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INVESTIGATION OF THE CONTRIBUTIONS OF SOUND SOURCES TO EXTERNAL TRAIN NOISE

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Abstract*: The article discusses the method and results of in-situ investigations of the contributions of noise sources of railway transport to the external sound field. The main sources that form the external sound field are pantograph, inter-car coupler and wheel-rail interaction. Experimental studies were carried out for electric trains, passenger, high-speed and freight trains moving with different velocities. The tests have shown the wheel-rail pair makes the main contribution to the external field formation for all types of trains is made by. For high-speed trains and electric trains at speeds over 100 km/h, the noise of the pantograph begins to make a certain contribution. The sound level of electric and high-speed trains increases by 1.5 dBA and sound level of passenger and freight trains increases by 3-3.5 dBA with the increase of speed per each 10 km/h.*

Keywords: *Rail transport, electric train, freight train, high-speed train, passenger train, sound field, rolling noise*

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1. INTRODUCTION

Noise of railway transport is a big problem for Russia since the sound levels of trains reach 75 dBA at the distance of 25 m from the railway line day and night. The sound level reduces by 3 dBA with the doubling of distance from the source to receiver. In the result the noise level at the territory of residential buildings at the distance of 100 m exceeds the limit up to 14 dBA, i.e. up to 3 times by the human sense of loudness. At night the noise limit is exceeded by more than 20 dBA that is about 5 times by the sense of loudness.

According to experts' opinion, the amount of people suffering from noise in the Russian Federation is about 10 million of citizens, since about 7-10% of dwellings is exposed to the influence of railway noise [1].

When studying the noise of railway transport, it is important to identify the contributions of noise sources of train at different speeds. The best way to evaluate and analyze the noise sources of rail transport is the on-site measurements. They help to investigate formation and propagation of noise [2].

The main noise sources of train are pantograph, inter-car coupling and wheel-rail interaction [3]. The article considers contributions of all these sources to the external sound field for different types of trains.

2. METHOD OF EXPERIMENTAL STUDIES

When measuring the noise of railway rolling stock, the measured characteristics are equivalent sound levels (hereinafter referred to as SL), dBA, and sound pressure levels (hereinafter referred to as SPL) in octave bands with geometric mean frequencies in the range from 31.5 to 8000 Hz, dB. Usage of these measuring parameters is recommended by [4] for the transport noise.

The measurements were carried out by integrating noise meters with octave bandpass filters of the 1st accuracy class in accordance with GOST R 53188.1-2019 (IEC 61672-1: 2013, NEQ).

The measurement conditions corresponded to the requirements of the normative and methodical documentation. Before and after each series of measurements, the meteorological conditions were monitored.

The measurements were executed in the absence of high precipitation with the wind speed less than 5 m/s. During tests the membrane of the measuring microphone was protected by a special screen. The values of the rest of meteorological parameters were not beyond the limit values given in the technical documentation for the measuring equipment.

The measuring equipment was not exposed to vibration, electric and magnetic fields, radioactive radiation exceeding the limits given in the technical documentation for the measuring equipment.

During the periods of noise measurements, the background noise was 10 dB (dBA) and more below the measured levels of the railway rolling stock passing in front of the measuring microphone.

The railway rolling stock was subjected to noise tests on the track section with a ballast layer of dry non-frozen rubble with reinforced concrete sleepers. The state of the track corresponded to a rating not lower than „good". The rails of the measuring section of the track had no joints or undulating wear. The measuring section of the track was straight, while the smallest radius of the available curved sections was at least 1000 m. The slope of the track section did not exceed 5%.

The section of the path for measuring external noise was chosen so that its acoustic environment would provide free propagation of noise within ± 1 dB, i.e. the SPL (SL) decreases by 6 dB (dBA) with each doubling of source to receiver distance.

When setting up the experiment, the measuring microphones were located on the test site as shown in Fig. 1. The test method was proposed in [5].

Fig.1 presents location of the following microphones:

- microphone No. 1 for recording the noise parameters of the tested rolling stock in the upper part, where interaction of the pantograph and contact wire system takes place, was located at a distance of 3.75 m from the track axis at a height of 6.5 m from the rail head level;
- microphone No. 2 for recording the noise parameters of the tested rolling stock in the middle part, where noise from vibrations and collisions of the inter-car coupling is generated, was located at a distance of 3.75 m from the track axis at a height of 1 m from the rail head level;
- microphone No. 3 for recording the noise parameters of the tested rolling stock in the lower part, where noise from interaction in the railhead-wheel system is generated, was located at a distance of 3.75 m from the track axis at the level of the railhead;
- microphone No. 4 for recording the parameters of the test rolling stock noise propagating in the external field, was located at a distance of 7.5 m from the track axis at a height of 1.5 m from the rail head level.

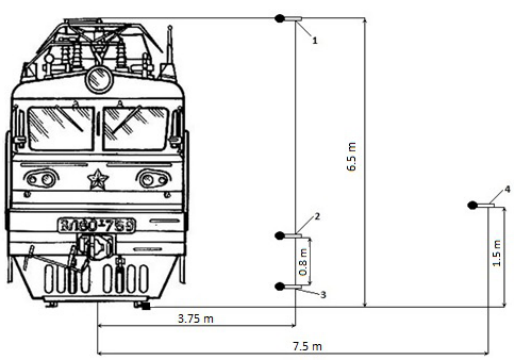

Fig. 1: Layout of measuring points (microphones and sensors)

3. ANALYSIS OF THE RESULTS OF INVESTIGATIONS

3.1. Electric trains

When analyzing the noise of electric trains, the measurements were executed for the trains passing at speeds of 60-115 km/h.

The sound pressure levels in octave frequency bands of the main noise sources of electric train that moves at a speed of 65 km/h are presented in Fig. 2.

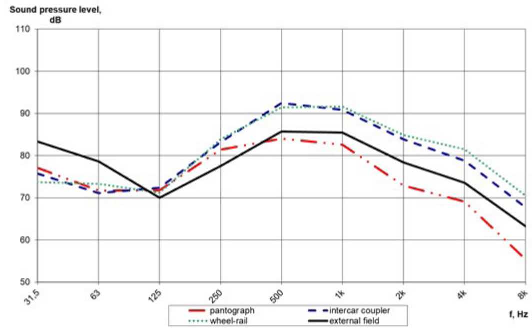

Fig. 2: Noise spectrum of electric train sources for a speed of 65 km/h

Analysis of the spectra of airborne noise measured at different heights shows the identity of microphones location the train noise sources. This allows us to assert that prevailing source contributing the process of noise generation is rolling noise caused by the interaction of the wheel-rail pair. Another source that could not be separated is the intercar coupler that also influences the process of noise generation.

In fig. 3 sound pressure levels in octave frequency bands of the main noise sources of electric train that moves at a speed of 115 km/h are shown. All spectra illustrate the presence of maximum SPL at a frequency of 1000 Hz.

In the frequency range 20-315 Hz, noise is generated by air flowing around the car bodies (aerodynamic noise). Considering the spectral nature of the curve of noise limit, low-frequency noise does not pose a serious problem for the population of residential buildings adjacent to the railway.

However, it should be noted that at the speed of electric trains above 100 km/h, the pantograph, which is available on every second car, begins to make a certain contribution to the formation of the external sound field (Fig. 3).

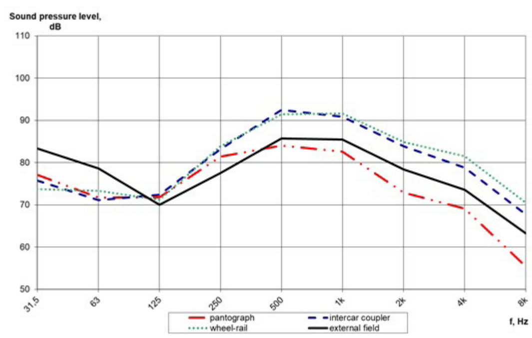

Fig. 3: Noise spectrum of electric train sources for a speed of 115 km/h

It should also be noted that the noise spectrum changes with the increase of speed: the peak in the spectrum shifts somewhat towards high frequencies.

The dependence of the sound levels of different noise sources of electric trains on the speed of train is presented in Fig. 4. The analysis of the data proves that there is a strong dependence of the external noise of train on the rolling noise at all speeds. The influence of pantograph and intercar coupler differs with the speed. When the contribution of pantograph prevails the influence of intercar coupler becomes lower.

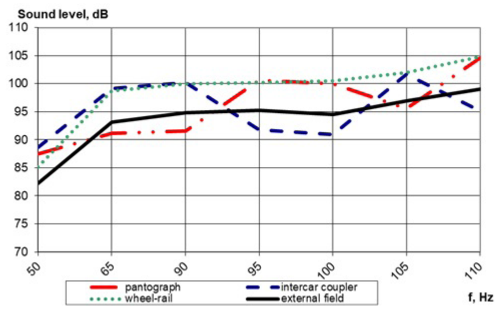

Fig. 4: Contribution of noise sources to the external noise of electric train at different speeds

In fig. 5 the external sound levels of electric trains at a distance of 7.5 m from the rail are shown. The analysis of the figure 6 demonstrates the direct dependency of sound level of electric trains on their speed. The increase of sound level makes 1,5 dBA per each 10 km/h increase of speed.

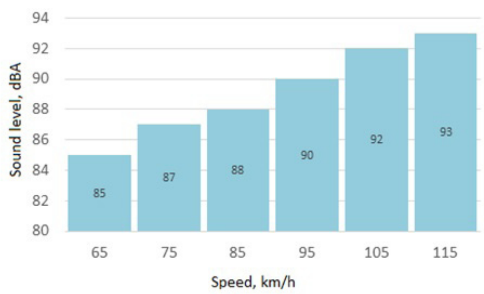

Fig. 5: Dependence of electric train noise on speed

3.2. Passenger trains

The study of the contributions of noise sources of passenger trains was carried out when they were moving at speeds from 70 up to 110 km/h.

In fig. 6 sound pressure levels in octave frequency bands of the main noise sources of a passenger train that is passing at a speed of 75 km/h are shown.

The distribution of sound pressure levels of passenger and electric trains by frequencies are quite similar. The low-frequency noise of both types of trains is produced by the aerodynamic noise formed by pantograph. A peak of noise spectrum is observed at the frequency of 1000 Hz due to wheel-rail contact spot. The character of sound attenuation for pantograph and intercar coupler allows to suggest the existence of a plane sound wave at the shorter distances, since the external field is approximated by a cylindrical sound wave existing at the larger distance from the noise source.

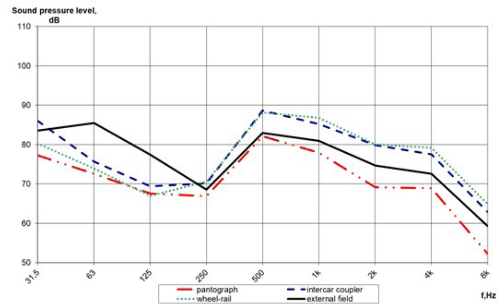

Fig. 6: Noise spectrum of passenger train sources for a speed of 75 km/h

The sound pressure levels in octave frequency bands of the main noise sources of a passenger train moving with a speed of 95 km/h are shown in Fig. 7.

The external sound field is formed mainly by the radiation of the wheel-rail pair and pantograph. At low frequencies the main contribution is made by pantograph that produces aerodynamic noise since the influence of wheel-rail interconnection does not influence significantly the external noise level.

With the increase of speed, the peak in spectrum of passenger train noise moves from 500 to 1000 Hz.

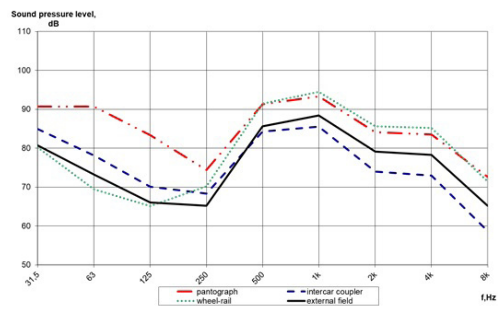

Fig. 7: Noise spectrum of passenger train sources for a speed of 95 km/h

The contribution of various noise sources into external sound level of a passenger train is presented in Fig. 8. The data in Fig. 8 confirms that the main sources of passenger trains are pantograph and wheel-rail interaction at all speeds.

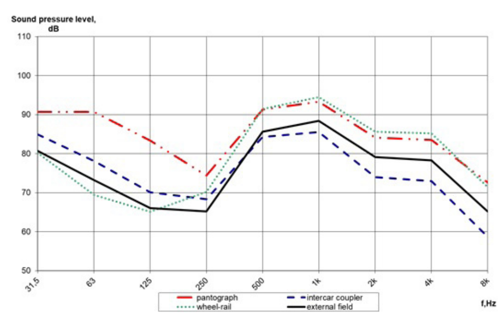

Fig. 8: Contribution of noise sources to the external noise of passenger train at different speeds

The sound levels of passenger trains are shown in Fig. 9 for different speeds. With the increase of speed from 75 to 110 km/h, sound levels have increased by 9 dBA. So, we should note that there is a noise increase by 3 dBA for every 10 km/h of speed increase.

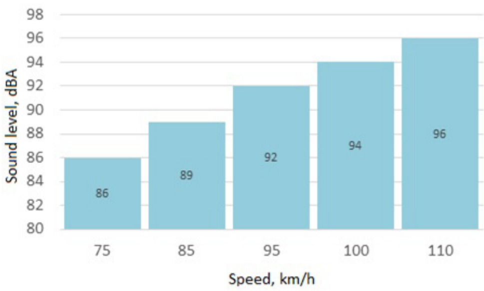

Fig. 9: Dependence of passenger train noise on speed

3.3. High-speed trains

The characteristics of high-speed train noise were investigated for the range of speed varying from 110 to 180 km/h.

In Fig. 10 the sound pressure levels in octave frequency bands of the main noise sources of a high-speed train for a speed of 110 km/h are shown.

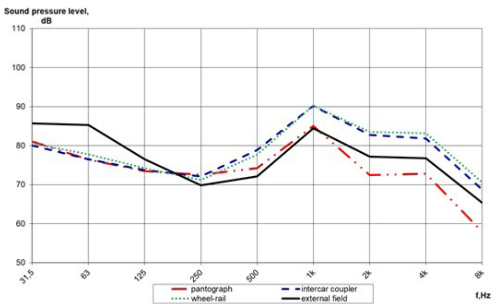

Fig. 10: Noise spectrum of high-speed train sources for a speed of 110 km/h

The arguments about the nature of the spectra and the prevalence of the contribution of the wheel-rail pair to the external sound field are also valid for high-speed trains. At a frequency of 1000 Hz, the presence of a characteristic peak for the spectra of air-born and structural sound should be noted. It confirms the previous assumption that the train noise with the increase of speed shifts to higher frequencies. The influence of pantograph of the high-speed train is smaller than for the passenger trains due to its streamlined shape. Though we can observe the contribution of the intercar coupler that is almost the same as the wheel-rail influence.

Data on the relationship between sound levels and speed of high-speed trains are shown in Fig. 11. The analysis of the data shows that the increase of noise level of a high-speed train makes about 1,5 dBA per each 10 km/h of speed.

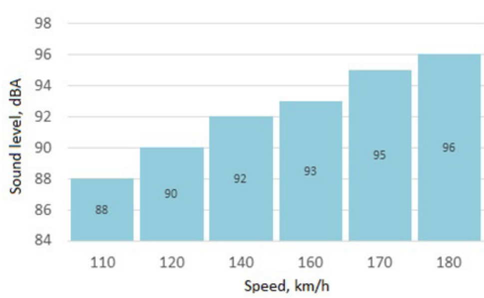

Fig. 11: Dependence of high-speed train noise on speed

It should also be noted that the noise of high-speed trains at the same speeds is 5-8 dBA lower than the noise of electric and passenger trains. This can be explained by the better technical condition and more advanced design of high-speed trains. But character of noise formation of high-speed trains is similar to formation of noise of electric trains.

3.4. Freight trains

The noise characteristics of freight trains were studied in for speeds of 55 to 75 km/h. In Fig. 12 the sound pressure levels in octave frequency bands of the main noise sources of a freight train for a speed of 55 km/h are shown.

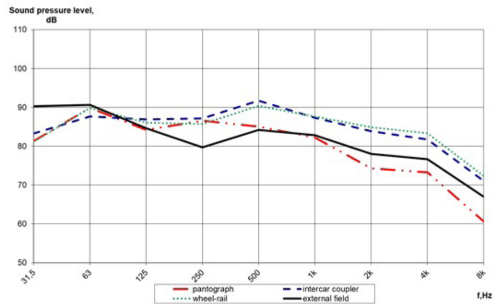

Fig. 12: Noise spectrum of freight train sources for a speed of 55 km/h

Analysis of the data presented in Fig. 12 show that at low frequencies all sources have almost equal contribution. We should also note that high values of SPL in the low-frequency area can be explained by higher weight loads. With the increase of speed pantograph becomes a minor source since the noise of wheel-rail and intercar coupler prevail.

In Fig. 13 the sound levels of freight trains at various speeds are shown. The data in Fig. 14 show that at speeds higher than 55 km/h wheel-rail interaction of freight train contribute less than pantograph and intercar coupler. So, the external noise of freight train at higher speeds are formed by the contributions of all three main noise sources.

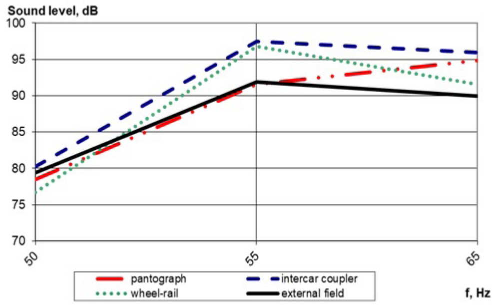

Fig. 13: Contribution of noise sources to the external noise of freight train at different speeds

Data on the dependence of the noise of freight trains on speed are shown in Fig. 14. The increase of sound level of freight trains makes 3.5 dBA per 10 km/h of speed.

The freight trains are the loudest ones. The sound level of a freight train is 2-3 dBA higher than the noise of electric and passenger trains moving with the same speed.

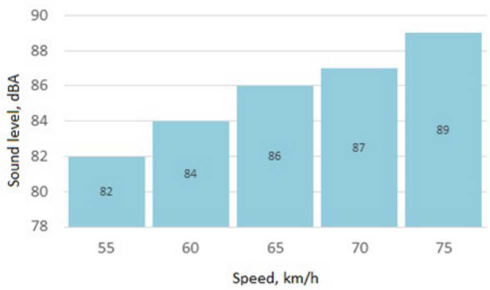

Fig. 14: Dependence of freight train noise on speed

4. CONCLUSION

1. The main contribution to the formation of the external sound field of trains is made by rolling noise caused by the interaction of „wheel-rail" pair. Though at the increase of speed we can observe the influence of pantograph for all trains besides high-speed trains. Noise of high-speed and freight trains is also influenced by the intercar coupler.
2. Noise levels depend on the type of train and its speed as follows:
    - the sound levels of electric trains increase by 1.5 dBA per each 10 km/h of speed;
    - the sound levels of passenger trains increase by 3 dBA per each 10 km/h of speed;
    - the sound levels of high-speed trains increase by about 1.5 dBA per each 10 km/h of speed increase;
    - the noise levels of freight trains increase by 3.5 dBA per each 10 km/h increase of speed.
3. The peak of spectrum of all types of trains is observed at a frequency of 500 Hz, but with the increase of speed higher than 90 km/h it moves to the frequency of 1000 Hz.
4. The freight trains are 2-3 dBA noisier than electric and passenger ones.
5. The high-speed trains are 5-8 dBA less noisy than electric and passenger ones.
6. The main direction the railway noise reduction is reducing rolling noise, that is, the interaction of a „wheel-rail" pair [6].

REFERENCES

[1] Butorina, M., Olejnikov, A., Kuklin, D.: Classification of railway lines by noise emission for noise protection design. – Akustika, Vol. 32, March 2019. P. 228-234, 2019
[2] Drozdova, L., Butorina, M., Kuklin, D.: Approaches to the rail noise reduction 24th International Congress on Sound and Vibration, ICSV 2017, 2017
[3] HandBook of noise and Vibration control / Edited by Malkolm J. Crocker,: NY, John Wiley and Sons Inc., 1569 p, 2007
[4] Ivanov, N.I.: Engineering acoustics. Theory and practice of noise control: textbook. - M .: University book, Logos, 424 p, 2008
[5] Kuklin, D.A.: The problem of reducing the external noise of trains at the source and on the path of propagation - thesis for the degree of Doctor of Technical Sciences, - St. Petersburg, BSTU «Voenmeh» named after D.F. Ustinov, 434 p, 2016
[6] Ivanov, N.I., Tyurina, N.V.: The problem of reducing the noise of railway transport. - Reports of the International Scientific and Practical Conference «Application of acoustic screens to reduce noise and increase the safety of train traffic» Moscow, December 14 2006, - St. Petersburg, BSTU «Voenmeh» named after D.F. Ustinova, p. 2-28, 2006

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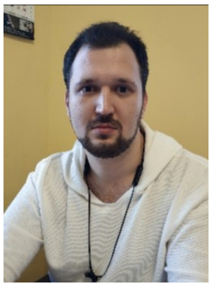

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