METHODS FOR CONTROLLING VIBRATION PARAMETERS OF PASSENGER COACHES

Skachkov, Alexander N., *CJSC Scientific Organization Tver Car Building Institute, Tver, Russia.*
Samoshkin, Sergey L., *CJSC Scientific Organization Tver Car Building Institute, Tver, Russia.*
Zaytsev, Andrey V., *CJSC Scientific Organization Tver Car Building Institute, Tver, Russia.*

ABSTRACT

When the car building plant in Tver began serial production of new generation passenger cars, its specialists had to face the facts of not always justified modification of, it would seem, already comfortable and safe designs. In particular, weakened vibration parameters during the construction of lounge cars, bars, laboratories were found out. The feasibility of reducing the vibration indicators of the lounge car by increasing the bending stiffness of the body and selecting the most rational vertical damper of the central suspension is given.

Keywords: railway, car building, lounge car, vibration, smooth running, bending stiffness, design, testing, parameters' control.

Background. *At the beginning of XX century, Tver Car-Building Plant developed designs and started serial production of a new generation of passenger cars with stainless steel body liner a service life of 40 years (old models have a service life of 28 years). All cars of the new generation are intended for transportation of passengers and maintenance personnel on electrified and non-electrified sections of railways of gauge 1520 mm with speeds of up to 160 km / h.*

Objective. *The objective of the authors is to consider methods for controlling vibration parameters of passenger cars.*

Methods. *The authors use general scientific and engineering methods, comparative analysis, graph construction.*

Results. *The compartment car model 61–4440 is considered as a base car. It is manufactured in two versions – for 36 berths in a four-berth version and for 18 beds in two-berth version of a compartment.*

The car model 61–4445 belongs to the compartment staff car. There is a specialized compartment and toilet for the disabled person with an accompanying person. The car is equipped with a lift for wheelchairs, as well as all the devices and systems necessary for the staff car. There are 26 berths for passengers here.

The car model 61–4447 is passenger non-compartment (car with reserved seat). The passenger section divided by transverse partitions into 9 six-berths sections, which gives 54 berths.

The car model 61–4458 is a passenger car with seats. Number of seats in a car with a standard interior (2 + 2) is 60and for a car with an improved interior (2 + 1) it is 40.

The restaurant car of the model 61–4460 has 32 passenger seats in the cabin and four – in the bar.

The bodies of all the cars of the model range are an all-metal bearing structure of the closed enclosure type with regular cutouts in the side walls for windows and doors, as well as with apertures in the roof for installation of equipment (air conditioning, water tank and boiler).

The center sill of the frame on the consoles and in the pivot zones is made of two channels 30V, in the middle part of one I-beam 30B2. The buffer bars are made of a channel 30V. Pivotal beams of box section: vertical sheets with a thickness of 6 mm, upper and lower sheets – 8 mm. Cross beams in the transition zones from the channels to the I-beam represent curved profiles of variable cross-section with a thickness of 6 mm. The remaining transverse beams are bent channel bars 100 × 60 × 4 mm and 100 × 60 × 5 mm. In the design of the longitudinal beams (bottom rail) of the frame, a 100 × 100 × 8 mm angle section is used. The frame material is steel 09G2S.

The floor covering in the middle part consists of corrugated sheets with a thickness of 1,5 mm, on the consoles – from flat sheets of 2,5 mm.

Stainless steel is used for the side walls of the car. In the lower belt, a single-layer covering is a 2 mm thick corrugated profile with four broad corrugations having the following geometric dimensions: height – 14 mm, width at the base – 120 mm, width at the vertex – 95 mm. Covering is supported by a set of longitudinal and transverse elements (over- and under-wall stringers, binders, racks).

The roof of the body is made of stainless steel. The middle part of the roof is rolled corrugated sheets with a thickness of 1,5 mm, the roof slopes are flat sheets of 2 mm.

The structures fully meet the requirements of sanitary standards for illumination, ergonomics, microclimate, noise and vibrations, safety requirements, as well as for finishing and facing materials.

Cars of all models are equipped with bolsterless bogies with disc brakes of models 68–4095 for the non-brake end of the car and 68–4096 for the brake end. All intra-car and under-car equipment is almost of the same type (except the restaurant car). The cars of the model line passed the acceptance tests and were repeatedly certified for compliance with the requirements of TR CU001/2011 [1] and standard [4]. Tests were conducted using modern methods adopted for mandatory certification [2, 3].

Table 1

Variants of tests of a lounge car on the basis of the compartment car model 61–4440

№ variant	Speed range, km/h	Diesel generator	Reinforcement of the car frame	Note
1	40–120	Installed	No	–
2	40–120	Dismantled	No	–
3	40–120	Installed	Yes	The car frame is reinforced with longitudinal beams

Recently, on the basis of a compartment car model 61–4440, a number of organizations have developed and manufactured lounge cars. Their distinctive feature is the reduction in the number of transverse and longitudinal partitions, which leads to a reduction in the load on the floating floor and a decrease in the number of internal surfaces to be contacted. This redesign reduces the dispersion of vibration energy within the technical system (passenger car) and bending stiffness of the body. In addition, in the lounge cars, as a rule, additional metal-intensive equipment is installed (diesel generator sets, fuel tanks, satellite communication systems, etc.), which adversely affects the body vibration level and affects the comfort level of passengers [5].

In 2014–2016, Tver Car-Building Institute carried out research aimed at eliminating excessive vibration in the interior of lounge cars [6].

PCTB for cars of JSC Russian Railways (Moscow) on the basis of model 61-4440 designed a lounge car, the layout of which is shown in Pic. 1. This car has a significantly changed layout, two transverse partitions in the cabin and one in the guest compartment and the VIP-compartment were removed. Under the car in the central zone, a diesel generator weighing about 750 kg and a fuel tank with a capacity of 250 liters are suspended.

When testing the lounge car in its separate sections, an increased level of vibration was again observed. To eliminate it, the strengthening of the central part of the frame with additional longitudinal beams was developed and implemented. In addition, during running tests, the influence of a suspended diesel generator was evaluated. In total, the car was tested in three different variants, listed in Table 1.

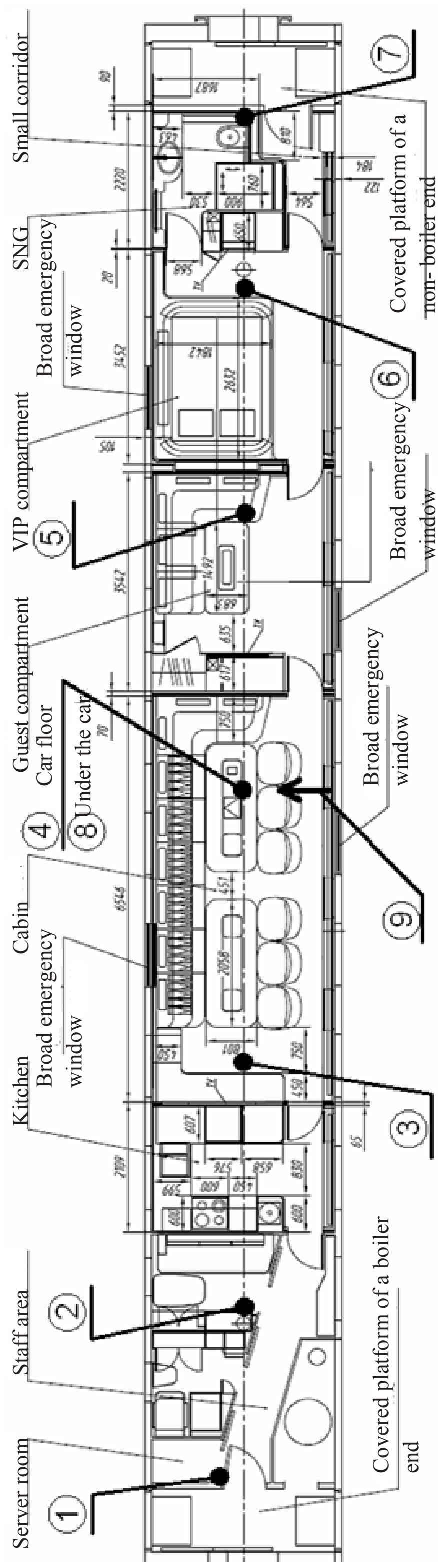
The reinforcement of the car frame is shown in Pic. 2.

In accordance with the purpose of the tests, an experimental train was formed to determine the values of maximum, rms values of vibration acceleration in the frequency range from 0,5 to 40 Hz and the indicators of the smooth run. The works were carried out on the section of the main tracks of the October Railway from station Tver to the station Moscow. The test car, mounted on bolsterless bogies of models 68–4095 and 68–4096, was in the middle of the train and was separated from the locomotive and the end of the train by the cover cars.

The tests were carried out using the noise-vibrometric complex «Ecophysics» with accelerometers of the AR-2082M type and the measuring amplifier MGCplus with accelerometers of the ARF-10A type. The equipment is checked in due course. The test procedure was chosen in accordance with [2].

The evaluation of the dynamic characteristics of the car was carried out in the speed range of 40–120 km / h by measuring vibration acceleration with accelerometers installed in seven zones inside the car along the floor, as shown in Pic. 1. The duration of the measurements in each zone and at each speed was at least 200 s. If necessary, the total measurement time was divided into intervals of shorter duration.

Table 2 shows the root-mean-square levels of vibration acceleration in the vertical direction in the problem zone – the location of the accelerometer 4 (middle–floor of the car) for the one-third octave frequency bands and the speeds at which the excesses were recorded. The table also indicates the permissible values of root-mean-square levels of



Pic. 1. Layout and scheme of arrangement of accelerometers in the interior of the lounge car on the basis of the compartment car model 61–4440.
• – accelerometers 1–7, fixing vibration acceleration in the vertical direction and mounted on the floor of the car; ↑ – accelerometer 9, fixing vibration acceleration in the transverse direction and mounted on the sidewall of the car; (1) – numbering of accelerometer installation zones.

Table 2

Root-mean-square levels of vertical vibration acceleration in the accelerometer installation zone 4 (middle – floor of the car)

Speed, km/h	Frequency bands, Hz	Permissible values, m/s^2	№ variant		
			1	2	3
80	8,0	0,11	0,31	0,22	0,08
100	8,0	0,11	0,26	0,25	0,11
	10,0	0,14	0,23	0,22	0,13
120	8,0	0,11	0,14	0,18	0,09
	10,0	0,14	0,18	0,19	0,12

Table 3

Indicators of smooth run in the vertical direction at different speeds in the installation area of the accelerometer 4

Speed, km/h	Permissible value	№ variant		
		1	2	3
80	3,25	2,67	2,51	2,49
100		2,69	2,61	2,52
120		2,66	2,59	2,47

vibration acceleration in accordance with [7]. Note that for other frequency bands and the speed the excess of the allowed values is not fixed.

Table 2 shows that the completion of the car according to the 3rd variant (the frame of the car is reinforced with longitudinal beams (Pic. 2)) ensures the reduction of maximum values of vertical vibration acceleration in the problem central part of the car (accelerometer installation zone 4) to a level below the permissible values at speeds of movements of the test train of 80, 100 and 120 km / h.

Thus, for the lounge car manufactured on the basis of the passenger compartment car of the model 61–4440, the task to reduce the level of vibration acceleration was solved by detuning from the resonance due to the increase in bending stiffnes of the body.

In addition, during running tests of the car, a smooth run index was determined. Table 3 shows the obtained indicators of smooth run in the accelerometer installation zone 4.

Analyzing Table 3, we can note the following results, which can be used in further work on the control of the vibration characteristics of passenger cars, namely:

– installation of a diesel generator on an non-reinforced car frame increases (worsens) the smooth run index to 7 % (it follows from the analysis of the results of the test variants № 1 and № 2);

– reinforcement of the car frame reduces (improves) the smooth run indicator to 8 % (follows from the analysis of the results of the test variants № 1 and № 3).

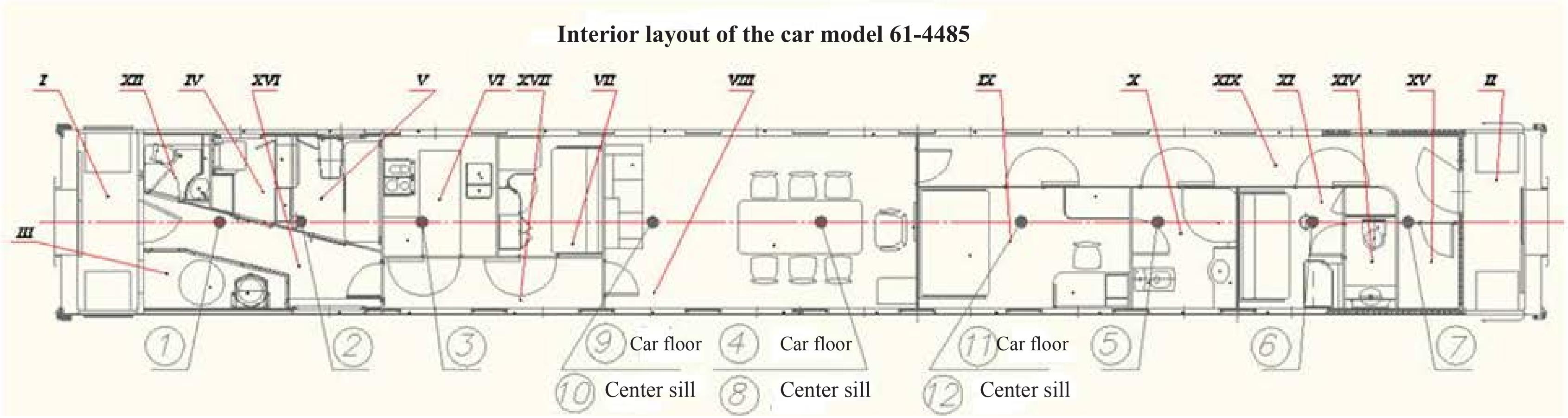
Pic. 2. Frame of the car, reinforced with longitudinal beams.

On the basis of the compartment car model 61–4440 lounge car model 61–4485 was developed and manufactured. During the tests, it shows an increased level of vibration in individual sections. Pic. 3 shows the layout of the lounge car. It can be seen that the transverse partitions in the cabin (2 pcs.) and the compartment-cabinet (1 pc.) were removed. In addition, the longitudinal partition of the large corridor was «torn». From the boiler end of the car to the cabin, the longitudinal partition is located along the boiler sidewall. From the cabin to the non-brake end of the car, the longitudinal partition is located along the non-boiler sidewall.

At the stage of preparation of recommendations on elimination of excessive vibration in individual sections of the lounge car of the model 61–4485 equipped with bolsterless bogies models 68–4095 and 68–4096 with disk brakes, the range of studies was expanded in comparison with the lounge car manufactured on the basis of serial compartment car model 61–4440.

To solve the problems, a number of dynamic running tests were carried out in various directions, with subsequent refinement of the body and selection of the most rational vertical damper of the central suspension. Evaluation of the dynamic characteristics of the car was carried out in the speed range from 50 to 120 km / h in increments of 10 km / h. The scheme of installation of accelerometers is shown in Pic. 3, and Table 4 shows the routes and variants of modernization of the lounge car.

At first, the frame of the car was reinforced in the middle part with longitudinal elements. As the trips and vibration measurements were made, the number



I – covered platform of the brake end of the car
II – covered platform of the non-brake end of the car
III – boiler room
IV – service room
V – compartment for rest of conductors, communications and video surveillance
VI – compartment- kitchen
VII – 2-seat passenger compartment (referent)
VIII – parlour
IX – compartment of the main passenger
X – toilet room of the main passenger
XI – 2-seat passenger compartment
XII – toilet of the general use of the brake end of the car
XIV – toilet room of the guest compartment
XV – wardrobe room (utility room)
XVI – corridor of the brake end of the car
XVII – small corridor
XIX – corridor of the non-brake end of the car

Pic. 3. Layout and diagram of arrangement of accelerometers during running tests.
• – accelerometers 1–7, 9, 11, fixing vibration acceleration in the vertical direction and installed on the floor of the car (accelerometers 8, 10, 12 fixing vibration acceleration of the center sill); (1) – numbering of accelerometer installation zones.

Table 4

Test variants of the lounge car model 61-4485

№ variant	Speed range, km/h	Route	Reinforcement of the car frame	Note
1	50–120	Moscow–St.Petersburg	No	–
2			Yes	Car frame is reinforced with longitudinal beams
3			Yes	Car frame was reinforced with longitudinal beams. Vertical and horizontal hydraulic dampers of central suspension of Sachs company were substituted with the dampers of CJSC «Vagonkomplekt»

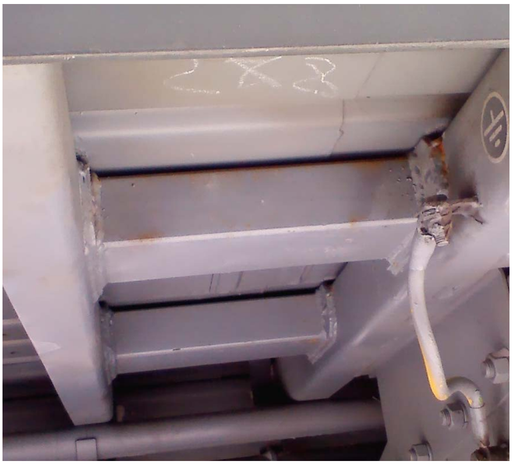
Table 5

Root-mean square levels of vertical vibration acceleration in the problem zones of the lounge car model 61-4485

Speed, km/h	Frequency bands, Hz	Permissible values, m/s^2	№ variant		
			1	2	3
80	8,0	0,11	0,38	0,11	0,04
	10,0	0,14	0,06	0,09	0,03
90	8,0	0,11	0,66	0,16	0,10
	10,0	0,14	0,06	0,08	0,04
100	8,0	0,11	0,16	0,07	0,05
	10,0	0,14	0,28	0,13	0,09
110	8,0	0,11	0,17	0,10	0,06
	10,0	0,14	0,28	0,14	0,08
120	8,0	0,11	0,13	0,05	0,04
	10,0	0,14	0,25	0,14	0,09

of reinforcing longitudinal elements increased and eventually the overall reinforcement resulted in four composite longitudinal beams, two of which are located near the longitudinal binders, and the other two around the I-beam of the middle part of the composite center sill. Pic. 4 shows the element of the car frame, reinforced with longitudinal beams.

The results of tests at different speeds for determining the root-mean-square levels of vertical acceleration in problem zones are given in Table 5, and the indexes of smooth run in the vertical direction in Table 6.



Pic. 4. Car frame reinforced with longitudinal beams.

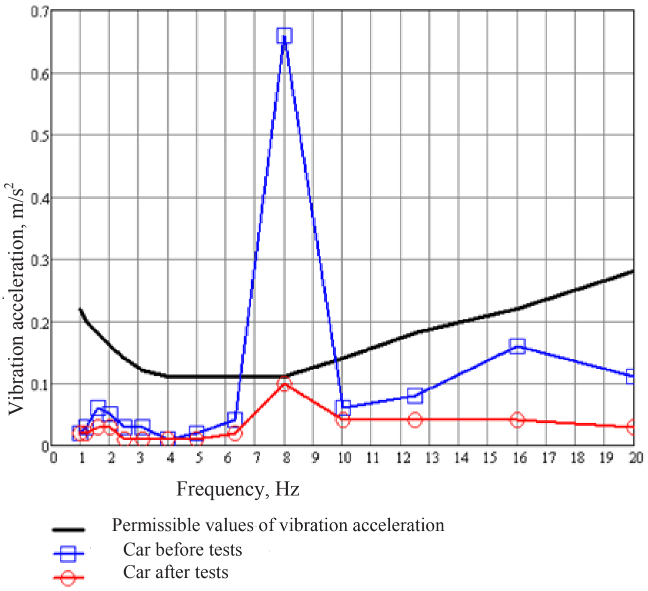
Estimating the results of work on the lounge car model 61–4485, it can be noted that the task of reducing the levels of vibration acceleration is solved by detuning from resonance by changing the characteristics of the system (increasing bending stiffness of the body) and optimizing the spring suspension by installing the most optimal dampers for domestic railways. In Pic. 5 shows the average vibration levels obtained in the performance of a lounge car in accordance with variant № 3 of Table 4.

Conclusions. *When manufacturing other types of cars (lounges, bars, laboratories) on the basis of serial compartment passenger cars, an increase in*

Table 6

Indicators of smooth run in the vertical direction at various speeds of the lounge car model 61-4485

Speed, km/h	Permissible value	№ variant		
		1	2	3
50	3,25	2,33	2,23	2,10
60		2,34	2,25	2,11
70		2,49	2,29	2,12
80		2,68	2,34	2,13
90		2,82	2,40	2,19
100		2,63	2,35	2,18
110		2,68	2,41	2,21
120		2,63	2,42	2,23



Pic. 5. Average vibration levels at the speed of the test car of 90 km / h (accelerometer installation zone 9 in Pic. 3).

vibration acceleration is possible in comparison with the requirements of normative documents. The main reason is the radical redevelopment of the interior of the car (reducing bending stiffness of the body) and the installation of additional material-intensive intra-car and intensive intra- and under-car equipment.

As the tests showed, the elimination of high vibration in such cars is an expensive and time-consuming measure. In connection with this, the development of methods for controlling parameters of bending oscillations and vibration parameters of passenger car bodies becomes an urgent task. Moreover, the required method should cover all stages of the creation of cars, including the preparation of design documentation, the manufacture and testing of prototypes, their transfer to production.

For models of cars that are manufactured on the basis of the basic model 61–4440, when introducing vibration control methods, first of all, it is necessary to provide a procedure for calculating the natural frequencies and forms of vertical bending oscillations of the body, taking into account the deformation of the cross-sectional contour of the body and the location of the most material-intensive intra- and under-car equipment.

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Information about the authors:
Skachkov, Alexander N. – Ph.D. (Eng.), director of CJSC Scientific Organization Tver Car Building Institute, Tver, Russia, +7 (4822) 55–54–32.
Samoshkin, Sergey L. – D.Sc. (Eng.), head of the department of CJSC Scientific Organization Tver Car Building Institute, Tver, Russia, +7 (4822) 79–40–33.
Zaytsev, Andrey V. – head of the laboratory of CJSC Scientific Organization Tver Car Building Institute, Tver, Russia, labr7@yandex.ru.

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