilities of the system of control and the information system in the monitoring system [4,5]. Another problem in this direction is the choice and the substantiation of creation the algorithm of the data treatment.
In this article an algorithm of statistical analysis was considered giving the results of processing the measurement information in the form of time expressed in percentage, during which each sound level was exceeded at this frequency at different time moments.

2. The possibilities of the statistic treatment of the measurement results

In [6] there is a method of determining the reliability and precision of the noise map based on the combination of the analysis and mathematical statistics. Separate results of measuring the city noise \( L = x_{ij} \) are given in the form of the matrix of the values \( M(x_{ij}) \), in the lines of which in the horizontal direction there are the values \( x_i \) and \( i \) in different space points with the total amount of \( n \), and in the vertical direction, in the columns, there are \( x_j \) values at different time moments \( j \) with the total number \( m \).

If the random deviations of the measurement \( x \) in the space do not depend on the random deviations of this value, then the matrix of the values \( M(x_{ij}) \) is transformed into the value matrix \( M(x_{ij} + x_{ij}) \), where the value \( x_i \) depends only on the space measurements and the value \( x_j \) depends only on time measurements. Using this method it is possible to express the average value, the dispersion of the space deviations, the dispersion of the time deviations, the dispersion of the deviations in space and in time.

The fault of this method with respect to middle-size and big cities is that for the reliability value \( P = 0.95 \) and the precision value at the level of \( \Delta L = 1 \text{dB} \) for one street with the length of 2 km it is necessary to perform the measurement \( m = 24 \) in \( n = 10 \) space points, i.e. it is necessary to make \( n \cdot m = 240 \) measurements of the sound level per day. While performing the measurement ten times per month the number of the measurements of the sound levels per year in one street will be \( 240 \cdot 10 \cdot 12 = 28800 \), which is rather difficult for middle or small cities because of the high cost of the work.

3. Time analysis of statistic distribution

Let us consider the so-called analyzer of the statistic distribution. In this case it possible to register the relative time part, during which the measured noise level was within the range of each scale step situated, for example, in 1 dB. The results of such measurements show during which part of the full time each of the sound pressure levels was exceeded.

In the calculating algorithm for the statistic distribution of the matrix acoustic noise

\[
M(L_{ij}) = \begin{pmatrix}
L_{11} & L_{12} & L_{1j} \\
L_{21} & L_{22} & L_{2j} \\
... & ... & ...
\end{pmatrix}
\]

we use an intermediary matrix of the statistic distribution, in the lines of which in the horizontal direction there are distributed levels of sound pressure \( l \) with the total amount \( k \) with equal intervals \( l' \) between the values

\[
M(P_{ij}) = \begin{pmatrix}
P_{11} & P_{12} & P_{1j} \\
P_{21} & P_{22} & P_{2j} \\
... & ... & ...
\end{pmatrix},
\]

where \( P_{ij} \) is the indicator of the statistic noise distribution expressed in percentage.

The distributed levels of the sound pressure \( l \) are chosen as per the required measurement scale with the step of \( l' \), the range of each includes the minimum and the maximum values \( L_{ij} \) of matrix \( M(L_{ij}) \).

To create an intermediary matrix it is necessary to calculate the values of the variables \( P_{ij} \) for the concrete column \( j \) using the algorithm:
If the identities \( \frac{l}{P_{ij}} \leq L_{ij} \) are correct, then \( P'_{ij} = P_{ij} + 1 \);

If \( l \leq L_{ij} \) is incorrect then \( l = l + \frac{l_{\max}}{n} \), \( i = i + \frac{l_{\max}}{n} \);

if \( P'_{ij} \leq m \) is incorrect, and \( l = L_{ij} \) is correct then \( P_{ij} = \frac{P'_{ij}}{n} \cdot 100\% \),

where \( P_{ij} \) shows the number of elements in the line \( i \) of matrix \( M(L_{ij}) \) exceeding the current scale value \( l \); \( l_{\max} \) and \( i_{\max} \) – the maximum matrix values \( M(P_{ij}) \) and \( M(L_{ij}) \) respectively, while the equation \( l_{\max} \leq i_{\max} \) must be observed.

And then using the intermediary matrix \( M(P_{ij}) \) the matrix of the full statistic distribution \( M(l_{Pj}) \) is calculated, in the horizontal lines of which there are values expressing the time \( P=1...100 \) expressed in percentage during which each of levels \( L_{ij} \) in the column \( j \) of the matrix \( M(L_{ij}) \) was exceeded with the total number \( \tau=100 \), in the vertical direction in the columns, the amplitude and frequency responses at different frequencies \( j=6...10000 \) (Hz) with the total number \( m=1000 \):

\[
M(P_{ij}) = \begin{pmatrix} P_{11} & P_{12} & \cdots & P_{1j} \\ P_{21} & P_{22} & \cdots & P_{2j} \\ \vdots & \vdots & \ddots & \vdots \\ P_{n1} & P_{n2} & \cdots & P_{nj} \end{pmatrix}, \quad M(l_{Pj}) = \begin{pmatrix} l_{11} & l_{12} & \cdots & l_{1j} \\ l_{21} & l_{22} & \cdots & l_{2j} \\ \vdots & \vdots & \ddots & \vdots \\ l_{m1} & l_{m2} & \cdots & l_{mj} \end{pmatrix}.
\] (3)

It is the most convenient method to use distribution with the values \( P=1; 10; 50; 90; 99 \) (%), where \( P=1 \) gives an idea about the maximum distribution of the noise level, \( P=10 \) – is the characteristic high level; \( P=90 \) – shows the noise level, so the level to which the noise is reduced in case of a temporary quiet period. The difference between the values \( P=10 \) and \( P=90 \) shows in what range at that place the noise level fluctuates. At that the noise indicator equalling to 10% is widely used while measuring and predicting the transport noise in many countries it is the basic characteristic showing the level of the acoustic and noise pollution of the territory. Usually the transport noise fluctuates in a concrete way so the level \( P=10 \) is a rather satisfactory noise indicator though it represents a statistic picture only partially.

So, we shall get a statistic distribution of the noise levels in case of significantly fluctuating noise climate in the form of matrix \( M(l_{Pj}) \), where \( P=1; 10; 50; 90; 99 \) (%):

\[
M(l_{Pj}) = \begin{pmatrix} l_{11} & l_{12} & \cdots & l_{1j} \\ l_{01} & l_{02} & \cdots & l_{0j} \\ l_{501} & l_{502} & \cdots & l_{50j} \\ l_{901} & l_{902} & \cdots & l_{90j} \\ l_{991} & l_{992} & \cdots & l_{99j} \end{pmatrix}.
\] (4)

In Fig. 1 there is a graph of the statistic distribution of one of the measurements of the street noise \( M(l_{Pj}) \), where \( j=6...10000 \) (Hz), with the total amount \( m=1000 \).

From the figure it is possible to see that the difference between the values \( P=10 \) и \( P=90 \) showing in which range at that place \( j \) the noise level fluctuates is from 35 to 45 dB. It says that at that place unstable noises prevail with the duration from 2 to 5 sec.

To evaluate the influence of the acoustic noise on the surrounding territory it is necessary to consider the distance, at which the concrete acoustic signal spreads characterizing the exposure area. So for the statistically distributed noise \( M(l_{Pj}) \) it is necessary to determine the exposure zone. For this purpose taking into account the correcting (meteorological) data it is necessary to determine the attenuation ratio of the clear tone sound in the atmosphere \( M(\alpha_{f}) \).
In its turn the exposure zone of the acoustic noise \( M(l_{pj}) \) can be characterized by the distance \( S \) from the point of its source to the point, where the level of the acoustic signal is not more than some zero threshold \( Q \), which, for example, can be equal to the threshold of hearing for the average human ear (GOST R ISO 226-2009 «Acoustics — Normal equal-loudness-level contours») or the values in the sanitary norms and rules.

This threshold can be represented as a matrix \( M(l_j) \) and calculating the exposure zone \( S_{pj} \) of the acoustic noise in free space. So, there are matrixes \( M(\alpha_j) \) and \( M(Q_j) \) have the type

\[
\left\{ \begin{array}{c} \alpha_1 \\ \alpha_2 \\ \alpha_j \end{array} \right\}
\quad \text{and} \quad
\left\{ \begin{array}{c} Q_1 \\ Q_2 \\ Q_j \end{array} \right\}.
\]

Figure 1. Statistic distribution of acoustic noise \( M(l_{pj}) \)

The free space \( S \) in the form of the distance from the source point to the point, where the identity becomes true \( l < Q \) can divided into equal sections \( S'_{pj} \). So, to determine the distance \( S_{pj} \) it is necessary to use the algorithm:

- if the identity \( l_j - \alpha_j \cdot S_{pj} > Q_j \) is true, then \( S_{pj} = S_{pj} + S'_{pj} \);
- if the identity \( l_j - \alpha_j \cdot S_{pj} > Q_j \) is not true then it says that at some distance \( S_{pj} \) from the source of the sound pressure \( l \) is not higher than the zero threshold \( Q \).

Finally we get the matrix of the distribution zone \( M(S_{pj}) \) of the acoustic noise \( M(l_{pj}) \) in free space:

\[
M(S_{pj}) = \begin{pmatrix}
S_{11} & S_{12} & S_{1j} \\
S_{101} & S_{102} & S_{10j} \\
S_{501} & S_{502} & S_{50j} \\
S_{901} & S_{902} & S_{90j} \\
( & ) & ( & ) \\
S_{991} & S_{992} & S_{99j}
\end{pmatrix}.
\]

(5)

In Fig. 2 there is the graph of the noise carpet \( M(S_{pj}) \) of the distributed acoustic noise \( M(l_{pj}) \) of one of the measurement results.
In Fig. 2 it is possible that the statistical noise distribution \( M(l_{Pj}) \) where \( P=99 \) and \( P=90 \) does not represent any threat for the population because of the characteristic peculiarity of the perception of different sounds of different frequencies by the human hearing organs and there is an exposure zone \( S \), close to zero. The zone of the noise distribution with the distribution ratio \( P=50 \), \( P=10 \) and \( P=1 \) is significantly higher. For example, the distance of the maximum noise spreading \((P=1)\) is more than two kilometers and for the noise of a higher level \((P=10)\) it is more than one kilometer.

This graph shows some distance from the source of acoustic noise to the point where it is level does not have any negative influence on a man. In other words at this distance the concrete studied acoustic noise is not perceived any more as a weak acoustic signal in case of complete quietness.

4. Conclusion

This method gives an opportunity to observe the amplitude and frequency characteristics of the average noise values and the background values (in case of temporary stillness). It gives an opportunity to evaluate in what range in each control zone the noise level fluctuates. The preservation of these data of the amplitude-and – characteristic of the background, average and the maximum ratios gives an opportunity to determine the frequency of their peak values and to find the source in case if it is a point source.

Of particular importance has the method in the analysis of urban areas, which adjoin tightly significant engineering and other manufacturing, highway heavy traffic and residential areas.

The work was supported by the grant of Russian Foundation for basic research №14-08-00186.

The work was supported by the municipality of the city Murom.

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