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DEVELOPMENT OF THE METHODOLOGY FOR MEASURING NOISE LEVELS IN THE UNDERGROUND ROLLING STOCK

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***Abstract**: This document specifies the methodology for measuring equivalent sound pressure levels in octave frequency bands (in dB rel. 20 μPa), equivalent and maximum A-corrected sound levels (in dB rel. to 20 μPa), generated in the rolling stock in the driver's cabins and in the passenger rooms of the salons, using acoustic meters - multifunctional analyzers Ecophysics, noise and vibration meters, spectrum analyzers Ecophysics 110A, Oktava 110A Eco, Oktava 110A, Oktava 111, B&K 2250, 2250L, 2270, noise and vibration analyzers ASSISTANT, noise and vibration meters, digital spectrum analyzers Algorithm-05, SVAN979. This methodology is applicable for noise measurements in the driver's cabins and in the passenger rooms of the rolling stock of both new and old models operated by the underground railway.*

***Keywords:** noise in the subway, noise level meter, sound pressure levels, measurement method*

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1. INTRODUCTION

Noise in the underground carriages, both in passenger and driver's seats, is a serious issue today. Excesses over the standards are recorded during measurements in any place of the carriage, complaints from passengers are received, cases of noise sickness are diagnosed among electric train drivers.

To date, there is no method for measuring noise levels in the underground rolling stock.

The methodology developed in this paper is intended for use by testing laboratories and centers, as well as other organizations that perform instrumental control for the purposes of sanitary and hygienic and technical assessment of the noise in rolling stock.

2. MEASUREMENT ACCURACY CHARACTERISTICS

The measurement accuracy of this method is characterized by an extended measurement uncertainty with a 95% coverage probability. [1,2]

- uncertainty of the equivalent sound pressure level measurements in the octave frequency bands $U_{Li,eq}$ in the underground rolling stock does not exceed 2.7 dB.
- uncertainty of the equivalent sound level $U_{LA,eq}$ measurements in the underground rolling stock does not exceed 3.8 dB.
- the uncertainty of the maximum sound level $U_{LA,Max}$ measurement in the underground rolling stock does not exceed 1.0 dB.

When developing the methodology, measurement ranges for different devices were determined, for example, here are the measurement ranges of the equivalent sound pressure levels in octave frequency bands using Ecophysics 110A, Ecophysics, Octave 110A Eco and Octave 110A devices with a microphone capsule VMK205, MK265, MP201 or their analogues: 13-139 dB rel. to 20 μPa.

The measurement range of A-corrected sound levels using Ecophysics 110A, Ecophysics, Oktava 110A Eco and Oktava 110A devices with a microphone capsule VMK205, MK265, MP201 or their analogues is: 22-139 dB rel. 20 μPa.

The methodology uses the terms and definitions adopted in GOST R 8.563, GOST 34100.1, GOST 8.736, GOST R 53188.1, GOST R 8.714, SP 120.13330.2012. [1-4]

People to be allowed to conduct measurements according to this method are:

- those who have a higher or secondary technical education or work experience, have mastered the method in the course of training and have achieved satisfactory results when performing measurements;
- those who have been instructed and have access to work at underground facilities.

When performing measurements, the specified safety requirements for the operation of electrical installations, power grids and measuring equipment used, as well as the safety requirements for working at underground facilities, are observed.

3. MEASURING METHOD

The principle of the method for measuring equivalent sound levels in underground rolling stock is to conduct direct multiple measurements of the equivalent sound levels at control points, followed by averaging over the measurements made, and in case of evaluating noise in passenger rooms - also averaging over control points.

The principle of the method for measuring equivalent sound pressure levels in underground rolling stock is to conduct direct multiple measurements of equivalent sound pressure levels at control points, followed by averaging over the measurements made, and in the case of noise assessment in passenger rooms - also averaging over control points.

The principle of the method for measuring maximum sound levels in the underground rolling stock is to conduct direct multiple measurements of the sound levels with a time characteristic S according to GOST 53188.1 [3] at control points, followed by the selection of the maximum value.

4. REQUIREMENTS FOR MEASUREMENT CONDITIONS

When conducting measurements of the equivalent sound pressure levels, equivalent sound levels and maximum sound levels, it is necessary to comply with the following general terms and conditions. [4]

1. The air temperature in the tested carriage during measurements should be in the range from 0 to +40 °C. In case of non-compliance with the requirements of Section 3.2 of SP 2.5.1337-03, temperature control is performed during the measurement period, the results of temperature control are entered into the working log or working protocol.
2. Relative humidity of the air (without condensation) in the tested carriage should not exceed 90%. In case of non-compliance with the requirements of Section 3.2 of SP 2.5.1337-03, the relative humidity of the air is monitored during the measurement period, the results of the relative humidity control are entered into the working log or working protocol.
3. Measurements should not be distorted by accidental interference caused by the operator, other people or equipment (for example, noise from the underground rolling stock (URS) movement on the adjacent track in a double-track tunnel or at a station).
4. The wheel pairs of the tested underground rolling stock (URS) must not have defects on the rolling surface, including sliders.
5. The rolling stock auxiliary equipment must operate normally during the measurements, with the exception of the voice notification in the carriages, which must be disabled.
6. Measurements are not conducted on the open ground or open areas.
7. Measurements must be conducted in trains with the number of carriages provided for by the regular operation on this line, but not less than three.
8. When measurements are made to compare the noise levels in the of carriage rooms of different models or different carriages of the same model, the following requirements are met:
   - consecutive measurements in the examined rooms are performed when driving along the same test track with the same speed mode in the same direction;
   - the condition of the windows and the mode of operation of the ventilation system in each passenger room under examination must comply with paragraphs 10-12 for this room.

When making measurements in the URS passenger rooms, the following conditions must be observed:

9. Depending on the purposes, any URS carriage except for the first and last is selected for conducting measurements.
10. Voice alerts in the URS under study should be disabled.
11. Windows in passenger rooms should be closed, except for those cases when their opening ensures compliance with the requirements for the microclimate inside the premises of the URS.
12. If there is a mechanical forced air ventilation system in the carriage, the measurements must be conducted when it operates in the maximum power mode.
13. Passing the stations without stopping is not allowed, stopping the rolling stock inside the tunnel is not allowed.
14. The rolling stock must move in accordance with the speed limit provided for this section of track, but not more than 60 km/h.
15. During the measurements, only the personnel conducting the measurements must be present in the passenger rooms of the URS. By agreement, it is permissible for other interested people to be there, at that they must follow the procedure of staying in the URS and not interfere with the operation of the measuring equipment, including not creating acoustic noise.

When making measurements in the URS driver's cabin, the following conditions are observed [5,6]:

16. During the measurements, only the personnel conducting measurements and the driver of the electric train should be in the URS driver's cabins. It is allowed to conduct measurements in the automatic mode without the personal presence of the personnel conducting the measurements, directly during the measurements.
17. Measurements in the driver's cabin should be conducted only in the first (head) carriage.
18. The operation of communication facilities in the driver's cabin must be carried out in normal mode.
19. Passing the stations without stopping is not allowed, stopping of the rolling stock inside the tunnel is not allowed.
20. The rolling stock must move in accordance with the speed limit provided for this section of track, but not more than 60 km/h.

5. PREPARATION FOR THE MEASUREMENTS

1. Preparation for the measurements includes:
   - monitoring conditions affecting measurement accuracy;
   - identification of possible interference sources;
   - identification and determination of the URS type;
   - identification and determination of the track type:

- installation and fixation of the microphone at a given reference point (RP);
- identification of the RP location;
- setting the measuring equipment mode.

2. Selection of measurement points (RP) in the URS passenger areas.

RT is located opposite the doors on the line of the central axis of the URS carriage (Fig. 1.1). When choosing a RT, the following requirements are followed

RT_1 - above the motor trolley at a height of 1.2 m above the URS floor level

RT_2 – in the middle part of the cabin opposite the doors at a height of 1.2 m above the URS floor level.

RT_3 – in the middle part of the cabin opposite the doors at a height of 1.2 m above the URS floor level.

All distances are set with the accuracy of 0.1 m.

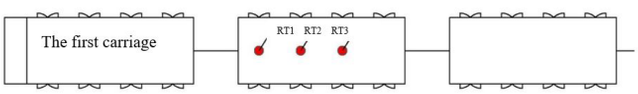

Fig. 1: Reference points layout - plan

3. Selection of the reference points (RT) in the URS driver's cabin.

The ***RT*** in the driver's cabin should be as close as possible to the geometric center of the cabin (Fig. 1.2), provided that the train traffic is safe (the operator and measuring instruments should not interfere with the driver in any way: close the view, restrict traffic, etc.).

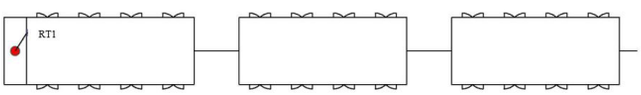

Fig. 2: Reference points layout - plan

4. Installation of the noise meter microphone:

- The main axis of the microphone (corresponds to the normal to the surface of the membrane) should be directed vertically downwards.
- The microphone should not have a rigid connection with the URS. This condition is implemented if the microphone is mounted in a TRP001R tripod or similar tripod with a soft and/or elastic layer in the microphone mounting adapter. In addition, this condition is implemented when the microphone is held in the hands of the operator.
- When measuring, it is recommended to use a windproof microphone screen. If the wind speed exceeds 1 m/s, using a wind shield is mandatory.
- If the noise measurement is conducted in manual mode (i.e. the microphone is not mounted on a tripod, but is held in the hands of the operator), the operator must be at least 0.5 m away from the measuring microphone.

5. Before and after each measurement, it is necessary to check the sensitivity of the measuring path of the noise meter (measuring system). The test is performed in accordance with the operating instructions of the noise meter. To check the sensitivity, an acoustic calibrator AK-1000, 4231, SV33, SV35 or another permissible calibrator of class 1 according to GOST IEC 60942, which has a certificate of verification and is approved by the manufacturer of the noise meter, must be used.

6. PROCEDURE FOR PERFORMING NOISE MEASUREMENTS IN THE URS PASSENGER ROOMS

1. In each RT_i (i=1, 2, 3), at least 3 measurements must be made (hereinafter, the index j is used to indicate the number of measurements). The following events should be included in these measurements collectively or separately:
   - driving along curved sections (if there are any on the section under examination);
   - passage through a closed-type station (if there are any on the section under examination);
   - acceleration up to 60 km/h.

The required number of sound level measurements in each ***RT*** is determined as follows – the root-mean-square deviation (RMS) for a series of measurement results should not exceed 1.2 dB. If the RMS exceeds the specified value, then additional measurements are performed, paying special attention to the fulfillment of all the conditions of the procedural instruction.

Note. This criterion is obviously met if the difference between the highest and lowest values in the sample of 4 measurements is 4.5 dB.

The required number of measurements of the sound pressure levels in each ***RT*** is determined as follows – the root-mean-square deviation (RMS) for a series of measurement results should not exceed 1.6 dB. If the RMS exceeds the specified value, then additional measurements are conducted, paying special attention to the fulfillment of all the conditions of the procedural instruction.

Note. This criterion is obviously met if the difference between the highest and lowest values in the sample of 4 measurements is 6.0 dB.

2. Before starting the measurement, install the microphones at the reference points. Measurements start at the beginning of the train movement after the sound signal is given by the train driver and the voice notification at the departure station (if such is provided). The measurements are completed at the moment when the train enters the station before the sound signal is given by the driver of the electric train.

It is allowed to select a measurement record that begins and ends according to this point from a long continuous record.

Note. In the case of simultaneous URS movement along the adjacent track (in a double-track tunnel or at a station), measurements must be stopped and resumed after its passage.

3. The directly measured parameters in each of the KT_i (i=1, 2, 3) are:

- equivalent sound pressure levels in the octave frequency bands $L_{p,eq,1/1,i,j;}$
- equivalent sound level with frequency response $A - L_{A,eq,i,j}$
- maximum sound level with time response ***S*** (Slow) and frequency response $A - L_{A,S,max,i,j.}$

7. PROCEDURE FOR CONDUCTING NOISE MEASUREMENTS IN THE URS DRIVER'S CABINS

In the specified ***RT***, at least 3 measurements must be performed (hereinafter, the index j is used to indicate the measurement number). The following events should be included in these measurements collectively or separately:

- driving along curved sections (if there are any on the section under examination);
- passage through a closed-type station (if there are any on the section under examination);
- acceleration up to 60 km/h.

The required number of sound level measurements in each ***RT*** is determined as follows – the root-mean-square deviation (RMS) for a series of measurement results should not exceed 1.3 dB. If the RMS exceeds the specified value, additional measurements are conducted, paying special attention to the fulfillment of all the conditions of the procedural instruction.

Note. This criterion is obviously met if the difference between the highest and lowest values in the sample of 3 measurements is 4.0 dB.

The required number of the sound pressure level measurements in each RT is determined as follows – the root-mean--square deviation (RMS) for a series of measurement results should not exceed 1.8 dB. If the RMS exceeds the specified value, additional measurements are conducted, paying special attention to the fulfillment of all the conditions of the procedural instruction.

Note. This criterion is obviously met if the difference between the highest and lowest values in the sample of 3 measurements is 5.0 dB.

2. Before starting the measurements, install the microphones at the reference points. Measurements start at the beginning of the train movement after the sound signal is given by the train driver and the voice notification at the departure station (if such is provided). The measurements are completed at the moment when the train enters the station before the sound signal is given by the electric train driver.

It is allowed to select a measurement record that begins and ends according to this point from a long continuous record.

Note. In case of the simultaneous URS movement along the adjacent track (in a double-track tunnel or at a station), measurements must be stopped and resumed after its passage.

The directly measured parameters are:

- equivalent sound pressure levels in the octave frequency bands $L_{p,eq,1/1,j;}$
- equivalent sound level with frequency response $A - L_{A,eq,j;}$
- the maximum sound level with the time characteristic ***S*** (Slow) and frequency characteristic $A - L_{A,S,max,j.}$

8. PROCESSING OF THE RESULTS OF NOISE MEASUREMENTS IN URS PASSENGER ROOMS

1. Calculation of the equivalent sound pressure levels in octave frequency bands.

In each noise measurement reference point i (i=1, 2, 3) equivalent sound pressure levels in octave bands $L_{p,eq,1/1}$, i are calculated according to the formula:

$$L_{p,eq,1/1,i} = 10 \times \lg\left(\frac{1}{N}\sum_{j=1}^{N} 10^{0,1\times L_{p,eq,\frac{1}{1}i,j}}\right) \quad (1)$$

where:

$L_{p,eq,1/1}$ is the j^{th} measurement of the equivalent sound pressure level in octave bands in the ith measurement point, dB;

N is the number of measurements at the i^{th} reference point (according to point 12.1 – at least 3), pcs.

The sound pressure levels $L_{\overline{p},eq,\frac{1}{1}}$ in the octave frequency bands in the passenger room under examination in each octave band are determined by the formula:

$$L_{\overline{p},eq,1/1} = 10 \times \lg\left(\frac{1}{3}\sum_{i=1}^{3} 10^{0,1\times L_{p,eq,\frac{1}{1},i}}\right) \quad (2)$$

where:

$L_{p\,,\,eq\,,1/1,i}$ is the average sound pressure levels in octave bands in the i^{th} measurement point, dB, calculated using the formula (14.1).

2. Calculation of the equivalent sound level.

At each noise measurement reference point ***i*** (i=1, 2, 3), the average equivalent sound level $L_{A,eq,i}$ is calculated using the formula:

$$L_{\mathrm{A},eq,i} = 10 \times \lg\left(\frac{1}{N}\sum_{j=1}^{N} 10^{0,1\times L_{\mathrm{A},eq,i,j}}\right) \quad (3)$$

where:

$L_{A,eq,i,j}$ is the j^{th} measurement of the equivalent sound level at the i^{th} measurement point, dBA;

N is the number of measurements at the ith reference point (according to point 12.1 – at least 3), pcs;

The equivalent sound level in the passenger room under examination $L_{\bar{A}eq}$ is determined using the formula:

$$L_{\overline{\mathrm{A}},eq} = 10 \times \lg\left(\frac{1}{3}\sum_{i=1}^{3} 10^{0,1\times L_{\mathrm{A},eq,i}}\right) \quad (4)$$

where:

$L_{A,eq,i}$ is the equivalent sound level at the i^{th} measurement point, dBA, calculated using the formula (3).

3. Calculation of the maximum sound level.

At each noise measurement reference point ***i*** (i=1, 2, 3), the highest of the measured sound levels $L_{A,max}$ is calculated using the formula:

$$L_{\mathrm{A},max} = \max_{i,j}\left(L_{\mathrm{A},S,max,i,j}\right) \quad (5)$$

where:

i is the number of the noise measurement reference point (***i*** = 1, 2, 3);

j is the measurement number at the i^{th} noise measurement reference point;

$L_{A,S,max,i,j}$ is the measured maximum sound level at the i^{th} reference point at the j^{th} measurement number, dBA.

9. PROCESSING OF THE NOISE MEASUREMENT RESULTS IN THE URS DRIVER'S CABIN

1. Calculation of the equivalent sound pressure levels in the octave frequency bands.

At the established noise measurement reference point the equivalent sound pressure levels in the octave frequency bands $L_{\bar{p},eq,1/1}$ are calculated using the formula:

$$L_{\bar{p},eq,1/1} = 10 \times \lg\left(\frac{1}{N}\sum_{j=1}^{N} 10^{0,1\times L_{p,eq,1/1,j}}\right) \quad (6)$$

where:

$L_{p,eq,1/1,j}$ is the j^{th} measurement of the equivalent sound pressure levels in the octave frequency bands, dB;

N is the number of measurements (according to point 13.1 – minimum 3), pcs;

2. Calculation of the equivalent sound level.

The equivalent sound level in the driver's cabin under examination $L_{\bar{A}eq}$ is determined using the formula:

$$L_{\bar{\mathrm{A}},eq} = 10 \times \lg\left(\frac{1}{N}\sum_{j=1}^{N} 10^{0,1\times L_{\mathrm{A},eq,j}}\right) \quad (7)$$

where:

$L_{A,eq,j}$ is the j^{th} measurement of the equivalent sound level, dBA;

N is the number of measurements at the i^{th} reference point (according to point 13.1 – at least 3), pcs.

3. Calculation of the maximum sound level.

The maximum sound level is defined as the highest of the measured sound levels $L_{A,max,j}$ using the formula:

$$L_{\mathrm{A},max} = \max_{j} L_{\mathrm{A},S,max,j} \quad (8)$$

where

j is the measurement number at the noise measurement reference point;

$L_{A,S,max,j}$ is the maximum sound level at the j^{th} measurement number, dBA;

$L_{A,max}$ is the maximum sound level in the driver's cabin under examination, dBA.

10. MONITORING THE ACCURACY OF THE MEASUREMENT RESULTS

The extended uncertainty of sound level and sound pressure measurements with a coverage factor of 2 corresponding to a confidence level of 95% does not exceed the values specified in paragraph 3, if the following conditions are met:

- the measurement conditions correspond to the conditions of application of the measuring equipment used;
- the measuring equipment used has a valid verification certificate;
- the readings of the noise meter and spectrum analyzer when checking the measuring path coincide with the level of the calibration signal within ±0.3 dB;
- the measuring equipment used is a subject to timely maintenance in accordance with their operating instructions.

The measurement report is filled in accordance to the form adopted in this testing laboratory (center), taking into account all the points specified in this procedure. [2]

11. CONCLUSION

The excessive noise level in the underground carriages, both in the driver's cabin and in the passenger rooms, is a serious issue in the modern world. Currently, there are no methods for measuring noise levels in rolling stock or they are under development.

To perform the work on reducing the sound exposure levels at underground facilities, it is necessary to first measure the sound level and sound pressure in underground carriages, at the workplaces of the underground drivers, compare them with the standard values, analyze the need for measures that are optimal for reducing noise levels.

The proposed version of the method for measuring noise levels in the underground rolling stock has sufficient accuracy and simplicity for use in real conditions. In the future, this will help to improve the quality of the sound level measurements, as well as to choose the best methods for noise reduction.

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