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Theoretical Research of Noise and Vibration Spectra in Cabins of Locomotive and Diesel Shunting Locomotive

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Abstract

It showed that the statistical analysis of the occupational diseases of the drivers and locomotive crews was 70% and associated with noise exposure (noise sickness), and 15.5% connected with diseases of the musculoskeletal system which was determined by the impact of vibrations. Consequently, 85.5% of the occupational diseases of drivers and locomotive crews were determined by the influence of vibroacoustic characteristics of the elevated levels. Therefore, the researches aim at a theoretical description of the processes of the excitation of vibration and noise emissions in workplaces of the locomotive brigades are relevant and have great scientific, engineering and socio-economic importance. In addition, it should be noted that the tiredness of drivers was primarily determined by the impact of vibration and acoustic characteristics that had negative affect on safety of traffic transport vehicles.

The processes of the noise emissions have been studied with reference to the cabs of road-building machines and electric locomotives. The article under consideration also points out that the nature of the sources of noise and vibration spectra in locomotive and diesel shunting locomotive has significant differences, in particular, the internal combustion engine is a complex aggregate that generates increased noise and vibration levels in the workplaces of locomotive crews.

Acoustic impact of the internal combustion engine (ICE) is formed by the influence of the exhaust noise, the noise of its frame, the sound emission and the sound energy passed through the hood. An important role is played by the sound emission from the hood due to vibration (structural noise component). Simultaneous sound radiation from these sources has not been adequately studied at present time. The rational selection of sound-absorbing and sound-insulating structures can be justified only on the basis of theoretical research of the influence of the air component of noise which is presented in this article.

Keywords: Noise, vibration, cabins, diesel shunting locomotives and locomotives.

INTRODUCTION

At present, a large volume of theoretical and experimental research as well as practical recommendations on noise and vibration problems of track and road construction machines have been carried out [1-12]. Basically, for railway transport, the laws of acoustic influence on the residential area have been studied.

It is devoted to the existing research of sound-absorbing materials [13-17]. However, nowadays in foot-plate of the locomotives and diesel shunting locomotives sound-absorbing linings are practically not used.

Despite on the different functional purpose of the locomotives and diesel shunting locomotives, the layout of the main sources of vibration and noise is relative to the impact on the driver's workplace and it is largely identical. Therefore the theoretical research description of the noise generation processes in the driver's foot-plate can be performed from the unified position.

FORMULATION OF THE PROBLEM

The purpose of the research and the results are presented in this article. It consisted in the theoretical description of the spectral composition of sound pressure levels in the cabs of diesel shunting locomotive drivers and locomotives under the influence of the sources of the air noise component.

The LTL-4 diesel shunting locomotive is a self-propelled biaxial crew. In the front part of the supporting frame there is a load-bearing foot-plate with a crane Figure 1. At the rear of the carrier frame, the power plant (diesel YaMZ-238B-14) is mounted under the hood transmitting power through a V-belt transfer to a three-phase generator and through the hydraulic transmission and a drive shaft to the axle reducers of the wheel sets and compressor.

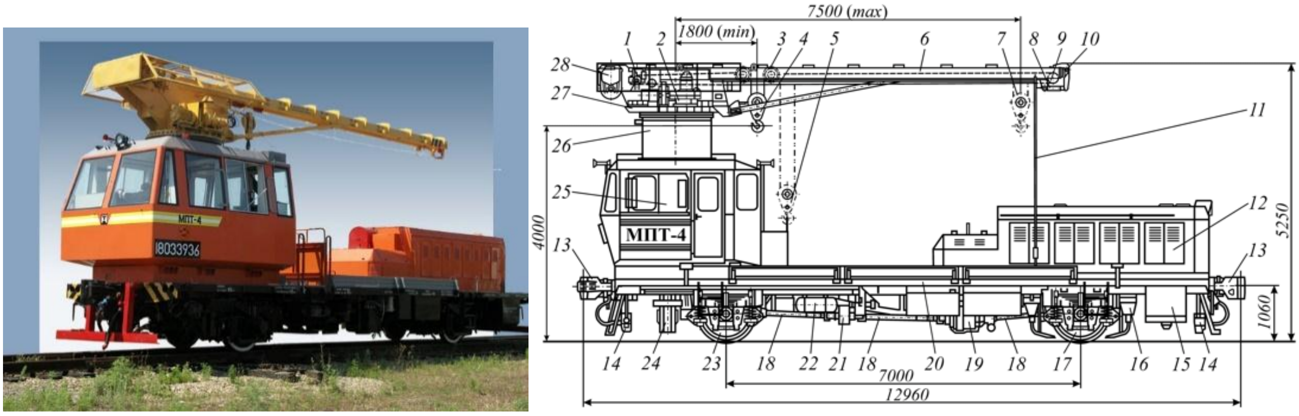

Figure 1: The configuration of the loading transport locomotive LTL-4 (overview):

1 – the pulling winch; 2 - the jib swing drive; 3-the loading trolley; 4, 7 - the extreme positions of the hook block; 5 - the transport position of the hook block; 6 – the jib of the crane; 8 - the warping; 9 – the bypass block; 10 – the load limiter; 11 – the transport spacers; 12 – the diesel generator; 13 – the automatic couplers; 14 – the coils of CLUB-OC; 15 – the fuel tank; 16 – the sandbox; 17, 23 –the driven wheel pairs; 18 – the drive shafts; 19 -the universal hydraulic transmission LT-300; 20 – the platform; 21 – the intermediate support; 22 – the pneumatic system; 24 – the outriggers; 25 – the control foot-plate; 26 -the intermediate crane support; 27 - the base of the crane; 28 – the cargo winch.

The diesel shunting locomotive LTL-6 power unit is located in the middle part under the frame Figure 2, and the power from the diesel is transmitted through: the drive shafts, the distribution gearbox to the hydraulic pumps, the compressor, the hydraulic transmission of the GMP-300; and from it through the universal drive to the axle reducers of the wheel sets and a three-phase generator.

Figure 2: The loading transport locomotive LTL-6 (overview)

The technical characteristics of the diesel shunting locomotives are given in table1.

Table 1: Technical characteristics of the locomotives

Parameter	LTL-4	LTL-6	LTL-6 version 2	LTL-6 version 4
Power of the powerplant, kW	220	220	220	220
Maximum trailer load on site, kN	3000	4000	4000	4000
Speed constructive, km / h	100	100+10	100	100+10
Weight, constructive, not more, t	31,0	28,5	34,0	36,0
Passenger capacity, per	11	11	15	22

The diesel shunting locomotive LTL-6 version 2 (Fig. 3) has a different layout that consists of two cabs (main and passenger with a set of tools) located on the front and rear consoles with control panels and places for the working crew, and a detachable autonomous road workshop in the middle which is equipped with tools and machines.

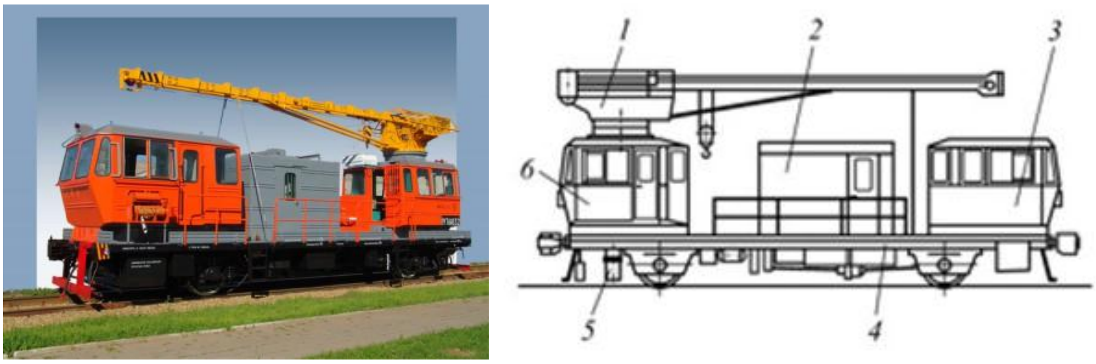

Figure 3: The configuration of the loading transport locomotive LTL-6 (overview): 1 - the jib of the crane; 2 – the locksmith's workshop; 3 – the cabin for transportation of mechanized brigades; 4 – the platform of the locomotive; 5 - outriggers; 6 – the control foot-plate

The shunting movable locomotive SML2 (Fig. 4) is designed to perform heavy shunting operations. The equipment is installed on the main frame which is supported by two three-axle carriages 41. The body of the diesel locomotive of the jib type consists of five main parts: the refrigerating compartment, the compartment above the diesel room, the compartment above the hardware (high-voltage) chamber, the driver's foot-plate and the compartment above the battery room. The rest of the body is welded to the main frame. In the diesel compartment on the main frame there are a diesel generator 12, a compressor 14 and other mechanisms.

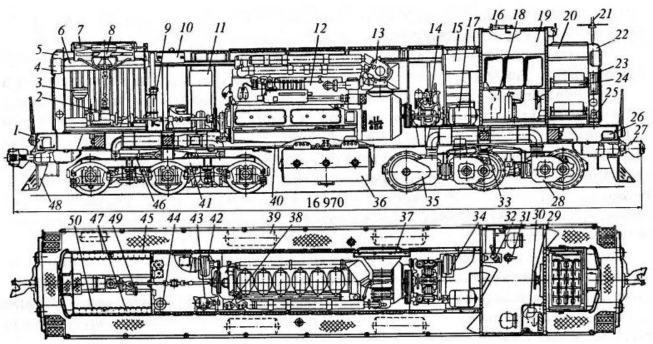

Figure 4: The Shunting movable locomotive SML2:

1-the buffer lamp; 2-the gearing ventilator of the refrigerated store; 3-the sidemount deflector blades; 4-the headlight; 5-the front leading; 6-the refrigerated store; 7-the cooling air baffle; 8- the gearing ventilator of the refrigerator; 9-the oil filters; 10 – the water tank; and - the oil tank; 12 – the diesel generator; 13 -the turbocharger; 14 - the compressor; 15-the high-voltage (hardware) camera; 16-the sound signal; 17-the twin-engine unit; 18 – the control panel; 19 – the driver's cab; 20 – the battery room; 21 – the antenna; 22 – the rear leadings; 23-the transceiver; 24-the rechargeable battery; 25-the converter; 26-the power unit of the radio station; 27-the automatic coupler; 28-the traction electric motor; 29-the hand brake; 30-the heater; 31 - the crane operator; 32 – the controller; 33 - the central bolster; 34 - cooling ventilator of traction electric motors of the rear trolley; 35 – the gearing case; 36-the fuel tank; 37-the air cleaner (air filter) of the diesel; 38-the fuel coarse filters; 39-the main reservoir; 40-the main frame of the locomotive; 41 - the trolley; 42 - cooling ventilator for traction motors of the front trolley; 43-the oil- and fuel-priming pumps; 44-the fuel pre-heater; 45-the oil cooling sections; 46 – the frame support; 47-the water cooling sections; 48 – the purifier; 49 – the water pump of the charge air cooling circuit; 50 – the water cooling sections for intercooling

From the main generator shaft through a special plate (packet) clutch, the rotation is transmitted to the brake compressor 14 which is located behind the generator and through the vane-driven transmissions to the twin-machine unit 17 and the cooling ventilator 34 of the traction motors of the rear trolley.

The driver's foot-plate inside has a heat and antidrumming compound (Figure 5).

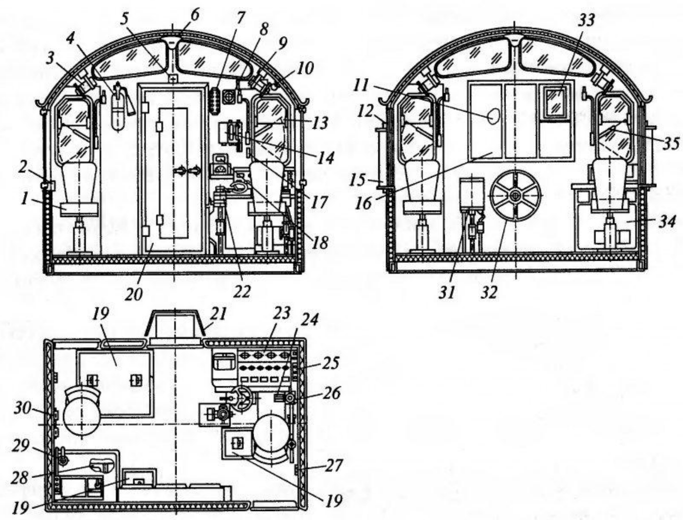

Figure 5: The location of the equipment in the cab (foot-plate) of the locomotive driver SML2:

1-the seat; 2 – the armrest; 3 - the ventilator; 4 – the fire extinguisher; 5 – the locomotive signaling button (white light); 6 - the lamp; 7 – the traffic light; 8 -the temperature sensor TSCB-53; 9 – the speaker; 10 - the lamp of green light; 11 – the cabinet unit; 12 – the sliding window; 13 –the inside board; 14 - control panel of the radio station; 15 – the paravan; 16 - the electric scheme; 17 – the paper holder; 18 – the speedometer; 19 – the floor hatches; 20 - the door to the hardware room; 21 – the block for opening the door to the hardware room; 22 - the crane operator; 23 - the control panel; 24 – the on/off sanding gear control sandbox; 25 - portable console; 26.29 – the auxiliary brake cranes; 27 –the ashtray; 28 - the heater; 30 –the signal valve; 31 – the electropneumatic valve EPK-150SB; 32 – the handbrake control; 33 - the mirror; 34 - the driver's desk; 35 – the windshield wiper

Diesel locomotives ChME3, ChME3T and ChME3E are designed for shunting and export operations. The diesel locomotive of the ChME3 series has a body of a hood type. The main power and auxiliary equipment of the ChME3 diesel locomotive is installed on the main frame (Figure 6).

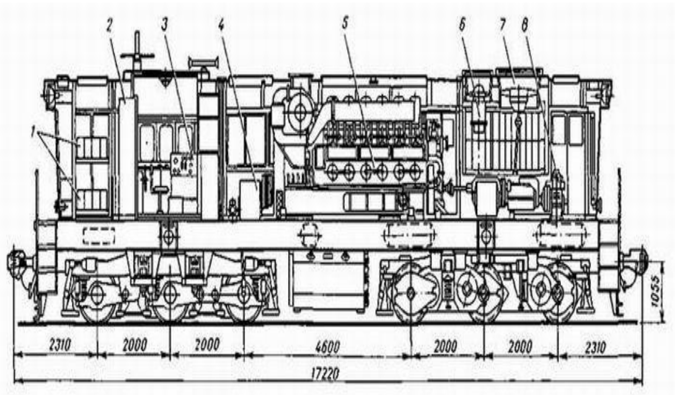

Figure 6: The location of the equipment on the locomotive of the ChME3 series:

1 – the rechargeable batteries; 2 – the high-voltage cabinet; 3 - the control panel; 4 - cooling ventilator of traction motors; 5 – the diesel engine; 6 – the motor-ventilator of the refrigerator; 7-the refrigerator fridge; 8 – the compressor

In the middle of the main frame there is a diesel generator set 5 consisting of a four-stroke six-cylinder diesel K6S310DR with a vertical cylinder arrangement with a capacity of 993 kW (1350 hp) and a traction generator with a direct current of 885 kW. From the front end of the diesel crankshaft through the drive and intermediate shafts and the hydromechanical gearbox, the main ventilator 7 and compressor 8 receive the drive, and through the V-belt the cooling ventilator of the traction motors of the front trolley is driven. The rear flange of the diesel crankshaft is rigidly connected to the anchor of the traction generator. At the end of the armature shaft, a pulley is attached, from which a two-machine unit and a cooling ventilator 4 of the traction motors of the rear trolley are driven via a V-belt drive.

The driver's cab is located between the engine room and the battery room. In the front of the locomotive to the diesel engine there is a refrigerator. The diesel of the locomotive is separated from the driver's cab by a heat and sound-proof wall 7.

Table 2: The main technical characteristics of the diesel shunting locomotives

Parameter	Series of Diesel Shunting Locomotives	
	SML2	ChME3
Constructive speed, km	100	100
Service weight, tons	120	123
Diesel engine power, hp (kW)	1200 (882)	1350 (993)
Type of diesel	PD1M 6CHN31	K6S310DR
Crankshaft rotation speed (nominal), rpm	750	750

The formation of the acoustic characteristics in the drivers` foot-plate of the diesel shunting locomotive and locomotives is determined by the simultaneous impact of the air and structural noise component. The calculation of the sound pressure levels in cabins is determined by the formula

$$L_{\Sigma} = 10\lg(10^{0,1L_a} + 10^{0,1L_s}) \quad (1)$$

where L_a - sound pressure levels of the air noise component dB; L_s- sound pressure levels of the structural noise component, dB.

As the main design scheme of the air noise component in the cabin of the locomotive, the scheme shown in Figure 7 is adopted.

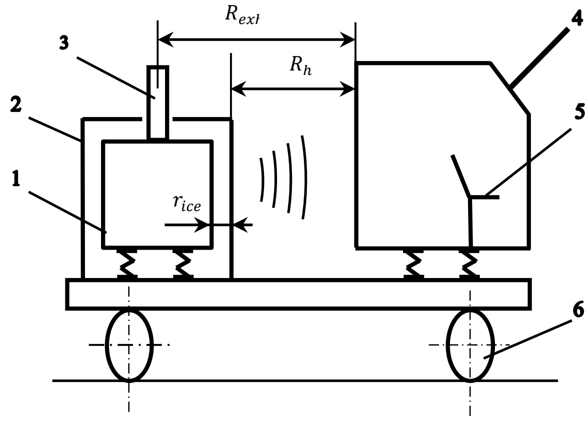

Figure 7: The calculation scheme for the formation of noise spectra of the air component in the cabin:

1-the cabinet ICE; 2-the hood ICE, 3-the exhaust; 4-the foot-plate; 5-the working place; 6-the wheel pairs

At theoretical researches of the noise formation in a cabin the following assumptions are accepted:

- the noise input of the ICE into the cabin through the elements of its blocks with the exception of noise;

- in contrast of the obtained research works [1-7] in determining the impact of noise ICE the simultaneous impact of the sound radiation from the frame of the body, both passed through the hood and the radiation of the hood elements, is taken into account as well as the explosion to the vibration of the carrier frame;

- the noise of the rail put into the cabin through all the elements of the block units including the floor.

$$L_{\text{a cab}} = 10\lg\left(10^{0,1L_{cab}^{exh}} + 10^{0,1L_{cab}^{ice}} + 10^{0,1L_h} + 10^{0,1L_r}\right), \quad (2)$$

where L_{cab}^{exh} and L_{cab}^{ice} are the noise components in the cab in the driver's workplace and are determined with reference to the work data [7] and are given to the following form:

$$L_{cab}^{exh} = L_{exh} - 20\lg R_{exh} + 10\lg\frac{\sum_1^5 S_{cabi}10^{-0,1(SI_{cabi}+t_{di})}}{\overline{\alpha}_{\text{каб}}S_{\text{каб}}} - 17, \quad (3)$$

where L_{exh} - exhaust emission levels, dB;

R_{exh} - distance from the exhaust to the cabin, m;

S_{cabi} and SI_{cabi} - area (m^2) and soundproofing (dB) of the corresponding cabin element;

$\overline{\alpha}_{cab}$ and S_{cab} - average coefficient of sound absorption and the area of the inner surface of the cabin, m^2;

t_{di}- additions to the soundproofing of the i-th element of the enclosure of the cabin depending on the location of the cabin in relation to the noise source, which are determined from Table 3 according to the performed [3,4].

Table 3 Diffraction corrections to sound insulation of the track machines` cabin and road construction machines

Location of the cabin to the source, m	Cabin block elements	Averaged correction values, dB						
		125	250	500	1000	2000	4000	8000
Close to the source $0,1 \leq R_{cab} \leq 2,0$	Side walls	7	7	7	7	7	9	9
	Ceiling	8	8	8	8	8	10	10
	Rear wall	12	12	12	12	12	18	18
$R_{cab} \geq 2,0$	Side walls	9	9	9	9	9	13	17
	Ceiling	9	9	12	12	12	15	18
	Rear wall	14	14	14	14	14	17	20

The noise levels created by the sound radiation of the frame of the body ICE and located under the hood are determined by the formula

$$L_{cab}^{ice} = L_{ice} - 10\lg\left(\frac{\chi}{4\pi r_{ice}^2} + \frac{4\psi}{B_h}\right) + 10\lg\frac{\sum_1^5 S_{hi}10^{-0,1(SI_{hi}+t_{di})}}{\overline{\alpha}_h S_h} +$$
$$+10\lg\frac{\sum_1^5 S_{cabi}10^{-0,1(SI_{cabi}+t_{di})}}{\overline{\alpha}_{cab}S_{cab}} - K10\lg R_h, \quad (4)$$

where L_{ice} - the sound levels of the housing ICE , dB.

The field distortion factor χ [8]:

$\chi = 4$ for $r/l_{max} < 1$;

$\chi = 4 - r/l_{max}$ for $1 < r/l_{max} \leq 3$;

$\chi = 1$ for $r/l_{max} \geq 3$,

where r - is the distance from the center of the noise source to the workplace, m;

l_{max} - maximum dimensions of the noise source, m.

The correction for the near field in the space between the machine and the soundproofing $\chi_{\text{м}}$ assumed equal to 1.

Diffusivity coefficient

$\psi = 1 - 0,3B/S$ when $0 < B/S \leq 1,5$;

$\psi = 0,55$ when $B/S > 1,5$;

where B - is the hood or cabin constant, m^2;

S - the area of the enclosing surfaces of the hood or cabin, m^2.

The constant hood is determined by the dependence

$$B = \frac{\overline{\alpha}\ S}{1-\overline{\alpha}}. \quad (5)$$

where $\overline{\alpha}$ - is the absorption coefficient.

The elements of the cabin have different sound insulation, in particular, the glazing elements have a lower sound insulation compared to the supporting structure. Therefore, the sound insulation of the cabin is determined according to the following relationship [8]:

$$SI = SI_o - \Delta SI, \quad (6)$$

where ΔSI - correction when the weakened fate of sound insulation, dB;

$$\Delta SI = 10\lg\left[S_{cab} + \sum_{i=1}^{n} S_i 10^{0,1(SI_o + SI_i)} \frac{\chi}{4\pi r_{ice}^2} + \frac{4\psi}{B_h}\right] - 10\lg S, \quad (7)$$

where S_{cab} and SI_o - the total area of the basic structure of the cabin (m^2) and its sound insulation (dB);

S_i and SI_i - the area of elements with reduced sound insulation (m^2) and the value of this sound insulation (dB);

$S = S_{cab} + \sum_{i=1}^{n} S_i$ – is the total area of he entire, m^2.

The noise levels created in the cabin by rails are defined as

$$L_{cab}^{r} = L_r - 20\lg R_r + 10\lg\frac{\sum_1^5 S_{cabi} 10^{-0,1(SI_{cabi} + t_{di})}}{\overline{\alpha}_{cab} S_{cab}} + 10\lg(1 - \alpha_b) - 5, \quad (8)$$

where L_r – noise levels from rail, dB;

R_r is the distance from the rail to the calculated point, m;

α_b - coefficient of sound absorption of the ballast layer.

The noise levels created in the cabin by the sound emission of the hood ICE when exposed to vibrations transmitted from the frame are determined by the formula

$$L_{cab}^{h} = L_h - 20\lg R_h + 10\lg\frac{\sum_1^5 S_{cabi} 10^{-0,1(SI_{cabi} + t_{di})}}{\overline{\alpha}_{cab} S_{cab}} - 8, \quad (9)$$

where L_h - noise levels emitted by the hood ICE, dB.

Consequently, to calculate the sound pressure levels in the cabs, it is necessary to determine the octave sound pressure levels emitted by the rails and hood elements of the ICE. It should be noted that the noise levels emitted by the ICE exhaustions are efficient to be taken from the experimental data or from the passport of the corresponding engine. With regard to the noise levels of the housing, it is necessary to use the dependence

$$L_{ice} = 10\lg\frac{\rho_0 c_0 V_i^2 S_{ice}}{10^{-12}} - 8, \quad (10)$$

where ρ_0 and c_0 are the density of air (kg / m3) and the speed of sound in the air (m / s);

V_i - octave amplitude of the vibration velocity of the motor casing, m / s;

S_{ice}- the surface area of the ICE, m^2.

So, in the conditions of the manufacturing plants ice, the theoretical calculation of vibration velocities dvs is practically impossible, it is necessary to use passport or experimental values.

CONCLUSION

The obtained dependences consider the characteristics of the sources of the air component of noise, the geometric and physic-mechanic parameters of the block elements of the driver's cab. The comparison of theoretically calculated sound pressure levels with maximum permissible values gives us results to substantiate at the design stage the sound-absorbing and sound-insulating parameters of the driver's cabin in accordance with the achievement of the sanitary noise standards.

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