STUDY OF BODY STRENGTH OF NEW GENERATION ELECTRIC TRAIN CARS

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ABSTRACT

Basing on computational-experimental methods, theoretical and experimental studies were carried out in Tver on carrying capacity of car bodies of electric trains of the new generation EG2Tv under the influence of various normative stresses. Based on the preliminary evaluation of stress-strain state individual components of the metal structure of bodies were changed. The results of static strength tests showed that the main indicators of strength of the body fully comply with the requirements of standards and thus the rationality of the decisions made is confirmed. Taking into account the positive results of the tests, the bodies were transferred for further tests, namely, to determine the parameters of flexural vibrations.

Keywords: *EG2Tv electric train, body metalwork, strength, bearing capacity, regulatory requirements, permissible stresses.*

Background. *The creation of EG2Tv electric train model 62-4496 was one of our joint innovative works with OJSC «Tver Car Building Plant». The main prerequisite for emergence of a new generation of electric trains was the need to improve economic efficiency of passenger transportation by intracity rail transport and to provide a modern level of comfort for passengers.*

The train consists of three types of cars: the head model 62-4497, the motor model 62-4498, and the non-motored (trailed) model 62-4499. The train composition patterns are determined by the customer and may include from 5 to 12 cars of various types. Table 1 shows the main technical parameters of EG2Tv. In this case, the following designation of car models is accepted: head – H, motor – M, non-motored (trailed) – N. Electric train movement is carried out at speeds of up to 120 km/h in electrified sections of 3 kV DC.

A general view of a fully formed electric train is shown in Pic. 1.

Objective. *The objective of the authors is to consider the issue of strengthening body strength of cars of the new generation train EG2Tv.*

Methods. *The authors use general scientific and engineering methods, simulation, computational and experimental methods, evaluation approach, statistical method.*

Results.

I.

The bearing metal structures of an electric train's car bodies are generally similar, made of the same steel, and differ only in individual structural units, due to the purpose of the cars. The car bodies are an all-metal supporting structure of a closed shell type with cutouts for windows and doors, flat exterior paneling of side and end walls, a roof of the frame structure with flat corrugated paneling and cutouts for equipment, as well as a floor of corrugated sheets. Bearing shell is supported by longitudinal and transverse stiffeners. Body frames consist of longitudinal and transverse beams (main beam, framing, pivot, transverse beams), on which floor paneling is installed.

Pic. 1. Electric train EG2Tv «Oriole» (Ivolga) at the testing track of VNIIZhT. Photo: S. D. Korshunov.

Table 1

The main technical parameters of electric trains and cars

Parameter name	Parameter value			
	El. tr. 2H+3M	Electric train cars		
		H	M	N
Tare weight, not more, t	249,7	48,5	50,9	45,5
Number of seats, pcs.	226	24+2	58	58
Estimated occupancy (with a density of standing passengers 3 people/m^2), people	836	130	192	192
Maximum load from the wheel set on the rail, not more, tf	–	19	20,5	19
Total power (hourly), KW	3600	–	1200	–
Length of the electric train of the main composition, m	116	23,8	22,8	22,8
Car base, m	–	15,0	15,0	15,0
Bogie base, m	–	2,6	2,6	2,6
Bogie weight, not more, kg	–	7000	10000	7000
Service life, years	40	40	40	40

Table 2

Mechanical characteristics and allowable stresses (MPa) for steel

Strength grade, steel grade	$\sigma_{v\,min}$	σ_t	I mode	II mode
			[σ]	[σ]
EN10088–2-X6GrNiTi 18–10+2B	370	260	260	175
345D, 09G2S/(09G2SD)	480	345	345/326	220/210

Table 3

Magnitude of main forces for calculating strength

Design parameters	Design modes	
	I	II
Longitudinal force, MN	-2,5	±0,4
Vertical static load	gross body	gross body
Vertical dynamic load	not taken into account	K_d* gross body
Lateral forces	not taken into account	12,5 % from gross body

Note: sign «+» for tensile strength, sign «–» for compressive strength.

The driver's cabin of the head car is made as a separate module and is attached to the supporting structure of the body by bolted connections. The steel frame of the cabin has a truss structure, the elements of which are welded closed profiles of rectangular cross section. The cabin safe guard is formed of plastic panels. The supporting elements of the body frame are made of low-alloy steel 09G2S according to GOST [Russian state standard] 19281, the exterior paneling, the body frame is made of stainless steel EN10088 2 X6CrNiTi18–10+2B.

The main units of bogies comprise frame, two wheel sets, four sets of axle box suspensions, central suspension, disk brake, lemniscate mechanism, bandage cleaning units (if any), equipment of the combing system, mounting brackets for mounting KP-RS rail signals, electrical installation of the bogie. The frame is the supporting element of the structure. The whole complex of equipment ensuring the work of the bogie is mounted mainly on the frame or with support on it.

Two-stage suspension is axle box spring and pneumatic central. In the central suspension, two pneumatic springs are applied, on which the car body rests.

Air springs with rubber-cord diaphragm shells with vibration-absorbing rubber-metal supports are installed on the supporting surfaces of the frame. Hydraulic dampers are used: vertical – to dampen the body's vertical oscillations relative to the bogie frame, horizontal – to dampen horizontal oscillations in the transverse direction, and wobble dampers – to dampen the oscillation of wobbling of the bogie.

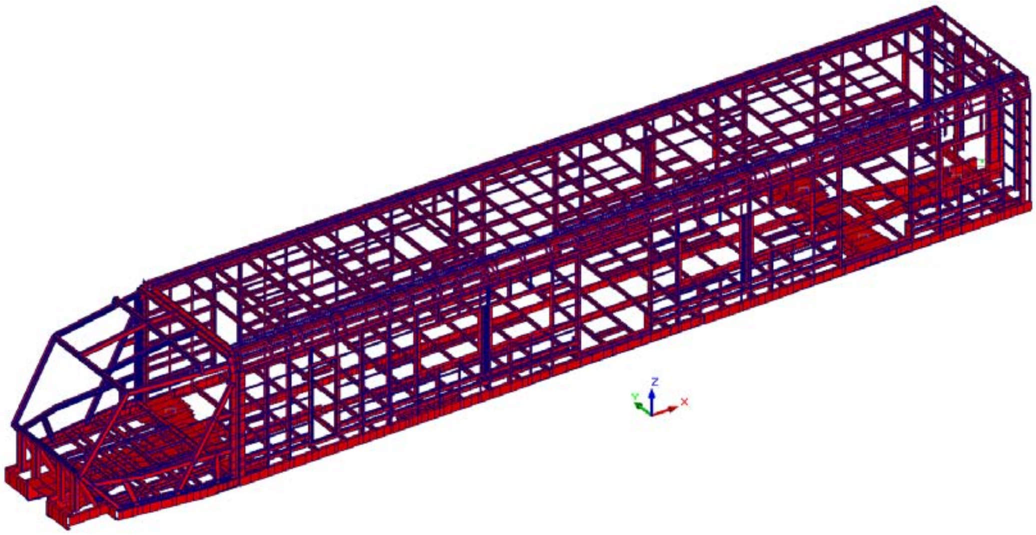
The wheel sets are made with wrought wheels and brake disks fixed on them, axle boxes are with roller rolling bearings. In axle box suspension, lever-type axle boxes with rubber-metal hinges are used to connect the wheel set to the bogie frame, sets of coil springs and hydraulic axle box dampers – for damping vertical oscillations of the bogie frame.

All bodies of electric train cars are longer compared to the cars of operational fleet and have wider doorways, increased capacity and additional equipment to ensure the modern level of comfort. In this regard, the requirements for the overall weight

Table 4

Reduced thickness (δ_{red}), elastic moduli and Poisson's ratios (E_x, ν_x, E_y, ν_y) for body panels

Panel name	δ, mm	δ_{red}, mm	E_x, MPa	ν_x	E_y, MPa	ν_y
Floor smooth	4,0	4,0	200000	0,3	200000	0,3
Floor corrugated	1,5	1,55	200000	0,3	479,4	0,00072
Lower and middle sidewall belts	2,0	2,0	200000	0,3	200000	0,3
Top belt of the side wall	2,0+1,0	3,12	200000	0,3	14652	0,022
Roof smooth	2,0	2,0	200000	0,3	200000	0,3
Roof corrugated	1,5	1,74	200000	0,3	323,0	0,00048
End wall	2,0	2,0	200000	0,3	200000	0,3



Pic. 2. Calculation scheme of the FEM of the body of the head car of the electric train (frame elements).

Table 5

Values of maximum design stresses (σ_x, MPa) in body paneling

Name of the structural element	σ_x			
	I mode	II mode(–)	II mode(+)	at repair loads
Flooring in the cabin	-235	114	144	94
Flooring in the driver's cab	-114	30	61	±25
Side wall 1	-202	-118	141	-195
Side wall 2	-204	-119	144	-98
Roof	40	-50	-60	-72
End wall	36	14	24	-30

parameters of the body and their carrying capacity are of paramount importance [1, p. 37; 2, p. 34; 3, p. 204; 4, p. 61].

II.

Let's start with the calculation of the body at the example of the most complex head car.

Table 2 shows the strength characteristics and allowable stress of materials in manufacture of the body. The denominator indicates the calculated stresses for the spinal and pivot beams [5, p. 33; 6, p. 10; 7, p. 12; 8, p. 47].

When performing calculations, the following initial data were taken:

Length of the body frame – 22,140 m.

Car base – 15,000 m.

Body width outside framing – 3,476 m.

Height of the body from the top of the pivot beam to the top of the corrugation of the roof – 2,925 m.

Constructional speed – 33,3 m/s (120 km/h).

Coefficient of vertical dynamics (taking into account the influence of lateral forces) – 0,214.

Tare of the body in the equipped state – 36000 kg.

Workload – 19310 kg.

Strength calculations were performed regarding the loads shown in Table 3.

I mode – conditional safety mode. It takes into account the possibility of occurrence of significant longitudinal forces due to shunting, transportation and emergency collisions.

II mode – operational, takes into account the forces acting on the body during acceleration of the

Pic. 3. The application of the vertical load on the metal work of the car body with pneumatic equipment.

Table 6

Values of maximum calculated normal stresses (σ_x, MPa) in the elements of the body frame

Name of the structural element		Stress range on I mode
main beam	center of the car	from -183 to -223
	behind the driver's door	from -291 to -298
	under the window	from -221 to -269
	console behind the pivot beam	from -225 to -320
	console of the head end	from -141 to -256
pivot beam	right end of the car	from -187 to 214
	head end of the car	from -147 to -159
frame binding	in the area of the right door	from -245 to -252
	in the area of the middle door	from -156 to -175
cross beams	100×60×4	from -251 to 169
	100×60×5	from 228 to 264
	80×60×5	from -189 to 234
longitudinal beams	door pillars	from -168 to 230
	roof framing	from 138 to 263
	roof stringer	from -145 to -301
	cabin beams	from 120 to 204

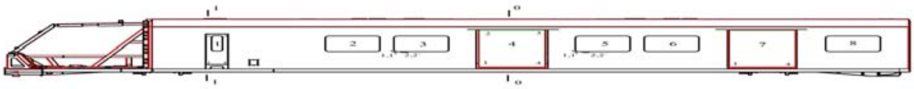
train to the design speed, running on the coast or braking from this speed when passing the curve.

To create the FEM computation scheme, the SCAD design and computing complex was used [9–10]. In the calculation, smooth sheets were modeled by isotropic flat elements, and the corrugated siding panels – by flat orthotropic elements having a reduced thickness (δ_{red}). The given thickness of cladding panels (δ_{red}), as well as elastic moduli and Poisson's ratios along (E_x, ν_x) and across (E_y, ν_y) of the panels are given in Table 4. For flat isotropic elements $E_x = E_y$, $\nu_x = \nu_y$ the frame elements were modeled by core elements. When creating a design scheme, an eccentric connection of frame elements with paneling was taken into account. A fragment of the design scheme is shown in Pic. 2. The scheme contains 6650 units, 11845 elements, the order of the system of equations is about 40000 unknowns.

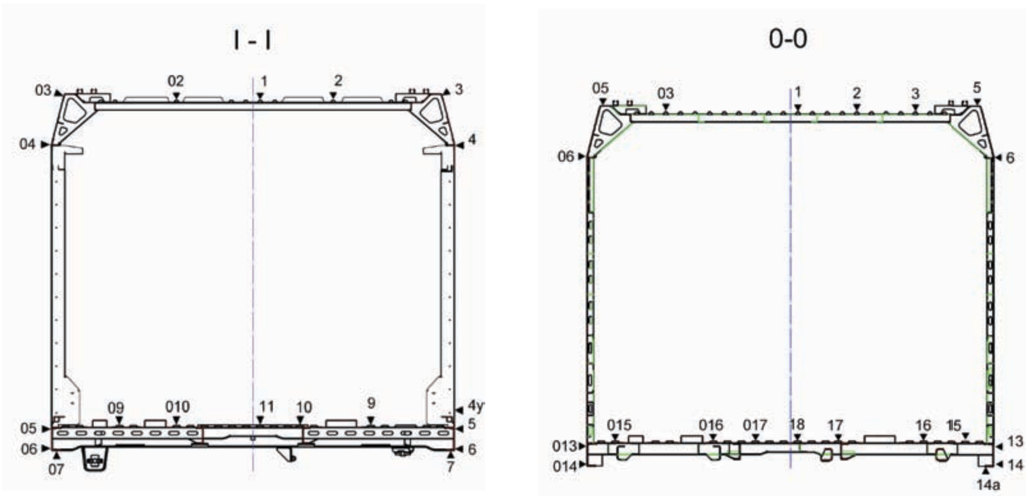
Fixing the design scheme in space as a solid when calculating by the modes was provided by four vertical Z-axis linear connections in the body mounting points on the pneumatic springs, two longitudinal linear connections along X axis at the place of application of the longitudinal load (at one end of the frame), as well as two additional cross linear links along Y axis at the ends of the body.

The vertical distributed load was applied across the floor area and the horizontal projection of the roof. The vertical load from equipment having a substantial mass was taken into account separately as a nodal load. Longitudinal forces with attached moment were applied to the front (tensile) or rear (compressive) resistant squares.

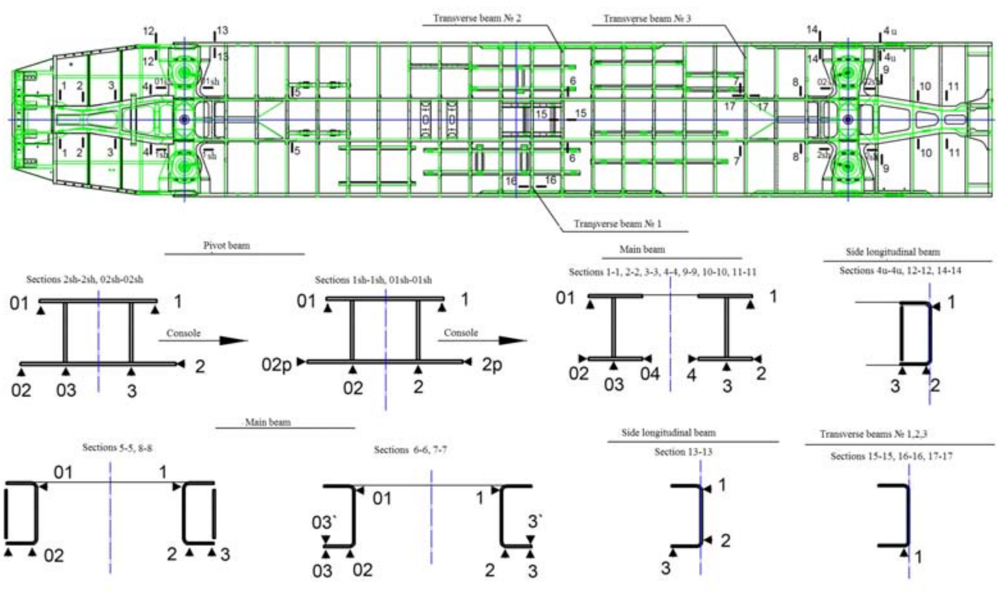
The results of the calculations are presented in tables 5 and 6, where the values of normal stresses for the most loaded elements of paneling and body frame are given.



Pic. 4. The layout of the considered sections on the body of the head car model 62–4497.



Pic. 5. Installation scheme of strain gauges in sections 0–0 and I–I of the car body of model 62–4497.



Pic. 6. Layout of cross sections and installation of strain gauges on the main bearing elements of the body of the head car model 62–4497.

Analysis of the calculation results showed that the head car bodies of EG2Tv electric train, as well as the motor (M) and non-motor (N) cars, meet the requirements for durability [5, p. 179].

III.

Body tests for durability under static action of normative loads were carried out in the premises of the experimental workshop of the car building institute on a special stand equipped with a hydraulic power system with load-bearing devices and allowing to create longitudinal (tension-compression), as well as vertical and repair loads [11, 12].

Vertical dead weight and gross loads were created by regular pneumatic devices of the stand, discretely distributed on the floor of the car bodies. Pic. 3 shows the application of the vertical load on

Table 7

Values of the maximum stress in the structural elements of the body of the head and motor cars (modified design)

Structural element	Allowable stresses on I design mode, MPa	Maximum experimental stresses on the body of the head car, MPa	Maximum experimental stresses on the body of the motor car, MPa
Roof	260	28	35
Doorway	260	130	76
Car frame. Main beam	345	331	301
Car frame. Pivot beam	345	271	244
Car frame. Side beam of the frame	345	238	220
Car frame. Cross beam of the frame	345	128	213

the metal structure of a motor car using pneumatic equipment.

During the tests the bodies were exposed to the standard static loads provided [5, p. 179; 6, p. 10].

Longitudinal loads:

- *compression along the axles of coupling devices 1,0 MN;*
- *compression along the axes of coupling devices 2,0 MN;*
- *stretching along the axles of coupling devices 1,0 MN.*

Vertical loads (according to the strength calculation):

- *vertical load, imitating dead weight of the car body;*
- *vertical load, imitating gross weight of the car body.*

The loads arising during repair:

- *lifting the empty body bearing against the ends of the pivot beam;*
- *lifting the loaded body bearing against the ends of the pivot beam;*
- *lifting the empty body leaning on the ends of the pivot beams and using three jacks;*
- *lifting the empty body diagonally, bearing against the ends of the pivot beams;*
- *emergency lifting of the empty body leaning on the coupling device with imitation of the mass of the motor bogie of 10 tons.*

The layouts of cross sections and placement of strain gauges on the body of the head car are shown in Pic. 4–6. For other models of cars they are not fundamentally different.

The experimental data obtained during testing of the metal structure of the head car body showed that the decisive load in terms of strength is compression along the axes of the coupling devices, and the main unit loaded is the body frame. In this case, the main part of the longitudinal loads is perceived by main and pivot beams. The highest stresses were recorded in the zones of connection of the main and pivot beams, where they reached 331 MPa in the rear section of the body, and slightly lower at the head, which is associated with transfer of the part of the load by the beams of the driver's cab frame to the bearing elements of the body. For the same reason, the stresses in the pivot beam of the head end of the body are lower than in the pivot beam of the rear end, where their value did not exceed 187 MPa. The stress distribution over the cross-section of the main beam is typical for bending in the horizontal plane and is associated with a change in its geometry in the plan [13–15].

Side longitudinal beams perceive a significant proportion of longitudinal loads, but have a pronounced uneven distribution of stresses across sections, due to door cuts in the sidewalls and, as a result, significant changes in the geometric characteristics of the bearing elements of the body. Thus, the stress in the areas of joint of the longitudinal beams with the pivots is almost two times higher than in the middle part of the body. The effect of other test loads (vertical, repair and emergency lifts) causes stresses of the order of 100–110 MPa only at certain points of the structure. Their average level is within 30–60 MPa.

From the results of the preliminary testing of the motor car, it follows that the most intense structural element is the main beam in sections 3–3 and 5–5, where, in the first design mode, the stresses came close to the allowable. The load that determines the stress state of these zones becomes a compressive load of 2,0 MN along the axes of the coupling devices. It led to the slight deformation of the hitch plate of the coupling device. The pivot beam proved to be less loaded, its sections showed no stresses exceeding the allowable ones. The largest values were fixed at the radii of transition of the lower sheet and along the edges of the upper sheet in the sections Ish-Ish and 0Ish-0Ish. In the other elements of the pivot beam, the stresses did not exceed 100 MPa, and it is possible to assume an excess safety factor for mode I.

The sufficiently high rigidity of the pivot beam makes it possible to transfer considerable loads to the side beams of the frame, which determines their optimal loading in the pivot section I–I. In the corners of the window cut-outs, the median stress values are within 70–80 MPa, the same level is noted in the corners of the door cut-out, window pillars, stringers, and piers. The effect of repair loads does not cause significant changes in the stress state of the bearing elements compared to the effect of the vertical gross load. The exceptions are the corners of the window and door cuts, but in these zones the level of median stresses does not exceed 70–80 MPa. When lifting an empty body with unladen weight with two jacks diagonally, the local deformation of the exterior paneling of the body in the jack installation zone is observed.

Examination of the results of static tests in the areas of maximum stresses showed that this applies to the lower shelves of the longitudinal elements of the main beam. Thus, over the cross section of the spinal beam 3–3 (Fig. 6), located in the console part of the frame, the magnitude of the maximum stresses lies in the range from 315 to 332 MPa (points 4 and 04). Over the cross section of the main beam 5–5, located in its middle part and slightly removed from the pivot beam, the magnitude of the maximum total stresses is somewhat higher (points 3 and 03 in Pic. 6).

To reduce the level of total stresses constructive solutions were proposed aimed at improving these zones:

• *to increase thickness of the hitch plate of the coupling device from 40 to 60 mm;*

• *to increase thickness of the lower plates of the longitudinal elements of the cantilever parts of the main beam from 10 mm to 12 mm;*

• *to weld along the axis of the car between the pivot beam and the transverse beam No. 1 a longitudinal element consisting of two bent channels 80 mm high and 5 mm thick, welded vertically together (form a composite I-beam);*

• *to weld into the area from the transverse beam No. 1 to the next transverse beam (to the middle of the car), two sheet plates measuring 550 x 350 x 6 mm with a bent of 40 mm high.*

These reinforcements were implemented on all head, motor and non-motor cars of the first two trains of EG2Tv electric train. Repeated control tests confirmed the rationality of the decisions taken.

Table 7 summarizes the static test data of the modified structure.

Conclusions.

1. According to the results of computational and experimental studies, assessment was made of the load-carrying capacity of the car bodies of the new generation EG2Tv electric train cars.

2. It has been established that in certain units and areas of the body frame normal stresses come close to the allowed in the first loading mode [5]. These include:

• *hitch plate of the coupling device;*

• *longitudinal elements of the console parts of the main beam;*

• *zone of connection of the longitudinal elements of the main beam with the transverse beams of the frame behind the pivot beam to the middle of the car.*

3. The carried out final development of the frame on all models of electric train EG2Tv cars, aimed at optimization of metal structures of bodies, allowed to reduce the level of total stresses, which under the influence of normative stresses did not exceed the allowed values.

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