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V. I. Bespalov, N. S. Samarskaya, E. P. Lysova, et al.

Mathematical Description of Physical Nature of Acoustic Pollution Dynamics of the Environment by Rail

V. I. Bespalov[1, a)], N. S. Samarskaya[1, b)], E. P. Lysova[1, c)], V. V.Baklakova[2, d)], N. V. Udina[1,e)]

[1]*Don State Technical University, Rostov-on-Don, Russian Federation*
[2]*Institute of service and entrepreneurship (filial) Don State Technical University, Shakhty, Russian Federation*

[b)]Corresponding author : nat-samars@yandex.ru
[a)]izos-rgsu@mail.ru
[c)]katerina.lysova0803@gmail.com
[d)]valeriya.baclackowa@yandex.ru
[e)]udi-natasha@yandex.ru

Abstract. The article is devoted to solving the actual problem - to reduce acoustic pollution which is made by rail. The purpose is to ensure the acoustic rail safety through physical modeling of the acoustic pollution dynamics of the railways process environment, followed by mathematical description of this process on the basis of methods of probability theory and mathematical statistics. Research methods were based on the analytical generalization of scientific and technical results of dynamic systems research on the basic provisions of the system analysis, theory, simulation of technical systems, methods of mathematical statistics and probability theory. A sound wave in the course of its dynamic interaction with physical objects in each stage changes its physical characteristics. Therefore, the essence of the physical process dynamics of the acoustic pollution caused by rail can be expressed in mathematical relationship characterizing the probability of the process realization. The resulting study of the mathematical description of dynamics physical nature of the acoustic pollution of the process fluid rail enables a scientific foundation for these or other technical solutions aimed at reducing the acoustic discomfort in the surrounding territories of populated areas.

INTRODUCTION

Modern hygienic studies [1-4] proved that currently on above-norm noise pollution for the triple-urban areas is produced first of all, from the rail transport, representing danger to public health, making discomfort in the life of people and causing many diseases. Therefore, the construction of new railway facilities undoubtedly provides the design of the complex noise-reducing measures. In this case, as practice shows, the choice of such events is quite a time-consuming task [5-10]. The biggest problem, in our opinion, is the lack of scientific evidence of the architectural and planning, organizational and technological solutions to reduce the acoustic impact. It is obvious that for every construction project, it must be taken into account the whole range of noise sources affecting both during construction and during operation. . However, in design practice, complex linear structures require, first of all, design decisions on the selection of optimal position of the track on the ground, which is often not the same as providing acoustic comfort in the surrounding areas of populated areas [11- 15]. The selected option will be considered optimal with maximum justification from technical and economic point of view, and at the same time, it is disadvantageous because of the acoustic discomfort on the track adjacent to populated areas. In this connection, an important task is to find solutions that would ensure not only economic efficiency but also an acoustic safety of any railway project. To achieve this goal, in our opinion, it is possible to do means of careful study of the dynamic

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process physical nature of the acoustic pollution rail followed scientifically by justified choice of the complex noise-reducing measures.

MATERIALS AND METHODS

It is mostly based primarily on analytical generalization of scientific and technical results [4-5,8,16-22]. Questions to assess the negative noise pollution on humans and the environment from the railway transport have been engaged many scientists, such as V.A. Asdrubali, E.N. Belaya, Y.S. Boiko, Brambilla G., Vasiliev A.V., Ivanov N.I., Kasini D., Kelai G., Kopitenkova O.I., Kuklin D.A., Lutsi S. Most of the works of these authors are devoted to methodology for calculating the sound pressure level of the rolling stock and the design of anti-noise technology.

The methods of our research are also based on the basic provisions of the system analysis, system simulation theory, methods of probability theory and mathematical statistics. For this research we selected an analogue of physical and energetic approach used previously to address the issues of air dust. [23] The essence of the approach is to study the behavior of dust aerosol from position disperse systems at stages of its formation, isolation and propagation in air. This approach allows to model any physical processes associated with environmental pollution and mathematically describe their probabilistic and statistical methods. Sound wave as the main object of study in such a way, similar to dust aerosol was reviewed [24,25]. According to physical-energy approach, the sound wave interoperates with physical objects in the process of its formation, and then with the radiation and propagation. Thus, we set a goal to investigate the noise pollution of the environment for rail transport, to identify all the physical objects involved in this process and mathematically describe his physical nature.

RESULTS OF THE RESEARCH

According to the selected physic-energy approach to investigate the process of the acoustic pollution by rail as a physical process is analyzed. This process is viewed as a series of interrelated and interdependent stages. Since the mechanical noise from railway transport is disordered with vibrations of physical character, differing in the spectral and temporal structure and resulting friction, collision, inertial exciting forces, we isolated the initial stage of the process of the acoustic pollution - a sonic wave formation. The resulting sound wave has its physical features: oscillation amplitude, intensity, density of sonic energy level of sound pressure and power, propagation velocity. Summarizing the results of many investigators [1, 4-5, 11, 21-21], we have found that the physical characteristics of the resulting sound wave will depend on many factors such as rolling design, its speed, type of brake system. Also the very source of the sound wave formation is important, which is a physical entity directly involved in the process of acoustic pollution. For railway rolling stock, we considered the group of such sources. So as noise pollution generators installed wheel sets during the movement, both direct and on curved track sections. : Interaction "wheel-block" and "wheel-rail" leads to such noise pollution, which is usually perceived as a grinding, squeaking, squealing, knocking. Also, as a source of formation of the sound wave, we considered compressors, electric trains and other mechanical equipment. Another source of formation of the sound wave, we believe, it can be called aerodynamic noise from the air flowing around the movable structure. Thus, the sound level pressure at the time of formation of the sound wave will be determined as the sum of the energy levels of sound due to all sources accounted.

The intensity of the sound wave of every source of its formation will be characterized as the value equal to the ratio dP sound energy flux through a surface perpendicular to the direction of acoustic wave propagation to destroy surface area, expressed by the formula:

$$I = \frac{dP}{dS}, \text{Вт/м2} \quad (1)$$

Expressing the intensity of the sound waves through a sound pressure amplitude p0 and vibrational velocity v formula becomes:

$$I = \frac{p_0 v}{2} = \frac{v^2 Z_s}{2} = \frac{p_0^2}{2Z_s} \quad (2)$$

Specific acoustic impedance ZS is counted by the formula:

$$z_s = \frac{\rho_{\text{зв}}}{u} = r \cdot c \quad (3)$$

where C is sound speed, r- density of the environment, kg/m^3, - sound pressure, dB, u- vibrational velocity of medium particles, m/s

sound energy density ε, which characterizes the energy contained in a unit volume of the propagation medium is measured in W • s / m^3 or J / m^3.

$$\varepsilon = \frac{I}{c_{зв}} \tag{4}$$

where: I- sound intensity, W • s / m^3; c- sound speed, m/s.

The energy density through its pressure:

$$\varepsilon = \frac{p_{зв}^2}{p_0 c_{зв}^2} \tag{5}$$

where: p_0- atmospheric pressure, Pa; p- sound pressure, dB; c- sound velocity, m/s.

For certain values of the oscillating sound wave velocity occurs next process step acoustic pollution - emission of the sound wave. At this stage, an important role is played by a physical object as the source of radiation. It will have an effect on the physical characteristics of the sound wave. In the role of sources of radiation in the process under consideration of acoustic pollution, in our opinion, are the rolling surface of wheel pairs, the surface of the motor or compressor. Sound pressure of Lw level, portable sound wave through the given surface per time unit, dB is determined by the formula:

$$L_w = 10\lg\left(\frac{w}{w_0}\right) \tag{6}$$

where: w- power of sound waves near sound noise, watts; w0- zero value of the power of the sound waves.

In the third phase of the acoustic pollution of the environment by rail takes place the spatial distribution of the emitted sound waves. In this stage, an important role is played by the space where the sound wave is propagated directly, i.e airspace undercarriage rolling stock. Step propagation of the sound wave is characterized by a large number of factors affecting the physical characteristics of the sound wave. Typically, in known different methods take into account factors such as fading due to divergence (decrease the distance), atmospheric attenuation, gain contribution due to sound reflections from obstacles (buildings facades and buildings on site) and the earth's surface, the damping due to diffraction effects on obstacles:

$$I = \frac{\overline{p^2}}{\rho \cdot c} \tag{7}$$

where: ZS- wave (acoustic) impedance of the medium, Pa • s / m; p- instantaneous sound pressure dB.

Therefore, the intensity of sound in free field is:

$$u = \frac{P}{Z_s} \tag{8}$$

where: p2- sound pressure, dB; ρ- environment density, kg/m^3.

If the source of the sound wave radiation is surrounded by a closed surface area S, m2, the sound source strength is given by:

$$L_w = \oint \bar{I} dS \tag{9}$$

Thus, the sound wave is in the process of interaction with physical objects in each stage changes its physical characteristics.Therefore, the essence of the physical process of the acoustic pollution caused by rail expresses the mathematical relationship:

$$P_{Az}=P_{обрЗВ} \cdot P_{излЗВ(обрЗВ)} \cdot P_{распрЗВ.(излЗВ)} \tag{10}$$

where PAz- the probability of the acoustic pollution of the process fluid caused by rail; PобрЗВ- the probability of phase sound wave formation; PизлЗВ(обрЗВ)– the probability of the phase of the sound wave radiation provided complete formation step; PраспрЗВ(излЗВ)- probability of phase spatial propagation of the sound wave provided complete radiation stages.

DISCUSSIONS AND CONCLUSION

The resulting study of mathematical description of dynamics physical nature of acoustic pollution caused by rails enables a scientific foundation or other technical solutions aimed at reducing the acoustic discomfort in the surrounding areas of populated areas. When considering the dynamic characteristics of the sound wave conditions of its formation, the radiation and propagation, we found that the basic physical object at all stages of acoustic pollution protrudes sound wave, which is interacted with physical objects, changes values of its dynamical parameters (oscillation frequency, the propagation velocity, sound intensity). It means that these parameters are guided by acoustic wave. Thus, the control parameters of the sound wave through the respective physical objects; means influence the process of reduction of the acoustic rail pollution.

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