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Study of stress concentration on the surface of a freight car traction clamp

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Abstract. The article presents a comprehensive analysis of the influence of loads on the structural integrity of a railway train elements. The focus is on load calculations using the Femap software package, which provides accurate modeling and analysis of mechanical systems. The study is aimed at identifying potential points of failure and stress concentration in the traction clamp as part of the automatic coupler of a freight car. The main problem addressed in the article is assessing the strength and durability of the traction clamp under operating conditions. The relevance of the study lies in the context of ensuring the safety and reliability of railway transport. The results obtained can be used to optimize the design and production process, as well as to develop recommendations for improving the design parameters of traction clamps, thereby reducing the likelihood of destruction and accidents.

1 Introduction

Rail transport is one of the most important modes of transport in the world, providing fast and efficient transportation of goods and passengers. However, the safety and reliability of railway transport depends on many factors, including the quality and condition of the rolling stock. The modern railway industry strives to continuously improve the safety and reliability of railway transport [1-6]. One of the key aspects of achieving this goal is the constant research and analysis of the structural condition of railway equipment, especially important for traffic safety, such as traction clamps of freight cars. In the context of this problem, the question arises about the concentration of stress on the surface of the traction clamp and its effect on the structural integrity of the element. This aspect becomes especially relevant when working with the draft gear in the automatic coupler of a freight car. The purpose of this study is to conduct a stress concentration analysis on the surface of a freight car traction clamp using modern engineering methods and tools. In particular, the article will present the calculation of loads using the Femap software package, as well as an analysis of possible points of failure. The results obtained will not only deepen the understanding of the mechanical characteristics of the traction clamp, but also offer practical recommendations for optimizing its design in order to improve the safety and efficiency of railway transport.

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One of the key elements of rolling stock is freight cars, which are subject to significant loads during operation. One of the main problems associated with freight cars is the concentration of stresses on the surface of the traction clamp. A traction clamp is an element that connects the car to the locomotive and transmits traction force. If the load is distributed incorrectly, high stresses can occur on the clamp, which can lead to its destruction. This, in turn, can cause a serious accident.

Over the past 5 years, uncouplings due to body faults in TR-2 have increased from 26 thousand cars in 2019 to 34 thousand in 2023 while in automatic coupling devices the increase was from 24 to 26 thousand (Table 1).

Table 1. Number of uncouplings in TOP due to malfunction of the main components of freight cars registered in the Russian Federation for the first half of 2022 and 2023.

Knot	2022	2023	± uncoupling
Wheelset	270.8	303.9	33.11
Body	198.5	173.4	-25.08
Bogie	96.4	101.6	5.18
Automatic coupler	19.1	40.8	21.66
Automatic braking device	24.1	24.5	0.38
Frame	20.5	19.0	-1.48

Data show that the number of uncouplings due to faulty main components is increasing. The increase in uncouplings for CA-3 is especially noticeable, which indicates a high positive growth of this indicator.

Analyzing the statistics of releases for the automatic coupler unit, we can identify a number of main malfunctions of automatic couplers. Next in importance and seriousness of these violations in operation, after the draft gears, are the malfunctions of the traction clamps, at the points of interaction of the component parts. Placing cars with at least one of these faults on trains and their further operation will necessarily entail derailment of the train:

1. Crack in the automatic coupler body, broken mechanism parts;
2. Widening of the mouth, wear of the working surfaces along the automatic coupler engagement contour beyond the permissible limits, ineffective lock safety catches against self-release;
3. Absence of the automatic coupling lift roller, a lift roller that is not secured from falling out or secured in an improper way;
4. A crack in any part of the traction clamp, a crack or break in the wedge or roller of the traction clamp;
5. A break or crack in the centering beam, pendulum suspension, as well as the guide rail of the centering device of a non-pendulum type. Incorrectly installed pendulum suspensions (with wide heads down);
6. Faulty or non-standard fastening of the wedge or roller of the traction clamp.

This article discusses the study of stress concentration on the automatic coupling device, as one of the complex elements of the car, which in turn consists of additional parts and units, and specifically examines the interaction of the SA-3 with a traction clamp the latter in turn being part of the coupling mechanism of the car to the locomotive. It transfers traction from the locomotive to the car, allowing the train to move.

2 Methods and materials

Studying the stress concentration on the surface of the traction clamp of a freight car makes it possible to determine the places where the stresses reach their maximum value. This is important to ensure the safety and durability of the structure, since these are the places where cracks and damage are most likely to occur. Stress concentrations can occur due to various reasons, such as improperly shaped or sized clamps, sharp corners or transitions, or the application of load. Identifying areas with the highest stress concentrations helps engineers optimize clamp design to reduce the risk of damage and increase car life. In addition, stress concentration studies can help in selecting materials for making a clamp. Some materials handle high stress better than others, so knowing where stress is concentrated allows to select the material that is best suited for a particular application.

The automatic coupler clamp is cast from steel 20GL, 20FL in accordance with GOST 977-88 and steel 20GTL, 20G1FL, 20FTL and 20GFTL in accordance with GOST 22703-91. The article uses grade 20GL with a high manganese content, which can improve the ductility of the material and reduce the likelihood of cracking (Figure 1).

The mechanical properties of steel for housings and housing necks after final heat treatment must be no less than specified in Table 2.

Table 2. Yield strength.

δ_t, MPa	δ_v, MPa	ε_{re} , %	ε_{rn}, %
490	657	10	20

Designations in the table: δ_t – yield strength; δ_v – temporary resistance; ε_{re} - relative elongation; ε_{rn} - relative narrowing. Hardness of housings and housing necks must be HB 207…255.

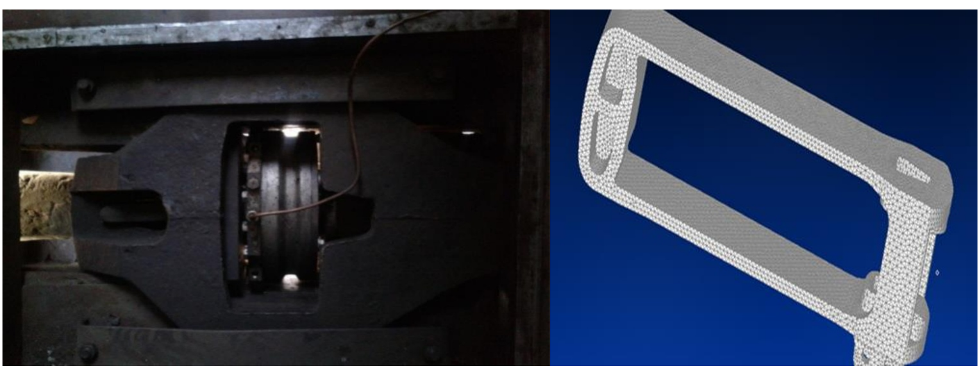


Fig. 1. a) Strain gauge on SA-3; b) Traction clamp in the Femap program.

By analyzing the parameters obtained from the traction and energy laboratory, it is possible to evaluate the dynamics of the locomotive and rolling stock as a whole. At the same time, traction and energy laboratories used to solve a wide range of problems become of great importance:

– determination of the load on locomotives in terms of adhesion and longitudinal-dynamic forces based on the strength of automatic coupling devices and the stability of cars in the rail track;

– establishing the optimal temperature regime for locomotive electric machines;

– determination and operational verification of the calculated, unified, critical weight standards of freight trains and the composition of passenger rolling stock, including the conditions for providing electric heating from the locomotive;

– development and adjustment of operating schedules for rolling stock;

– checking the standards for the traffic schedule of passenger and freight rolling stock and the compliance of the calculated and actual braking distance with the current rules and instructions of the Ministry of Transport of Russia and JSC Russian Railways;

– development of regulatory documents, recommendations and guidelines for the control mode of traction and automatic brakes, taking into account local conditions;

– determination and verification of standards for the consumption of fuel and energy resources for traction of trains.

Table 3. Quasi-static forces of cars with different cargo masses.

Railway carriage with cargo weight, t	Axle load, t	Radii of curves, m				
		150	200	250	400	700 or more
Tensile forces in motion, kN						
0	5.5	392.4	490.5	490.5	490.5	490.5
10	8.0	686.7	784.8	882.9	1177.2	1275.3
20	10.5	981.0	1079.1	1177.2	1275.3	1275.3
30-70	13-23	1275.3				
Compressive forces, kN						
0	5.5	392.4	441.4	490.5	490.5	490.5
10	8.0	588.6	637.6	686.7	735.7	784.8
20	10.5	784.8	833.8	882.9	931.9	931.9
30-70	13-23	931.9				

The task of the traction and energy laboratory (TEL) includes many factors related to the registration and processing of parameters taken from strain gauge automatic couplers (dynamometer cassettes). TEL is also used to assess dynamic loads and their relationship with the causes of wheel derailment (Table 3).

Traction and energy tests are carried out constantly, since sections of the Eastern Railway are characterized by a complex profile and track layout. In these areas there are long ascents and descents with a steepness of up to 24% several tens of kilometers long with curves including those of small radius (up to 250 m).

As a result of experimental trips with freight trains of various masses, the critical norm of train mass for a given electric locomotive and the dependence of its calculated adhesion coefficient on the speed of movement are determined. Generalized indicators of slippage of electric locomotive wheel sets during trips with trains of various masses are determined. An assessment is made of the energy performance of the electric locomotive, the consumption of electrical energy for traction of trains and the power factor. An analysis of the influence of operating conditions on the distortion of the shape of the voltage and current consumption curves is also carried out.

An assessment of the rolling stock performance indicators recorded by the traction and energy laboratory during train operation makes it possible to reveal the influence of technical parameters on the interaction of the wheel-rail system. The obtained, processed and generalized parameters, which are formed from a large number of factors in motion (speed, track topography, type of rolling stock, etc.) connect the various elements of the wheel-rail system into a single whole.

Sea trials are carried out using a traction and energy laboratory, which is located behind the experimental locomotive in front of the first car of the rolling stock. This laboratory is based on a passenger carriage equipped with all the necessary measuring and computing equipment. A set of measuring sensors is installed on the locomotive and the laboratory car (on their automatic couplers), connected by a loop to the measuring and computing complex of the laboratory car.

To measure longitudinal forces from locomotive traction and braking forces, the laboratory is equipped with strain gauge automatic couplers or a hydraulic cassette single-chamber dynamometer.

When recording the parameters of housings and housing necks it should be noted that hydraulic and strain gauge methods for measuring traction and braking force have their own advantages and disadvantages which must be taken into account when analyzing the results obtained and their reliability.

The strain gauge method of obtaining information is based on the deformation of the tail part of the automatic coupler by traction and braking forces through strain gauge sensors that record signals, and the equipment dynamically evaluates the traction and braking forces of the locomotive during testing. It is convenient to present the analysis of registered parameters and their dynamics in tabular form and generalized graphs.

As an example, Figure 2 shows a diagram of the parameters when performing braking. The graph clearly and dynamically shows changes in current parameters.

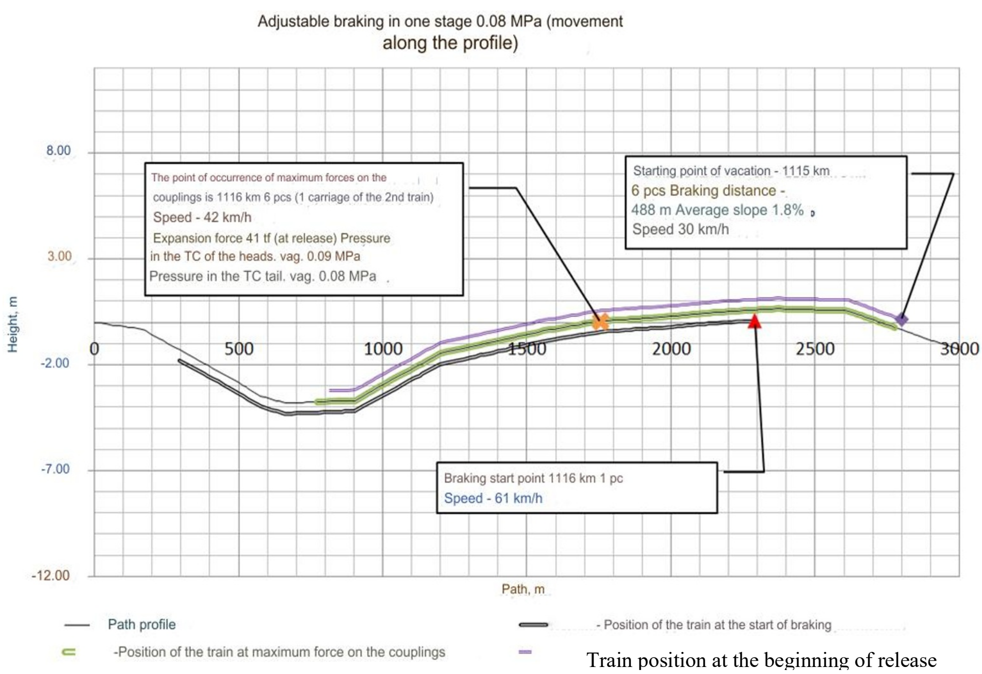


Fig. 2. Profile map.

On the profile map, the lines represent the position of the connected train on a given track profile during braking periods:

- at the moment the braking begins - a black line with a red triangle indicating the position of the lead locomotive;

- at the moment of a complete stop (for stopping braking) or the start of release (for braking with subsequent release) - a purple line with a purple diamond indicating the position of the lead locomotive;

- at the moment of maximum longitudinal forces occurring in the train - a green line with an orange cross, indicating the section of the train in which the maximum force was recorded.

Figure 3 shows the measurements recorded by the traction and energy laboratory:

- along the horizontal axis there is a braking time scale, which is shifted relative to the start of braking, to depict the longitudinal forces acting in the train before the start of braking;
- along the vertical axis on the left is the combined speed scale (in kilometers per hour) and the reaction force in the train sections (ton-force), on the right is the pressure scale (in mega pascals).

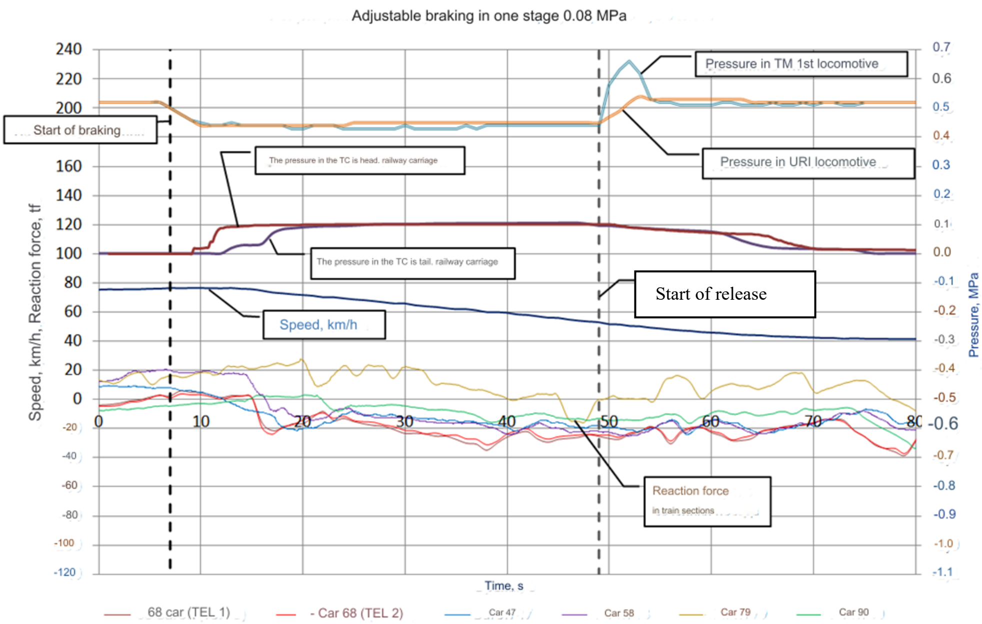
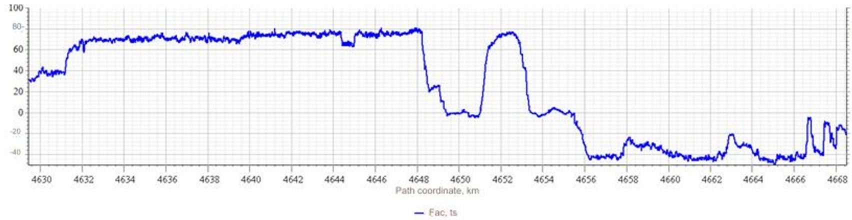


Fig. 3. Parameters measured by the traction and energy laboratory.

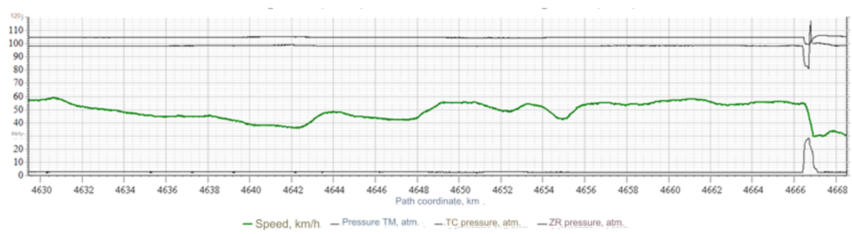
The parameters measured at the traction-energy laboratory are shown in motion:

- the moment of the start of braking and release (for braking with subsequent release) – a vertical dotted line;
- reaction forces in train sections - multi-colored lines at the bottom of the graph;
- train speed – blue line in the middle part of the graph;
- pressure in the brake line and surge tanks of the head and tail locomotives and in the brake cylinders of the head and tail cars. These lines have different colors and are indicated by callouts with corresponding inscriptions.

Figure 4 shows the power characteristics taken from the traction and energy laboratory when testing a high-weight train on a pass section of the track, with a locomotive of the Ermak series. The presented data make it possible to evaluate the longitudinal dynamics in straight and flat curves, their influence on the lateral forces of wheel-rail interaction when driving heavy trains along pass sections of the road (Figure 5).



a) force on the automatic coupler of the laboratory car, tf



b) speed (km/h) and pneumatic brakes (atm.)

Fig. 4. Power characteristics of the traction and energy laboratory.

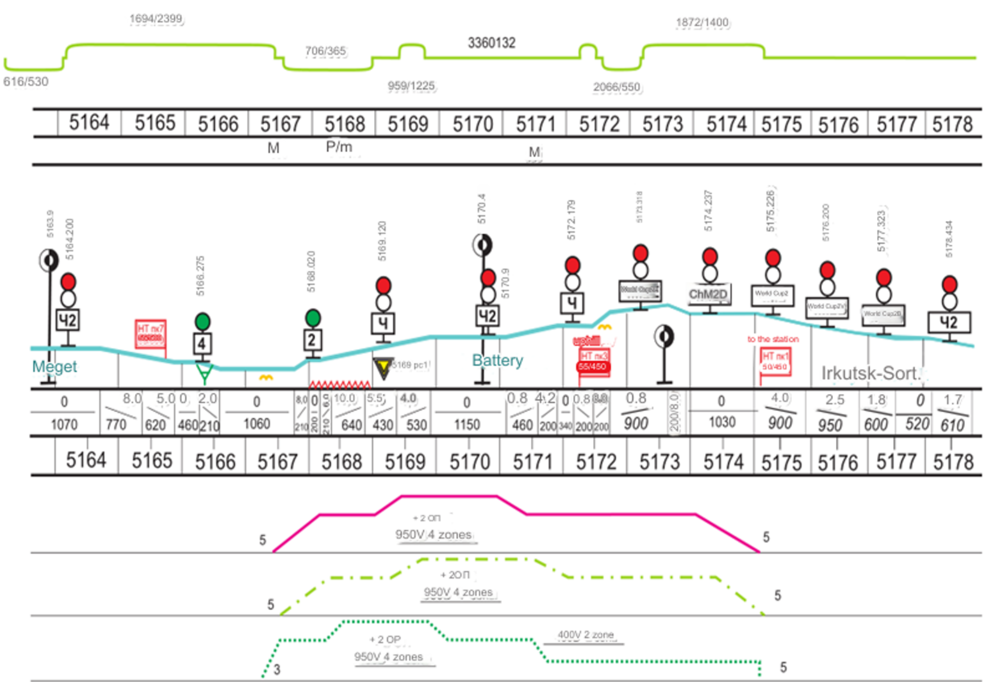


Fig. 5. Regime map.

3 Results and discussion

The stress concentration on the surface of traction clamps can vary depending on several factors. As the load on the clamp increases, the stress concentration on its surface increases. This is due to the fact that the material of the clamp begins to deform under the action of the applied force, and in places with sharp corners or transitions this deformation can be significantly greater, which leads to an increase in stress. The shape and size of the clamp also affect the stress concentration. Sharp corners, transitions, or other geometric features can cause increased stress on the surface of the clamp. Different materials have different properties, such as strength and ductility. A stronger material can withstand greater stresses without failure, while a less durable material may fail at lower stresses. The surface of the clamp, in turn, may be subject to corrosion, wear, or other types of damage, which can lead to changes in the stress distribution on its surface. All these factors together determine how the stress concentration on the surface of the traction clamps changes.

To do this, in the Femap software package, after constructing a discrete mathematical model and fixing it in space, a unit load is set on the inner surface of the traction clamp in order to find out the location of the occurrence of stress concentration, which is also necessary for studying and visually representing the deformed state at the junctions of individual automatic coupler nodes, thanks to which it is clear to observe the expected zones of the source of possible destruction depending on the grade of steel.

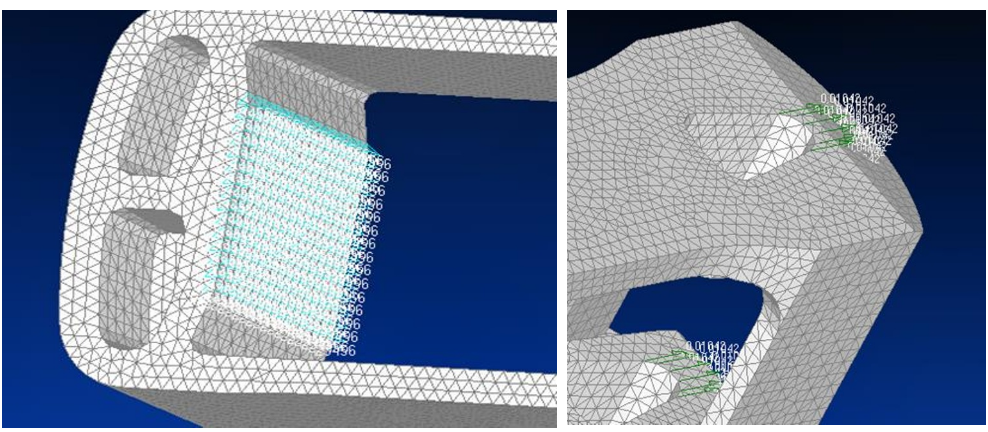


Fig. 6. Creating a discrete mathematical model and specifying the material (fastening and loading).

At this stage a material is being created for finite element model (Figure 6). For steels used in structures, it is recommended to take the following values of physical characteristics: elastic modulus (E) - 2.06×10^{5} MPa; shear modulus (G) - 0.79×10^{5} MPa; lateral deformation coefficient (nu) - 0.3; linear extension coefficient (a) - 0.12×10^{-4} °C $^{-1}$; density (r) - 7850 kg/ m^3 . Limitation of the degrees of freedom of the traction clamp model is associated with the constructive interaction of the traction clamp with other elements of the automatic coupling device: With a stop onto the absorbing mechanism. After forming the knotted seal, the surface was marked, corresponding to the traction clamp and rear stop. Thus, this surface is recured.

The initial data for the calculation are presented below.

1. Material: 20GL
2. Endurance limit : $[\delta] = 400\ MPa$
3. Young's modulus : E= $2 \cdot 10^5\ MPa$
4. Poisson's ratio : η = 0.33

5. Shear modulus : G = 7.4· 10^4 MPa
6. Density :$\rho = 7800$ $^{kg}/_{м^3}$
7. Friction coefficient of the main working surface μ_1 = 0.34
8. Load: distributed over the entire surface 25 Pa.

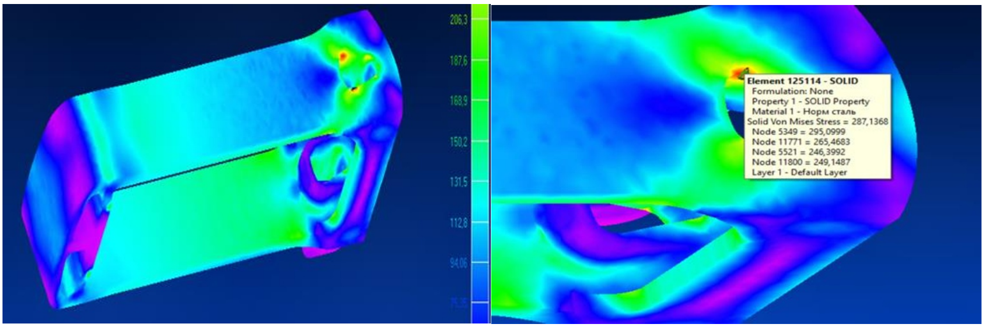


Fig. 7. Analysis results with load on the traction clamp.

Material 20GL provides traction clamp at a given load. Particularly stressed-strained areas are colored in color, where the places for crack initiation are most pronounced (Figure 7).

4 Conclusion

The stress concentration on the inner surface of the traction clamp affects its performance and reliability. If the stresses exceed the permissible values, this can lead to destruction of the traction clamp and, as a result, to an accident. Therefore, it is important to research this problem and find ways to solve it. The connection between the traction clamp and the automatic coupling device is direct, therefore the data obtained from the calculations showed that stress concentration does not occur on all loaded surfaces of the unit and suggesting that the values of dynamic forces obtained during testing make it possible to assess the safety of trains of various weights. A traction and energy laboratory with a complex of measuring equipment makes it possible to evaluate the relationship of power loads when a locomotive drives a train in mountainous terrain. The data obtained, especially longitudinal-lateral loads, indicate that when moving from straight sections of track to gentle curves (R = 800-1200 m) with significant unabated acceleration wheels of the wheelsets, in turn, run (while wobbling) onto the rails with oblique impact on the side edges of the rail, which leads to a sharp increase in lateral force. Calculations performed on a model 18-100 bogie with an axle load of 230.5 kN (23.5 tf) at speeds from 40 to 120 km/h showed that the average frame force (transverse) can reach 40 kN or more. These loads pose a danger, for example, to composite insulated joints on rails and the axle box assembly as a whole.

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