The loading of the low-sided car bodies when restoring coal flowability by thermal means

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Abstract. Methods for restoring coal flowability are considered and some of them are accentuated. The results of the analysis of load-carrying structures of low-sided cars when exposed to thermal methods of restoring coal flowability are presented. The study was conducted using the industrial FEM software complex. The assessment was carried out for two typical low-sided car structures - with a solid floor and hatches on the frame. Studies have shown that thermal loading significantly affects the low-sided car supporting structures and should be taken into consideration when designing cars of enhanced performance properties. The main low-sided car design feature, considered in the paper, is the presence or absence of load-bearing flooring with longitudinal reinforcements. The presence of a carrier floor in the body reduces the load level of the lower trim in its average section. When comparing the loading of both types of bodies, it can be seen that the backward body of the low-sided car perceives loads, both power and thermal, better. According to the results of the calculations, it is possible to say about the priority of the use of infrared irradiation, as a scheme for restoring the flowability by the criterion of minimizing the thermal loading of the supporting systems of the low-sided cars.

1. Introduction

Russian railways and bulk freight in low-sided cars are the key ways of delivering coal to consumers in our country. At the same time, in spite of the constant process of the development of low-sided car design and their operation methods, the low-sided cars are affected by the loads that occur during the unloading process in the harsh climatic conditions of our country. Climatic conditions are often determined by extremely low ambient temperatures, and as a result, bituminous coal freezes. At the same time, unloading of low-sided cars becomes impossible without prior procedures for restoring coal flowability [1-3]. Several technologies have been developed and are used to restore coal flowability during unloading [4-6].

The implementation of the technologies is characterized by restoration methods: thermal means, mechanical action (loosening) and chemical treatment of coal (pre-loading).

2. Research methods

When studying load bearing systems of railway rolling stock units, industrial software systems are employed in which various interpretations of the finite element method are implemented [6-9]. During the study, the authors used their own models that made it possible to calculate the stress-strain state of low-sided cars in the process of thermal loading and in a quasi-static formulation [10-13].
Materials and their property characteristics were used in the linear domain of the elasticity law implementation. The material thermal behavior was also considered in the linear formulation, taking into account linear expansion coefficient of the simulated steel of the low-sided car structure [14-15].

3. **Investigation of thermal loading of low-sided cars for coal transportation.**

Thermal agents, i.e. the means of heating the car with the cargo as a whole or the cargo surface, according to the implementation frequency are: a system of free coolant supply of the low-sided car and cargo (coal), a system with controlled heat transfer using heat pipes with temperature preservation zones and an infrared heating system for the cargo. Thermal loading of the car body structure depends on the heating system. Schemes of heat load for each of the systems are shown in Figure 1.

![Figure 1](image_url)

**Figure 1.** Systems for technological recovery of coal flowability in low-sided cars: a – heat transfer agent flow; b – controlled heat transfer by pipelines; c – infrared heating of the cargo cap of the low-sided car body.

The modeling of heat transfer systems is carried out using special types of thermal loads [16, 17]. These loads are applied to the surfaces of the perception zones of the finite element schemes of the models of low-sided cars of two types: the body with a solid floor (Figure 2, a) and with hatches on the frame (Figure 2, b).

Models are made with a sufficient degree of detail, which, in turn, has been verified. Models mainly consist of finite elements of four-node plates [18-20]. The geometry of low-sided cars is fully preserved. The models are developed directly by the authors of the study.

For each of the two models, temperature simulations were performed in three variants of thermal loads. In addition to thermal loads of the models the authors considered the load on the weight of the body itself and the cargo, taking into account its thrust.

For the scheme with a free flow of a heat transfer agent (Fig. 1, a), the temperature is uniform over the entire outer surface of the low-sided car body and its value is 473K. In addition, the internal space of the body with cargo has the initial recovery temperature equal to 233K. The temperature is evenly distributed over the inner surface of the body.

For the scheme with the controlled heat transfer (Fig. 1, b) with pipelines, the external temperature is different. For the most part, it is constant and equal to 473K. In the zones of forced cooling (upper and lower railings of the side wall of the low-sided car), the temperature does not exceed 285K. For the internal space of the body with a cargo, we have an initial recovery temperature equal to 233K. The temperature is evenly distributed on the inner surface of the body.
Figure 2. Models in the FEM complex: a - body with a solid floor; b – a body with hatches on the frame.

In the implementation of the third scheme (Fig. 1, c), it is necessary to take into account the uneven nature of the heating of the car body with the cargo. The maximum temperature occurs in the top cord zone with a value of up to 473K, and then the temperature falls linearly in height with a minimum in the side sill zone. The value of the minimum in this case may be 233K. The inner surface of the body with cargo is also unevenly heated and changes under the same conditions as the heating of the body surface outside.

Using the developed models and thermal loading schemes, simulations were carried out to determine the loading of model elements. A total of six variants of the result sets were obtained, taking into account thermal stresses and two additional sets of results from the static load of the gross body and the bulk material (coal) thrust.

Table 1 presents the numerical values of the maximum equivalent stresses in the middle section of the low-sided car. Stresses are given for both a top cord and a side sill, as well as for the lower flange of the center sill. These bearing elements are key longitudinal elements of the low-sided car body structure.

| Thermomode | Body with a solid floor | Body with hatches on the frame |
|------------|-------------------------|-------------------------------|
|            | Top cord | Side sill | Center sill | Top cord | Side sill | Center sill |
| Fig. 1, a  | 27,9     | 164,9     | 201,1       | 8,5      | 45,2      | 241,1       |
| Fig. 1, b  | 120,3    | 5,7       | 207,4       | 139,5    | 125,8     | 235,7       |
| Fig. 1, c  | 4,9      | 90,7      | 61,8        | 8,7      | 33,6      | 77,6        |
| Norm       | 1,96     | 34,8      | 19,8        | 7,6      | 8,8       | 16,1        |

In addition to the results presented in the table, in Figure 3, there are pictures of diagrams of stress-strain states of the considered loading schemes, including non-temperature ones.
Figure 3. Loading of models (on the left – a body with a solid floor a, c, e.g; on the right – a body with hatches on the frame b, d, f, h): a, b – diagram 1; c, d – scheme 2; e, f – scheme 3; g, h – norm.
The analysis of the simulation results showed that the stress state in all thermal load circuits deteriorates as compared with the considered basic loading, which is presented in the form of the cargo weight as well as the low-sided car body weight itself.

When the simulations are over, it is necessary to analyze the data obtained according to several criteria: change in the level of loading, the influence of design features on loading and the assessment of the level of loading on the low-sided car body type.

The results can be interpreted for the first criterion as follows: the third heating system (Fig. 1, c) is best for the carrier system, systems numbered one and two (Fig. 1 a, b) are almost equivalent, and significantly worsen the stressed state of the low-sided cars. The ratio of change levels can be easily seen from Table 1.

The main design feature of the low-sided car bodies, considered in the paper, is the presence or absence of the load-bearing floor with longitudinal reinforcements. The presence of a carrier floor in the body reduces the load level of the side sill in its average section.

When comparing the loading of both types of bodies, it can be seen that the solid floor body of low-sided cars perceives loads, both power and thermal, better, but, unfortunately, there is no way to clearly recommend the construction of a low-sided car with a solid floor for priority use.

4. Conclusions

After computer simulations, processing of the results and their analysis, it can be concluded that the main goal of this study has been achieved, namely, a significant effect of thermal loading when restoring cargo flowability (coal) during transportation in harsh climatic conditions of our country has been proven.

The main known methods for restoring flowability are considered. According to the results of the calculations, it is possible to say about the priority of using 3 schemes of restoring the flowability according to the criterion of minimizing the thermal loading of the low-sided car body supporting system.

In addition, the fact of a better bearing capacity of low-sided car bodies with a solid floor compared to low-sided cars with hatches on the frame is established.

In ongoing research, mechanical ways to restore the flowability will be examined and their impact on the low-sided car bodies will be assessed.

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