Construction of a system for assessing the acoustic signal attenuation

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Abstract. Acoustic noise is one of the main factors affecting humans. The task of the urban environment operational monitoring is urgent as it will facilitate the solution of population protection problem. This problem can be solved by carrying out measurements in a full-spectrum mode with an assessment of the acoustic signal attenuation along typical noise propagation paths deep into residential areas. It has been shown that monitoring the noise level or its changes within the propagation limits deep into residential areas is possible provided that measuring microphones are located along this path at least in two characteristic points. An estimate of the potentially required microphone separation distance in case of using a system with two microphones is given. It is determined that at the preliminary stage of the measuring system construction, the measuring microphones' location at a distance of 1 km from each other is sufficient. A block diagram of the meter, including two radio transmitters combined with the microphones and a receiver-analyzer, is proposed. It has been determined that acoustic signal delay on the way to the second microphone must be taken into account and the system calibration problem must be solved.

1 Introduction

The number of hazards caused by various factors, both natural and man-made, affecting city residents is constantly increasing and, as a result, the percentage of diseases, the risk of undesirable events of a man-made nature, etc. are increasing. [1, 2]. Acoustic noise is one of these influencing factors.

Recently, according to the State Report of the Ministry of Natural Resources and Environment for 2020 [3], the proportion of facilities where noise levels are found to be non-compliant with the sanitary legislation requirements tends to decrease, however, from 21.2% to 12.0% of measurements by level noise indicate an excess of sanitary standards.

Because of this, the task of the urban environment operational monitoring becomes urgent, as it will facilitate the solution of population protection problems.

For acoustic monitoring, standard measuring equipment (sound level meters) is usually used. However, as shown in [4, 5], taking measurements at weighted average frequencies of octave ranges [6] leads to significant errors in estimating noise sound pressure levels.

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To solve this problem, measurements in a full-spectrum mode should be taken. In addition, it is necessary to have acoustic signal attenuation values along typical noise propagation paths from the source deep into residential areas.

Thus, the development of means for monitoring acoustic noise and assessing attenuation in specific areas (in real time) is an important and relevant task.

The aim is to study the possibility of constructing a portable meter to analyze noise propagation nature deep into residential areas, and to formulate basic principles of the system construction.

2 Possibility of a measurement system construction

Monitoring noise level or its changes within the propagation path deep into residential areas is possible provided that measuring microphones are located along this path at least in two characteristic points: in the area of the acoustic noise source and at a certain distance from the source in the direction of propagation.

This measurement scheme assumes that either two independent meters or one are used, but with at least two sensors (microphones) with the ability to transmit information about the results to the main device unit over relatively long distances.

The use of two independent meters requires solving a whole set of additional problems, primarily synchronization and correlation of measurements. When using one instrument and two microphones, it is necessary to ensure that these microphones are connected to the base meter. A natural communication option in such conditions is to transmit signals via a radio channel.

3 Assessing sufficient microphone separation range

It is known that the attenuation of a pure tone sound is characterized by: attenuation due to geometric divergence (due to the energy divergence when radiated into free space) A_{div}; attenuation due to sound absorption by the atmosphere A_{atm}; attenuation due to the influence of the earth A_{gr}; attenuation due to shielding A_{bar}; attenuation due to the influence of other effects A_{misc} [7]

$$A = A_{div} + A_{atm} + A_{gr} + A_{bar} + A_{misc} . \quad (1)$$

Attenuation due to sound absorption by the atmosphere A_{atm} is the main, most important reason for sound attenuation [8]. At a distance d from the noise source, the attenuation value is determined by two parameters:

$$A_{atm} = \alpha \cdot d . \quad (2)$$

The atmospheric attenuation coefficient α is highly dependent on variations in temperature and humidity.

The attenuation coefficient in the atmosphere α is determined by the formula

$$\alpha = 8{,}686 \cdot f^2 \left(\left[1{,}84 \cdot 10^{-11} \left(\frac{P_a}{P_r}\right)^{-1} \left(\frac{T}{T_0}\right)^{\frac{1}{2}} \right] + \left(\frac{T}{T_0}\right)^{-\frac{5}{2}} \cdot \left\{ 0{,}01275 \left[\exp\left(\frac{-2239{,}1}{T}\right)\right] \left[f_{rO} + \left(\frac{f^2}{f_{rO}}\right)\right]^{-1} + 0{,}1068 \left[\exp\left(\frac{-3352{,}0}{T}\right)\right] \left[f_{rN} + \left(\frac{f^2}{f_{rN}}\right)\right]^{-1} \right\} \right), \quad (3)$$

where f is the sound frequency, Hz; f_m is the geometric mean frequency; P_r=101.325 kPa is the reference atmospheric pressure; P_a is atmospheric pressure, kPa; T is air temperature, K;

T_0=293.15 K is the reference air temperature; f_r is the relaxation frequency, Hz; O and N oxygen and nitrogen.

The main influence on the value of A_{atm} is caused by variations in temperature and humidity. Without taking into account the influence of stationary environmental parameters (buildings, screens, absorbers, etc.), as well as without taking into account the influence of wind parameters for frequencies 2000, 4000 and 10000 Hz with temperature fluctuations from minus 20° C to plus 30° C, the variation in the magnitude of sound attenuation can be, respectively, from 10 to 30 dB/km, from 25 to 65 dB/km, from 30 dB/km to 200 dB/km. Similarly, for changes in atmospheric humidity from 50% to 100%, the attenuation value at the same frequencies can be, respectively, from 7 to 22 dB/km, from 20 to 42 dB/km, from 80 to 150 dB/km.

If we evaluate the attenuation value under standard climatic conditions recommended in [7], (air temperature – 20 ºC; relative humidity – 60%; atmospheric air pressure – 760 mm Hg), then, for example, for 1000 and 2000 Hz frequencies (the most sensitive range for the human ear) we obtain, respectively, A_{1000}=11.8 dB/km and A_{2000}=1.1 dB/km.

Based on these values, we can estimate the potentially required microphone separation distance in case of using a system with two microphones.

If we rely on the attenuation value A_{1000} =11.8 dB/km for a frequency of 1000 Hz, as a standard frequency value when assessing acoustic noise, then, based on the ratio

$$A = 20 \cdot lg\,(L_{ref} / L_{cont}), \tag{4}$$

where L_{ref} and L_{cont} are the sound pressure levels (SPL), respectively, at the location of the acoustic signal source (noise) and at the control point, we find that for A_{1000}=11.8 dB/km the ratio L_{ref}/L_{cont}=3.9 occurs. In other words, under standard climatic conditions at a distance of 1 km, the SPL is reduced by approximately four times (provided there is a fairly “simple” propagation path, not loaded with additional objects such as buildings, cars, etc.). Since within the urban environment noise propagation paths deep into residential areas are streets with more or less constant traffic and the presence of structures that distort the nature of signal propagation [9], it can be assumed that in reality the attenuation value will be greater.

Thus, we can assume that at the preliminary stage of a measuring system construction designed to assess acoustic noise attenuation in urban environment (the nature of propagation deep into residential areas), the location of measuring microphones at a distance of 1 km from each other will be sufficient.

4 Block diagram of the meter

Based on the calculations performed and the assumptions made earlier, we proceed from the choice of a circuit using a radio channel for both microphones.

The measurement circuit general structure can be as shown in Fig. 1.

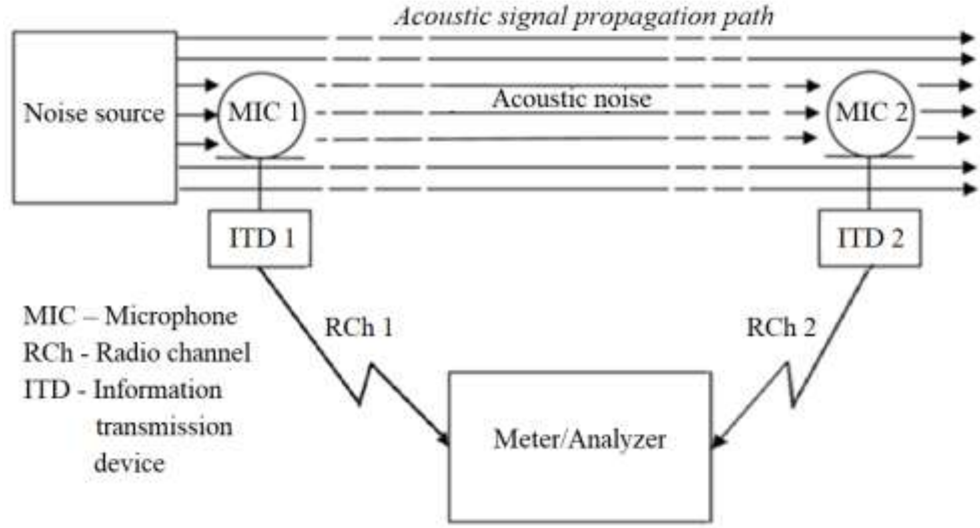

Fig. 1. Measuring scheme.

Another important task that needs to be solved when carrying out measurements of this kind is to ensure reliability, a sufficient degree of accuracy of measurements. One possible option is to carry out a calibration procedure, for example, using a microphone calibrator, before and after taking measurements.

5 Conclusion

The analysis of the possibility of constructing a portable system used to estimate the attenuation of noise form acoustic signals when this noise propagates deep into residential areas allows us to conclude that it is fundamentally possible to create such a meter. In general, the following should be considered:

1. The structure of the measurement process must correspond to that shown in Fig. 1.
2. At the first stage, it is necessary to proceed from the maximum separation distance of microphones - 1 km. When carrying out measurements, it is necessary to place the measuring microphones and the UPI at the same distance from the base unit.
3. When performing a comparative analysis in real time, it is necessary to introduce a time correction that takes into account the duration of the sound wave passage from the noise source (from the first microphone) to the control point (to the second microphone).
4. When carrying out measurements, the task of ensuring a sufficient degree of accuracy of measurements can be solved by carrying out a calibration procedure before and after measurements, for example, using a microphone calibrator.
5. Measurements should be carried out not in octave ranges, but in full-spectrum mode.

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