DOI: 10.15587/978-617-8360-05-4.CH4

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CHAPTER 4

ESTABLISHING A HIGH-QUALITY TECHNICAL CONDITION AT THE DESIGN STAGE: PROMISING CONCEPTS OF LOAD-BEARING COMPONENTS OF CAR STRUCTURES

ABSTRACT

Most often in the practice of creating multifunctional technical means, a combination of elements that are separate in terms of their functions is used. Its main directions include: connecting different levels of the constructive hierarchy (modules, nodes, basic elements) of components without changing their forms and properties, and with mutual coordination of forms and properties; introducing new principles of functioning to car constructs on the existing element base and on a new element base; taking into account at the design stage the prerequisites for the constructive implementation of future innovative design solutions.

Today, the most promising from the point of view of the practical creation of multifunctional freight car components are the following directions identified and presented in detail in the article: elastic-dissipative, non-rigid articulated and multi-material. It was the solution of such a scientific and applied task that became the aim of the research, the results of which are presented in this section of the monograph.

To achieve the aim, the following scientific and applied objectives were identified and solved: analysis of information sources that highlight the issues of the prospects for the development of non-load-bearing components of freight car structures; development of a mathematical description of the procedure for creating car components with a useful pre-stressed and/or deformed state; development of theoretical aspects of creating useful pre-stressed and/or deformed non-load-bearing components of car structures; development of a promising useful pre-stressed and/or deformed concept of a covered hopper car for transporting cement and a pellet car, a platform car from leaf springs, a hopper car for transporting grain from leaf springs, a hopper car for transporting mineral fertilizers from leaf springs, a hollow-bottomed gondola car made of leaf springs, a universal covered car with racks with damping properties, a universal hopper car for transporting grain with racks with damping properties; development of a promising concept of a railway tank car with supports in the form of leaf and disc springs; development of a promising articulated concept of a 4-axle dump car, a hopper car for transporting grain and mineral fertilizers, a universal platform car, a universal covered car, a hollow-bottomed gondola, a railway tank; development of a promising multi-material concept of a covered car and a railway tank; development of a promising railway tank with a multi-material concept of supports; systematization of the obtained developments and formulation of general conclusions.

The presented directions for creating multifunctional components of freight cars will allow to obtain positive results in their manufacture and operation. Such positive results include: increasing the life cycle of the studied means, reducing their material consumption and increasing the load-bearing capacity, improving maintainability, increasing crack resistance, reducing/completely eliminating stresses of different signs.

KEYWORDS

Transport mechanics, railway transport, cars, load-bearing systems, promising structures.

The results of the analysis of world and national trends in the development of means of transport have shown that a promising direction for improving their structures is the implementation of innovative principles of functioning into the components. The corresponding trends are defined in various levels of transport development strategies and programs. Of particular importance in this regard is the resolution of relevant issues for the load-bearing systems of means of transport. Among means of railway transport, in the development of this direction, special attention should be paid to freight cars, the structures of which mainly represent general load-bearing mechanical systems.

The aim of the publication is to highlight the obtained scientific and practical developments in the creation of promising concepts of load-bearing component structures of freight cars.

To achieve the aim, a number of the following scientific and technical objectives were identified and solved:

1) analysis of information sources that highlight the issues of the prospects for the development of non-load-bearing components of freight car structures;

2) development of a mathematical description of the procedure for creating car components with a useful pre-stressed and/or deformed state;

3) creation of theoretical aspects of creating useful pre-stressed and/or deformed non-load-bearing components of car structures;

4) development of a promising useful pre-stressed and/or deformed concept of a covered hopper car for transporting cement;

5) development of a promising useful pre-stressed and/or deformed concept of a pellet car;

6) development of a promising elastic-dissipative concept of a platform car made of leaf springs;

7) development of a promising elastic-dissipative concept of a hopper car for transporting grain with leaf springs;

8) development of a promising elastic-dissipative concept of a hopper car for transporting mineral fertilizers with leaf springs;

9) development of a promising elastic-dissipative concept of a hollow-bottomed gondola car with leaf springs;

10) development of a promising elastic-dissipative concept of a universal covered car with racks with damping properties;

11) development of a promising elastic-dissipative concept of a universal hopper car for transporting grain with racks with damping properties;

12) development of a promising concept of a railway tank with supports in the form of leaf springs;

13) development of a promising concept of a railway tank with supports in the form of disc springs;

14) development of a promising articulated concept of a 4-axle dump car;

15) development of a promising articulated concept of a hopper car for transporting grain;

16) development of a promising articulated concept of a hopper car for transporting mineral fertilizers;

17) development of a promising articulated concept of a universal platform car;

18) development of a promising articulated concept of a universal covered car;

19) development of a promising articulated concept of a hollow-bottomed gondola car;

20) development of a promising articulated concept of a railway tank;

21) development of a promising multi-material concept of a covered car;

22) development of a promising multi-material concept of a railway tank;

23) development of a promising railway tank with a multi-material concept of supports;

24) systematization of the obtained developments and formulation of general conclusions.

4.1 ANALYSIS OF INFORMATION SOURCES THAT HIGHLIGHT THE ISSUES OF THE PROSPECTS FOR THE DEVELOPMENT OF NON-LOAD-BEARING COMPONENT STRUCTURES OF FREIGHT CARS

The search for information sources was aimed at finding works that are devoted to highlighting the developments and results of research on the creation of promising concepts of non-load-bearing component structures of transport engineering.

Works [1–4] present the prospects for the development of freight car structures determined by the authors. At the same time, the need to apply the latest achievements in materials science is identified as the main areas of development.

Research [5–9] is aimed at finding scientific and practical solutions to improve transport processes. And as one of the key aspects, the need to update transport fleets with new generation models is highlighted, which requires the creation of appropriate scientific and practical tools.

Works [10–13] present the scientific results of theoretical and practical developments on the prospects for the development of machine-building structures. The importance of scientists and engineers paying attention to the problems of structural and material innovative solutions is separately highlighted, which is certainly connected with the deployment of design works of materials science and architectural and structural search.

In articles [14–16], the authors presented scientific results on the optimization of processes occurring in the power module of a vehicle. At the same time, the main attention was paid to increasing energy efficiency.

In scientific works [17–20], damage to cars at the final stages of the life cycle (corrosion, accident, impacts) was considered. The feasibility of deploying scientific research and development work to reduce and correct operational deformations was determined.

Scientific research highlights a new approach to improving energy transfer processes between various components of vehicles. However, not enough attention has been paid to the redistribution of stresses.

In works [24–26], the results of experimental studies of subway rolling stock are presented. The main attention is paid to energy efficiency. However, the force interaction of the corresponding modules and blocks has not been studied.

Summarizing the above, it can be noted that in all the above scientific works, the features of determining promising concepts of load-bearing component structures have not been studied.

4.2 MATHEMATICAL DESCRIPTION OF THE PROCEDURE FOR CREATING CAR COMPONENTS WITH A USEFUL PRE-STRESSED AND/OR DEFORMED STATE

This section focuses on the author's hypothesis about the feasibility of introducing prestressed and/or deformed load-bearing elements into the design of freight cars. Pre-stressing and/or deformation of structures should be understood as various methods of artificially regulating stresses (manipulating the stressed-deformed state) in structures to increase their efficiency.

Intervention in the natural operation of an object to directional change its potential deformation energy can occur at different stages of the life cycle: during manufacturing, during repairs, during operation or modernization and at different levels: structural elements or assemblies, modules and the system as a whole.

The criteria for the effectiveness of applying prestressing in metal structures can be both economic requirements for reducing the mass and cost of objects, and technological (increasing rigidity, preserving the shape of load-bearing structural elements, changing dynamic characteristics, increasing crack resistance and reducing fatigue strength, etc.). In this regard, metal structures have wider possibilities for applying prestressing and/or deformation than reinforced concrete and reinforced concrete structures, where this technique has developed primarily as a means of combating low strength of concrete during tension.

Generalizing the universal mathematical record of the procedure for implementing a useful prestressed and/or deformed state in the components of railcar structures, it is necessary to take into account the following requirements:

1) systematically consider economic efficiency at the stages of the freight car life cycle;

2) as the main criterion for the implementation of the useful prestressed and/or deformed state, the total vector of the useful prestressed and/or deformed state is used, which in magnitude and direction is directed towards counteracting the total vector of operational loads;

3) the mathematical model must include an objective function (OF), which is a vector for finding (searching for) the optimal design option from the region of admissible solution area (ASA) selected from the possible solution area (PSA).

Due to the fact that the application of a mathematical notation (model) must effectively operate as an implementation of the prestressed and/or deformed state, or their combinations, it is necessary to create sufficient prerequisites for describing the corresponding states, namely, for example, the dependences of various deflections and bends, internal and external mechanical stresses on thermal or mechanical effects.

As noted above, the main criterion for creating a useful prestressed and/or deformed state is the total vector of the useful prestressed and/or deformed state, which in magnitude and direction is directed towards counteracting the total vector of operational loads:

$$\sum \overline{F^{UPSDS}}\left(\bar{Y}\right) \rightarrow -\sum \overline{F^{OPER.}}, \tag{4.1}$$

where $\sum \overline{F^{UPSDS}}\left(\bar{Y}\right)$ – where the total vector of the useful pre-stressed and/or deformed state;

$\sum \overline{F^{OPER.}}$ – the total vector of operational loads.

In this case, the total vector of the useful pre-stressed and/or deformed state is a function of the scalar sum of the vectors of stresses and deformation of the component. That is, the possible solution area (PSA) is formed by the fields of possible changes in the factors of the implementation of the corresponding methods for creating a pre-stressed and/or deformed state:

$$PSA = \left\{ \bar{\mathrm{Y}} \left| \begin{array}{lll} \sum \overline{a_x}^{\min} \leq \sum \overline{a_x} \leq \sum \overline{a_x}^{\max}; & \sum \overline{a_y}^{\min} \leq \sum \bar{a}_y \leq \sum \overline{a_y}^{\max}; & \sum \overline{a_z}^{\min} \leq \sum \overline{a_z} \leq \sum \overline{a_z}^{\max}; \\ \sum \overline{b_x}^{\min} \leq \sum \overline{b_x} \leq \sum \overline{b_x}^{\max}; & \sum \overline{b_y}^{\min} \leq \sum \bar{b}_y \leq \sum \overline{b_y}^{\max}; & \sum \overline{b_z}^{\min} \leq \sum \bar{b}_z \leq \sum \overline{b_z}^{\max} \\ a \in \left[1;s\right]; b \in \left[1;k\right] & & \end{array} \right. \right\}, \tag{4.2}$$

where $\sum \overline{a_x}^{\min} \leq \sum \overline{a_x} \leq \sum \overline{a_x}^{\max}; \sum \overline{a_y}^{\min} \leq \sum \bar{a}_y \leq \sum \overline{a_y}^{\max}; \sum \overline{a_z}^{\min} \leq \sum \overline{a_z} \leq \sum \overline{a_z}^{\max}; a \in \left[1;s\right]$ – the specified variable parameters: the magnitude and direction of the useful prestresses; $\sum \overline{b_x}^{\min} \leq \sum \overline{b_x} \leq \sum \overline{b_x}^{\max}; \sum \overline{b_y}^{\min} \leq \sum \bar{b}_y \leq \sum \overline{b_y}^{\max}; \sum \overline{b_z}^{\min} \leq \sum \bar{b}_z \leq \sum \overline{b_z}^{\max}; b \in \left[1;k\right]$ – the specified variable parameters: the magnitude and direction of the useful prestresses.

The admissible solution area (ASA) in which the desired solution is located, is separated from the possible solution area (PSA) by the functional requirements and constraints of the secondary criteria:

$$\bar{Y} \in ASA \in PSA. \tag{4.3}$$

Previous studies have shown that the above criteria and their corresponding limitations for freight cars should be considered taking into account technical, economic and operational limitations. The above criteria and limitations for freight cars should be considered the following technical, economic and operational characteristics:

M_C – tare weight of the car, which must be within the specified design limitations;

P_C – load capacity, which must be within the specified design limitations;

V_C – full (loading) volume of the body, which must be within the specified design limitations (in particular, taking into account the dimensions and features of the cargo to be transported);

P_C^{run} – running load, which must be within the specified design limitations and is determined by the formula:

$$P_C^{run} = \frac{M_C + P_C}{L_{coup.}}, \tag{4.4}$$

where $L_{coup.}$ – coupling length of the car, m;

C_B – characteristics of the chassis module (for example: flexibility and static deflection of the spring suspension, design speed, etc.), within the specified design limitations established by the NTD;

f_C – structural rigidity, which must be no less than the specified allowable value;

n_y^C – structural stability, which must be no less than the specified allowable value;

n_C – fatigue strength of the structure, which must be no less than the specified allowable value;

B_C – maximum costs for the production of the component, which must be within the specified limitations;

E_C – energy consumption of the absorbing device, which must be within the specified design limitations;

T_C – characteristics of the brake equipment module (for example: calculated brake pressure coefficient, pressure loss in the brake line per unit of time, etc.), which must be within the specified design limitations;

σ_C^I – strength according to the first design mode according to the car design standards, the value of which should not exceed the permissible;

σ_C^{II} – strength according to the second design mode according to the car design standards, the value of which should not exceed the permissible;

σ_C^{III} – strength according to the third design mode according to the car design standards, the value of which should not exceed the permissible;

σ_C^{imp} – impact strength according to the car design standards, the value of which should not exceed the permissible;

P_C – calculated static load from the wheelset on the rails, which should not exceed the permissible value established by the regulatory and technical documentation.

It is possible to take into account other functional requirements and restrictions of the corresponding secondary criteria, which are added depending on the design features of the studied car model.

Then the admissible solution area (ASA) will take the following form:

$$ASA = \left\{ \bar{Y} \left| \begin{array}{l} {}_{\min} \le M_C \le {}_{\max};\ P_{\min} \le P_C \le P_{\max};\ V_{\min} \le V_C \le V_{\max}; \\ P_{\min}^{run} \le P_C^{run} \le P_{\min}^{run};\ !_{\min} \le C_C \le C_{\max};\ \left[f\right] \le f_C;\ \left[n_y\right] \le n_y^C;\ \left[n\right] \le n^C; \\ B_{\min} \le B_C \le B_{\max};\ {}_{\min} \le E_C \le E_{\max};\ T_{\min} \le T_C \le T_{\max}; \\ \left[\sigma\ \right] \le \sigma_C;\ \left[\sigma\ \right] \le \sigma_C;\ \left[\sigma\ \right] \le \sigma_C;\ \left[\sigma^{imp}\right] \le \sigma_C^{imp};\ \left[P_C\right] \le P_C^C; \\ \sum \bar{a}_x^{\min} \le \sum \overline{a_x} \le \sum \bar{a}_x^{\max};\ \sum \bar{a}_y^{\min} \le \sum \bar{a}_y \le \sum \bar{a}_y^{\max};\ \sum \bar{a}_z^{\min} \le \sum \overline{a_z} \le \sum \bar{a}_z^{\max}; \\ \sum \bar{b}_x^{\min} \le \sum\limits_{a\in\left[1;s\right];b\in\left[1;k\right]} \overline{b_x} \le \sum \bar{b}_x^{\max};\ \sum \bar{b}_y^{\min} \le \sum \bar{b}_y \le \sum \bar{b}_y^{\max};\ \sum \bar{b}_z^{\min} \le \sum \bar{b}_z \le \sum \bar{b}_z^{\max} \end{array} \right. \right\}. \quad (4.5)$$

The highlighted approach to creating a generalizing universal mathematical notation of the procedure for implementing a useful prestressed and/or deformed state in the components of car structures and the results of its implementation can be used in solving other similar problems.

4.3 THEORETICAL ASPECTS OF CREATING USEFUL PRESTRESSED AND/OR DEFORMED LOAD-BEARING COMPONENTS OF CAR STRUCTURES

One of the main scientific and technical tasks, the results of which directly affect the efficiency of the freight car fleet, is the development of new or modernization of existing models of freight cars in order to reduce their material consumption. At the same time, a promising method for reducing the material consumption (with a corresponding increase in load capacity) of freight cars is the search and implementation of structural excess safety margins, by providing their component elements with optimal structural forms and their execution from materials with directional properties while meeting the conditions of strength and operational reliability. In addition, the results of the analysis of the impact of operational factors on the structures of the load-bearing systems of freight cars showed that one of the main types of damage to their elements is cracks.

As the positive experience of other industries related to the manufacture of metal structures shows, one of the promising directions for solving both of the above scientific and technical problems is the use of useful pre-stressed and/or deformed multifunctional structures in the load-bearing systems of mechanical engineering. However, consideration of the current scientific and technical background on the profile of the issues studied showed the lack of meaningful information on the creation of relevant theoretical aspects of solving such a problem for freight cars.

The main purpose of considering and applying the specified approach is to increase the life cycle of railway rolling stock, reduce their material consumption and increase load capacity, improve maintainability, increase crack resistance, reduce/completely eliminate stresses of different signs.

According to the current and prospective regulatory documentation, when calculating all types of cars, two main calculation modes are established: I and III [1–4].

According to the I calculation mode (rare combination of extreme loads), the permissible stresses are selected close to the yield point of the material used, taking into account the nature of the load action and the properties of the material (from 0.85 to 1.1 of the minimum yield point σ_t) in order to prevent the appearance of residual deformations and destruction of the elements and parts of the car.

According to the III calculation mode (frequent combination of moderate operational loads), the permissible stresses are selected based on the endurance limit of the material at a level of from 0.5 σ_t to 0.65 σ_t in order to prevent fatigue destruction of the assembly or part.

General rules for calculating the bearing capacity of railcar structures provide:

– calculation of body elements shall be performed according to permissible stresses and a margin of stability;

– calculation of individual frame elements shall be performed according to permissible stresses and a margin of fatigue resistance.

The basic parameters in the calculation and design of freight cars of all types are:

1) permissible stresses, the value of which, taking into account the margin factors, is determined by the yield strength of the material (σ_t). The margin factor for rolled metal is 0.9–0.95, depending on the operating conditions. The value of the yield strength, as well as other indicators of the mechanical properties of the material;

2) a margin of stability, the value of which, among other things, is determined by the yield strength of the material (σ_t).

The useful prestressing of structures is understood as various methods of directed artificial regulation of stresses (control of the stressed-deformed state) in structures to increase their efficiency in perceiving loads at the stages of the life cycle. In this case, intervention in the natural operation of the object for a directed change in its potential deformation energy can occur at different stages of the life cycle: during manufacturing, during installation, during operation or reconstruction and at different levels. For example, for freight cars: in modules, components, assemblies or basic elements.

The main task of introducing a pre-stressed and/or deformed state is to reduce the magnitude of stresses and/or deformations in the structural components of freight cars by using one or a combination of methods for their creation:

1. Compression of individual stretched, compressed and bent hollow/solid closed/unclosed profiles and entire elements (beams, frames) with various types of tightening from high-strength materials.

2. Preliminary elastic bending of individual elements with subsequent fixation (or welding) of them in a bent state into a whole structural element (beam).

3. Pre-stretching of entire structures or their individual parts in order to increase the elastic work area of the material.

4. Pre-tensioning of individual included flexible rods (cables, wire bundles, reinforcement) in order to perceive compressive forces by them.

5. Temporary loading during the manufacturing and installation of individual elements of structures or the entire structure with or without subsequent fixation, of the structure under load for rational distribution of forces and increasing its rigidity and stability.

6. Creation of pre-stress in rolled profiles by rolling pre-tensioned high-strength wire into them (for example, when creating flexible car joints).

7. Pre-heating/cooling of individual parts in order to increase/decrease their geometric dimensions). An example of an application for freight cars is preheating, which can be used to prevent the formation of cracks and/or to provide the required mechanical properties, for example, impact strength. Preheating can be performed in a furnace or using heating burners, electric plate radiators or induction or radiant heaters.

Next, it is necessary to analyze the load application schemes (**Fig. 4.1**) in accordance with the regulatory framework, which must be taken into account when assessing the strength of the elements of the car bodies according to the modes.

The criteria for the effectiveness of the use of useful prestressing and/or deformation in metal structures can be both economic requirements for reducing material consumption and the cost of objects, and structural and technological (increasing rigidity, preserving the shape of load-bearing structural elements after the influence of technologically determined factors (for example, welding), improving dynamic characteristics, etc.). In this regard, metal structures have broader opportunities and greater prospects for the use of prestressing than reinforced concrete and steel-reinforced concrete, where this technique has developed primarily as a means of combating the low strength of concrete during tension.

In all cases, additional labor is required to regulate internal forces in structures and there remains the possibility of loss or restructuring of the induced background of internal stresses over time due to the development of long-term processes in materials and joints. Therefore, the introduction of rational methods of stress-strain state management into the practice of creating modern railway engineering structures requires the development of appropriate theoretical provisions, methodological foundations and practical tools for each structural form.

The goals of creating useful prestressed and/or deformed multifunctional structures:

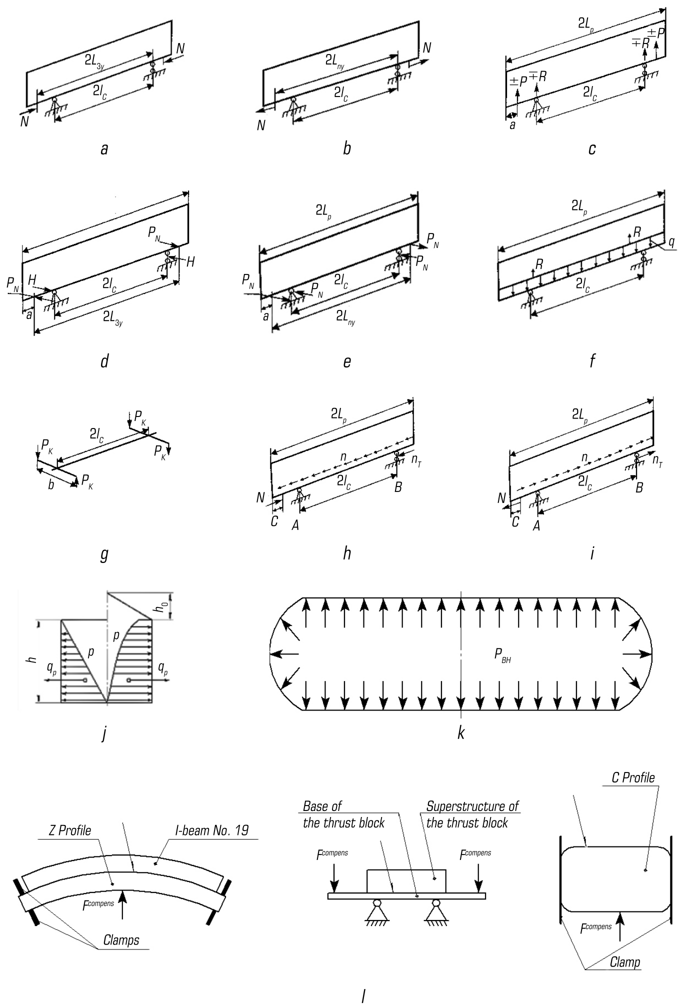
1) saving metal and resources in the structures being constructed due to a more favorable distribution of external forces, increasing the area of elastic work;

2) increasing the bearing capacity of structures that are at the stage of operation or reconstruction due to increased loads;

3) reducing the deformability of the entire structure or its individual elements, reducing the frequency or amplitude of oscillations;

4) increasing the stability of individual elements or the entire structure as a whole;

5) increasing the endurance of individual elements under cyclic loads by improving the cycle characteristics;



○ **Fig. 4.1** Expanded scheme of applying loads to car structures in various design cases of the life cycle: *a* – longitudinal quasi-static compression force; *b* – longitudinal quasi-static tensile force; *c* – vertical force due to eccentricity between the axles of the auto couplers; *d* – transverse forces in curves under quasi-static compression; *e* – transverse forces in curves under quasi-static tensile force; *f* – vertical load from the mass of the cargo and its own mass; *g* – oblique symmetrical loading (for cars with a base of more than 16 m); *h* – hitting the auto-coupler; *i* – spurt; *j* – expansion (pressure) forces of loose and bulk cargo; *k* – pressure forces of liquids and gases and water hammer forces in tank boilers, reservoirs, tanks; *l* – forces for creating a deformed state (vertical bending) during assembly and welding work

6) favorable change in some properties of the structure (dynamic characteristics under dynamic and seismic influences, aerodynamic characteristics under wind influences, increased resistance to temperature loads (for example, frost resistance);

7) ensuring in some cases ease of installation, and in this regard, a reduction in labor costs;

8) counteracting the occurrence of negative residual deformations from technological factors. For example, in freight car construction, preliminary deflection of the fixed overall structure when applying large welds: welding an I-beam to welded Z-shaped profiles of the backbone beam of gondolas, assembly structures of the upper gondolas' straps, etc.

The same goals can be achieved by other methods (increasing the area or changing the type of cross-section, the method of connecting elements, etc.) that are more materially expensive. Preliminary useful stress and/or deformation is advisable if the effect obtained from it fully pays off the additional costs. The choice of the final design option should be made on the basis of a feasibility study.

4.4 A PROMISING USEFUL PRESTRESSED AND/OR DEFORMED CONCEPT OF A COVERED HOPPER CAR FOR CEMENT TRANSPORTATION

A promising useful prestressed and/or deformed concept of a covered hopper car for cement transportation relates to car construction and can be used for railway transportation of bulk and bulk cargoes that require protection from precipitation, in particular cement.

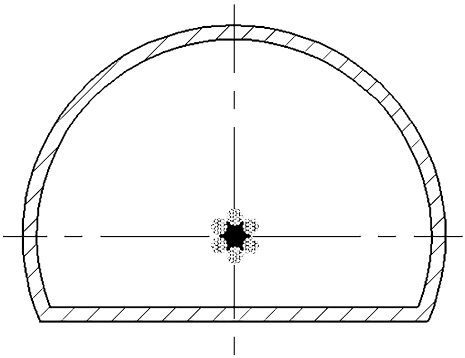


Fig. 4.2 Cross-section of a half-pipe with cables tensioned in the middle

The concept is based on the task of improving the design of the main elements of the frame and body modules, based on the execution of the backbone, end, pivot, middle intermediate beams of the frame module, the strapping of the upper and vertical side wall racks, the strapping of the upper, side racks and intermediate end walls from half-pipes (**Fig. 4.2**) with cables stretched (usefully pre-tensioned) in their middles, the backbone beam (**Fig. 4.3**), the frames (**Fig. 4.4**) of the side and end (**Fig. 4.5**) walls are curved parabolically (usefully pre-tensioned) curved into the middle of the body, while meeting the conditions of strength and operational reliability, which will allow reducing its material consumption and wear of non-bearing elements, and as a result, reducing the cost of manufacturing and operating the covered hopper car for cement transportation.

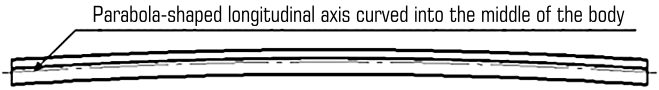


Fig. 4.3 Side view of a useful pre-deformed backbone beam of a covered hopper car concept for transporting cement

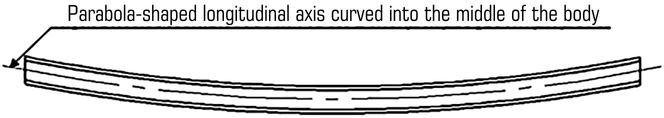


Fig. 4.4 Top view of a useful pre-deformed side wall of a covered hopper car concept for transporting cement and pellet car

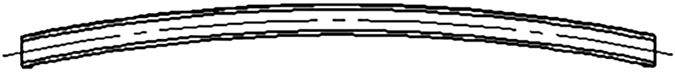


Fig. 4.5 Top view of a useful pre-deformed end wall of a covered hopper car concept for transporting cement and pellet car

4.5 PROMISING USEFUL PRESTRESSED AND/OR DEFORMED PELLET CAR CONCEPT

Promising useful prestressed and/or deformed pellet car concept relates to railcar construction and can be used for rail transportation of hot pellets and sinter with temperatures up to 700 °C from the production site to the receiving hoppers of the blast furnace.

The concept is based on the task of improving the railway gondola-hopper car for hot pellets and sinter by improving the design of the main elements of the frame and body modules, based on the execution of the backbone, end, pivot, middle intermediate beams of the frame module, the strapping of the upper and uprights of the vertical side walls, the strapping of the upper, uprights of the side and intermediate end walls from half-pipes (**Fig. 4.2**) with cables stretched (usefully pre-tensioned) in their middles, the backbone beam (**Fig. 4.3**), the frames (**Fig. 4.4**) of the side and end (**Fig. 4.5**) walls are curved parabolically (usefully pre-tensioned) into the middle of the body, while meeting the conditions of strength and operational reliability, which will allow reducing its material consumption and wear of load-bearing elements, and as a result, reducing the cost of manufacturing and operation.

4.6 PROMISING ELASTIC-DISSIPATIVE CONCEPT OF A PLATFORM CAR MADE OF LEAF SPRINGS

The promising elastic-dissipative concept of a platform car made of leaf springs relates to car construction and can be used for railway transportation of wheeled and tracked vehicles, piece goods, forest and long-length goods, box-packed goods, containers and other goods that do not require protection from atmospheric precipitation.

The concept is based on the task of improving the platform car by making the middle part of the backbone beam (**Fig. 4.6**), transverse and end beams in the form of leaf springs (**Fig. 4.7**).

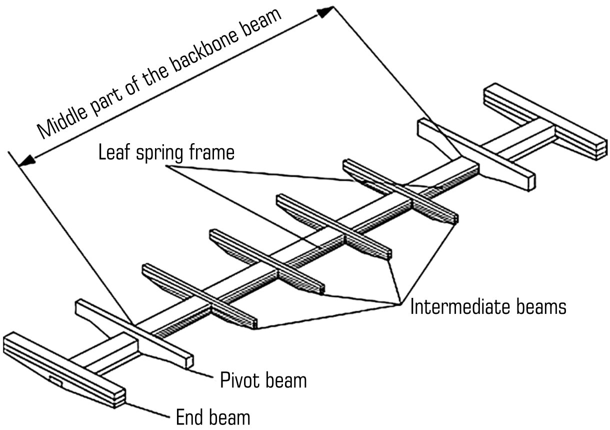


Fig. 4.6 Concept of a leaf spring platform car frame

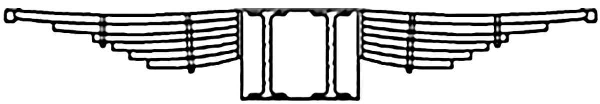


Fig. 4.7 Cross-section of the concept of transverse beams of a leaf spring frame

CHAPTER 4

The introduction of new features in interaction with known ones ensures the absorption of vibration and impact energy, which, as a result, improves the dynamics and strength of the platform car, reduces material consumption, accordingly increases load capacity and increases the service life of the car.

4.7 PROMISING ELASTIC-DISSIPATIVE CONCEPT OF A HOPPER CAR FOR TRANSPORTING GRAIN FROM LEAF SPRINGS

The promising elastic-dissipative concept of a hopper car for transporting grain from leaf springs relates to railcar construction and can be used for freight rail transportation of bulk cargo that requires protection from precipitation, in particular grain.

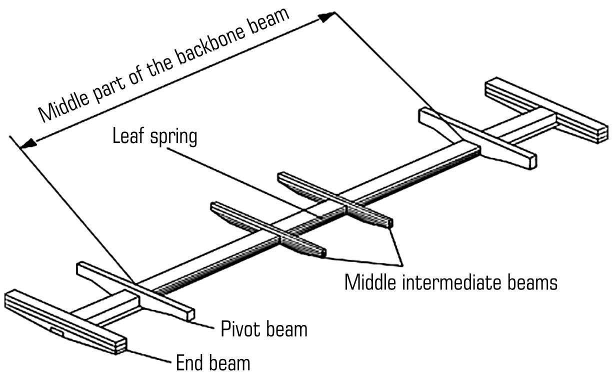


Fig. 4.8 Concept of a frame of a hopper car for transporting grain from leaf springs

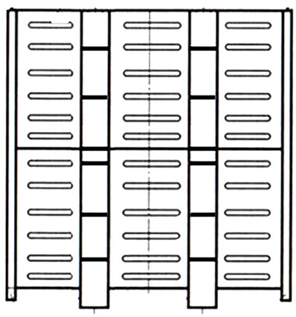


Fig. 4.9 Concept of an end wall of a hopper car for transporting grain from leaf springs

The concept is based on the task of improving a hopper car for transporting grain by making the middle part of the backbone beam (**Fig. 4.8**), end beams, middle intermediate beams and vertical racks of the side walls and intermediate racks of the end walls (**Fig. 4.9**) in the form of leaf springs.

The introduction of new features in interaction with known ones ensures the absorption of vibration energy, which, as a result, improves the dynamics and strength of the hopper car for transporting grain, provides a reduction in material consumption and, accordingly, increases the load capacity and extends the service life of the car.

4.8 PROMISING ELASTIC-DISSIPATIVE CONCEPT OF A HOPPER CAR FOR TRANSPORTING MINERAL FERTILIZERS FROM LEAF SPRINGS

The promising elastic-dissipative concept of a hopper car for transporting mineral fertilizers from leaf springs relates to railcar construction and can be used for freight rail transportation of bulk cargo that requires protection from precipitation, in particular mineral fertilizers.

The concept is based on the task of improving a hopper car for transporting mineral fertilizers by making the middle part of the backbone beam (**Fig. 4.10**), end beams, middle intermediate beam and vertical racks of the side walls and intermediate racks of the end walls (**Fig. 4.11**) in the form of leaf springs. The introduction of new features in interaction with known ones ensures the absorption of vibration energy, which, as a result, improves the dynamics and strength of the hopper car for transporting mineral fertilizers, reduces material consumption and, accordingly, increases the load capacity and extends the service life of the car.

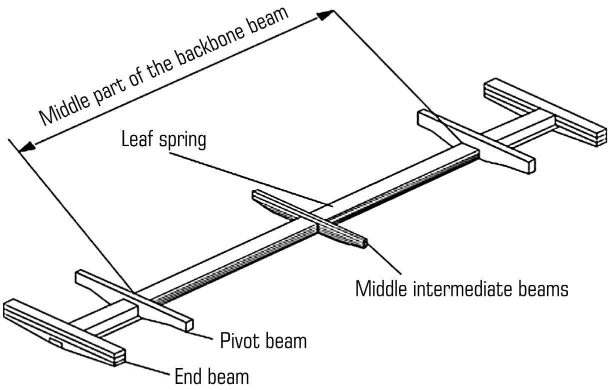


Fig. 4.10 Hopper car frame concept for transporting mineral fertilizers from leaf springs

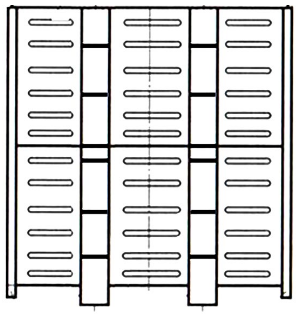


Fig. 4.11 Hopper car end wall concept for transporting mineral fertilizers from leaf springs

4.9 PROMISING ELASTIC-DISSIPATIVE CONCEPT OF A HOLLOW-BOTTOMED GONDOLA WITH LEAF SPRINGS

The promising elastic-dissipative concept of a hollow-bottomed gondola with leaf springs relates to car construction and can be used for railway transportation of bulk and bulk cargo that does not require protection from precipitation.

The concept is based on the task of improving the hollow-bottomed gondola by making the middle part of the backbone beam (**Fig. 4.12**), intermediate beams, vertical side wall uprights and horizontal end wall belts (**Fig. 4.13**) in the form of leaf springs.

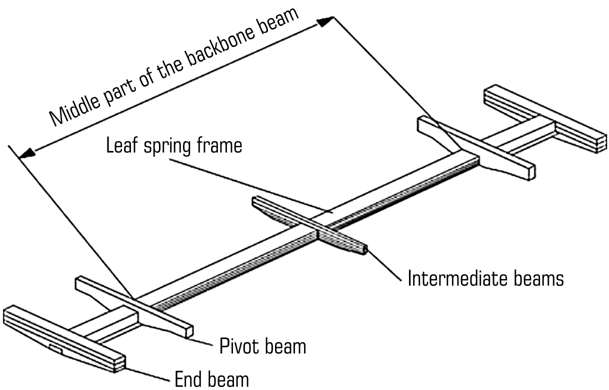


Fig. 4.12 Leaf spring gondola frame concept

CHAPTER 4

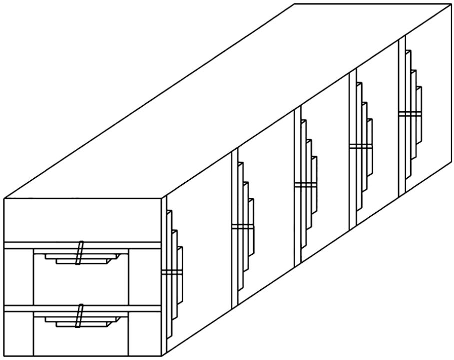


Fig. 4.13 Leaf spring gondola body concept

The introduction of new features in interaction with known ones ensures the absorption of vibration energy, which, as a result, improves the dynamics and strength of the hollow-bottom gondola, reduces material consumption, accordingly increases load capacity and increases the service life of the car.

4.10 PROMISING ELASTIC-DISSIPATIVE CONCEPT OF A UNIVERSAL COVERED CAR WITH RACKS WITH DAMPING PROPERTIES

The promising elastic-dissipative concept of a universal covered car with racks with damping properties relates to car construction and can be used for freight rail transportation of goods that require protection from precipitation.

The concept is based on the task of improving the technical and economic indicators of a universal covered car by making parts of the body module in a stamped manner, namely, making the side walls and intermediate racks of the side walls solid, in a stamped manner, with additional stiffening edges (**Fig. 4.14**); making the end walls and end racks solid, in a stamped manner, with additional stiffening edges; making the roof of the car solid in a stamped manner with additional stiffening edges.

The introduction of new features in interaction with known ones ensures the appearance of damping of the body module design, which implements in it the principle of adaptive perception of operational loads in the loaded or unloaded states, which, as a result, improves the dynamics and strength indicators of the universal covered car, reduces the mass of material for the manufacture of the universal covered car, simplifies the technological process of manufacturing the universal covered car, increases the load capacity, and its service life.

CHAPTER 4

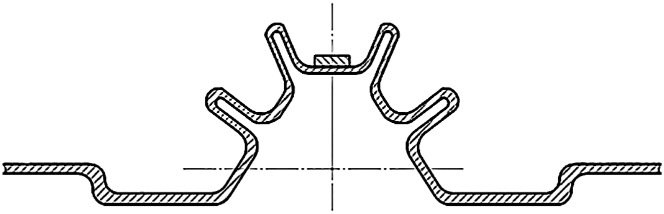


Fig. 4.14 Cross-section of a stamped rack with damping properties

4.11 PROMISING ELASTIC-DISSIPATIVE CONCEPT OF A UNIVERSAL HOPPER CAR FOR TRANSPORTING GRAIN WITH RACKS WITH DAMPING PROPERTIES

The promising elastic-dissipative concept of a universal hopper car for transporting grain with racks with damping properties relates to railcar construction and can be used for freight rail transportation of bulk cargo that requires protection from precipitation, in particular grain.

The concept is based on the task of improving the technical and economic indicators of the grain hopper car by making parts of the body module stamped, namely, making the side walls and intermediate racks of the side walls solid, stamped, with additional stiffening edges (**Fig. 4.14**); making the end walls and end racks solid, stamped, with additional stiffening edges; making the roof of the car solid, stamped, with additional stiffening edges. The introduction of new features in interaction with the known ones ensures the appearance of damping of the body module design, which implements the principle of adaptive perception of operational loads in the loaded or unloaded states, which, as a result, improves the dynamics and strength of the grain hopper car, reduces the mass of material for manufacturing the grain hopper car, simplifies the technological process of manufacturing the grain hopper car, increases the carrying capacity, and its service life.

4.12 PROMISING CONCEPT OF A RAILWAY TANK WITH SUPPORTS IN THE FORM OF LEAF SPRINGS

The concept is based on the task of improving a railway tank by replacing the supports located between the boiler and the frame with leaf springs that absorb vibration energy, which, as a result, improves the dynamics of the railway tank.

The task is achieved by the fact that in a railway tank, which contains bogies, a frame, braking equipment, automatic coupling devices, a boiler, fastening the boiler to the frame and boiler supports on the frame, according to the concept, the boiler supports on the frame are made in the form of leaf springs (**Fig. 4.15**).

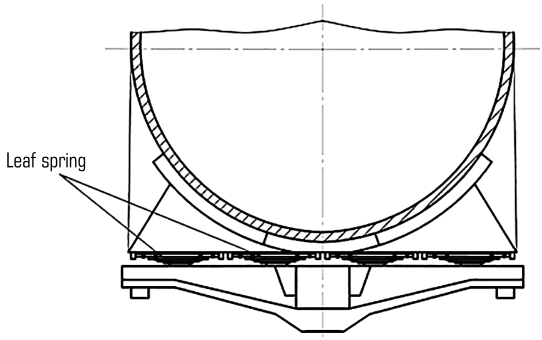


Fig. 4.15 Concept of a railway tank with supports of the boiler on the frame in the form of leaf springs

4.13 PROMISING CONCEPT OF A RAILWAY TANK WITH SUPPORTS IN THE FORM OF DISC SPRINGS

The concept of a railway tank with supports in the form of disc springs belongs to railway transport, namely railway tanks and can be used for the transportation of liquid cargo.

The concept is based on the task of improving the railway tank by replacing the supports located between the boiler and the frame with disc springs that absorb vibration energy, which, as a result, improves the dynamics of the railway tank.

The task is achieved by the fact that in a railway tank containing bogies, a frame, braking equipment, automatic coupling devices, a boiler, fastening of the boiler to the frame and boiler supports on the frame, according to the concept, the boiler supports on the frame are made in the form of disc springs (**Fig. 4.16**).

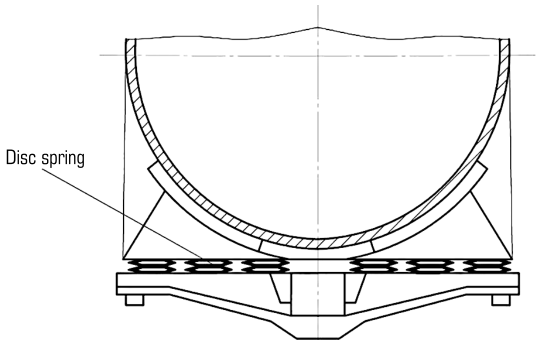


Fig. 4.16 Concept of a railway tank with supports in the form of disc springs

4.14 PROMISING ARTICULATED CONCEPT OF A 4-AXLE DUMP CAR

The promising articulated concept of a 4-axle dump car refers to railcar construction and can be used for rail freight transportation of bulk cargo that does not require protection from precipitation and mechanical unloading.

The concept is based on the task of improving the dump car by having articulated elements in its design instead of existing fixed elements (solid beams, welded joints), namely the presence of an articulated element in the middle part of the backbone beam (**Fig. 4.17**), the presence of articulated elements (**Fig. 4.18**) at the points of joint of the backbone beam with: buffer walls, pivot and cylinder beams. The introduction of new features in interaction with known ones provides the appearance of additional degrees of freedom of the design and implements in it the principle of adaptive perception of operational loads in the loaded or unloaded states, which, as a result, improves the dynamics and strength of the dump car, ensures a reduction in material consumption and, accordingly, increases the load-bearing capacity and extends the service life of the dump car.

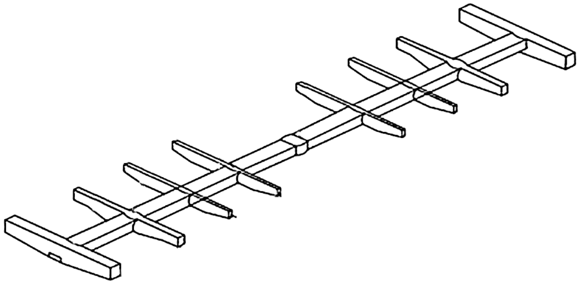


Fig. 4.17 Multifunctional articulated concept of the frame of a 4-axle dump car

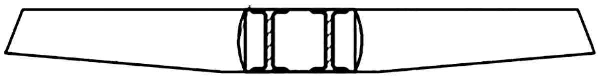


Fig. 4.18 Concept of articulated joint of beams of the frame of a 4-axle dump car

4.15 PROMISING ARTICULATED CONCEPT OF A HOPPER CAR FOR GRAIN TRANSPORTATION

The promising articulated concept of a hopper car for grain transportation relates to car construction and can be used for rail freight transportation of bulk cargoes that require protection from precipitation, in particular grain.

The concept is based on the task of improving the hopper car for transporting grain by using articulated elements in its design instead of existing fixed elements (solid beams, welded joints), namely, installing a articulated element in the middle part of the backbone beam (**Fig. 4.19**), installing articulated elements (**Fig. 4.20**) at the joints of the end beams, pivot beams and middle intermediate beams.

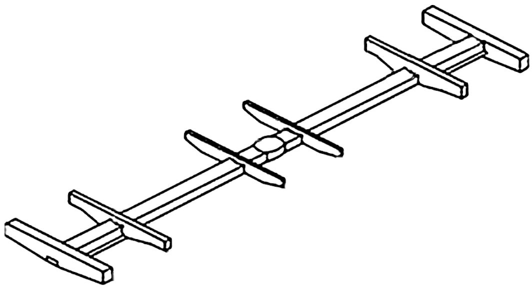


Fig. 4.19 Multifunctional articulated concept of the frame of a hopper car for grain transportation

Fig. 4.20 Concept of articulated joint of beams of the frame of a hopper car for grain transportation

The introduction of new features in interaction with known ones provides the appearance of additional degrees of freedom of the structure and implements in it the principle of adaptive perception of operational loads in the loaded or unloaded states, which, as a result, improves the dynamics and strength of the hopper car for grain transportation, provides a reduction in material consumption and, accordingly, increases the load-bearing capacity and increases the service life of the car.

4.16 PROMISING ARTICULATED CONCEPT OF A HOPPER CAR FOR TRANSPORTING MINERAL FERTILIZERS

The concept is based on the task of improving a hopper car for transporting mineral fertilizers by using articulated elements in its design instead of existing fixed elements (solid beams, welded joints), namely, installing an articulated element in the middle part of the backbone beam (**Fig. 4.21**), installing articulated elements at the joints of the end beams, pivot beams and the central intermediate beam.

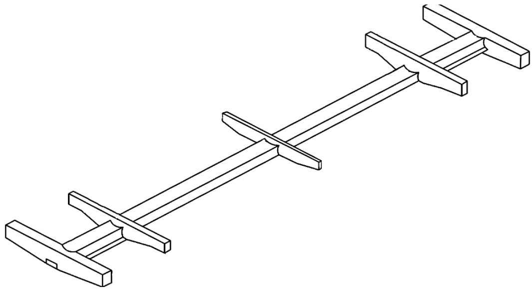


Fig. 4.21 Multifunctional articulated concept of a hopper car frame for transporting mineral fertilizers

The introduction of new features in interaction with known ones provides the appearance of additional degrees of freedom of the design and implements in it the principle of adaptive perception of operational loads in the loaded or unloaded states, which, as a result, improves the dynamics and strength of the hopper car for transporting mineral fertilizers, provides a reduction in material consumption and, accordingly, increases the load capacity and increases the service life of the car.

4.17 PROMISING ARTICULATED CONCEPT OF A UNIVERSAL PLATFORM CAR

The promising articulated concept of a universal platform car refers to car construction and can be used for railway transportation of wheeled and tracked vehicles, long-sized, piece, forest and other cargo, containers and equipment that does not require protection from atmospheric influences.

The concept is based on the task of improving the universal platform car by using articulated elements in its design instead of existing fixed elements (solid beams, welded joints), namely, installing a articulated element in the middle part of the backbone beam (**Fig. 4.22**), installing articulated elements at the joints of the end beams, pivot beams and main cross beams.

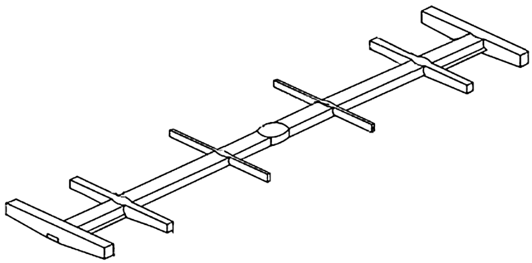


Fig. 4.22 Multifunctional articulated concept of the frame of a universal platform car

The introduction of new features in interaction with known ones provides the appearance of additional degrees of freedom of the structure and implements in it the principle of adaptive perception of operational loads in the loaded or unloaded states, which, as a result, improves the dynamics and strength of the universal platform car, provides a reduction in material consumption and, accordingly, increases the load capacity and increases the service life of the car.

4.18 PROMISING ARTICULATED CONCEPT OF A UNIVERSAL COVERED CAR

The utility model relates to car construction and can be used for freight railway transportation of goods that require protection from atmospheric precipitation.

The concept is based on the task of improving a universal covered car by using articulated elements in its design (**Fig. 4.23**, **4.24**) instead of existing fixed elements (solid beams, welded joints), namely the presence of a articulated element in the middle part of the backbone beam, the presence of articulated elements at the joints of the end beams, pivot beams and main beams, the presence of articulated elements at the joints of the side wall uprights with the lower skin and at the joints of the roof with the side wall uprights.

The introduction of new features in interaction with the known ones ensures the emergence of additional degrees of freedom of the structure and implements in it the principle of adaptive perception of operational loads in the loaded or unloaded states, which, as a result, improves the dynamics and strength indicators of the universal covered car, provides a reduction in material consumption and, accordingly, increases the load capacity and increases the service life of the car.

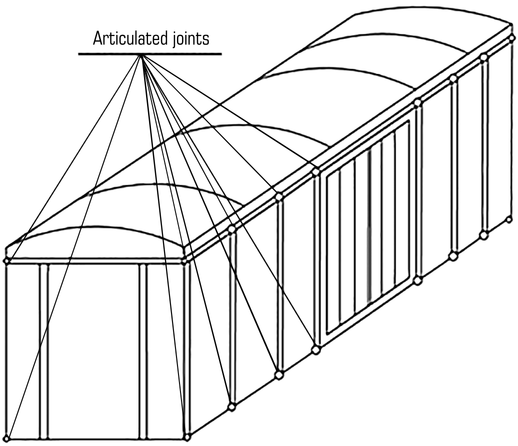


Fig. 4.23 Multifunctional articulated concept of a universal covered car body

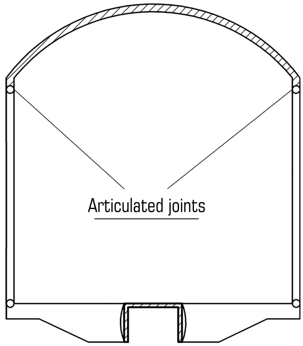


Fig. 4.24 Cross-section of the multifunctional articulated concept of the body of a universal covered car

4.19 PROMISING ARTICULATED CONCEPT OF A HOLLOW-BOTTOMED GONDOLA

The concept is based on the task of improving the hollow-bottomed gondola by using articulated elements in its design (**Fig. 4.25–4.27**) instead of existing fixed elements (solid beams, welded joints), namely, installing a articulated element in the middle part of the backbone beam; installation of articulated elements at the points of joint of the backbone beam with: end, pivot and intermediate beams; installation of articulated elements at the points of joint of end, pivot and intermediate beams with side walls; installation of articulated elements at the points of joint of vertical side wall uprights with upper strapping.

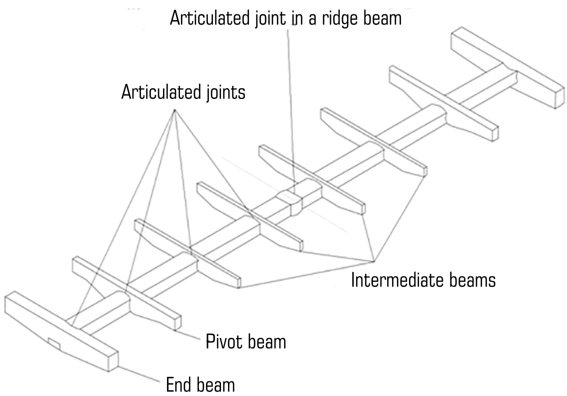


Fig. 4.25 Multifunctional articulated concept of a hollow-bottomed gondola frame

The introduction of new features in interaction with known ones provides the appearance of additional degrees of freedom of the structure and implements in it the principle of adaptive perception of operational loads in loaded or unloaded states, which, as a result, improves the dynamics and strength of the hollow-bottomed gondola, provides a reduction in material consumption and, accordingly, increases the load-bearing capacity and increases the service life of the car.

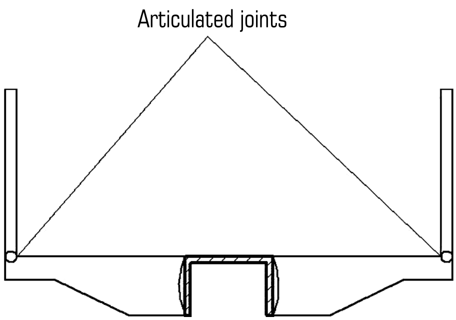


Fig. 4.26 Cross-section of a multifunctional articulated concept of a hollow-bottomed gondola body

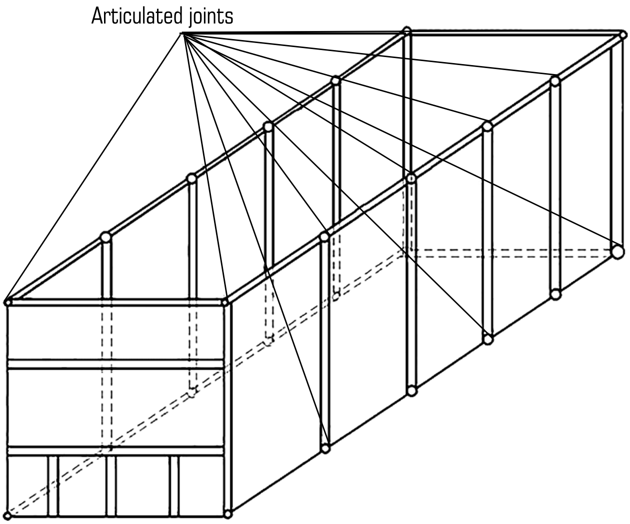


Fig. 4.27 Multifunctional articulated concept of a hollow-bottomed gondola body

4.20 PROMISING ARTICULATED RAILWAY TANK CONCEPT

The promising articulated railway tank concept belongs to railway transport, namely railway tanks and can be used for the transportation of liquid cargo.

The concept is based on the task of improving the railway tank for the transportation of liquid cargo by using articulated elements in its design (**Fig. 4.28**) instead of existing fixed elements (solid beams, welded joints), namely, installing the articulated element in the middle part of the backbone beam, installing articulated elements at the joints of the end and pivot beams.

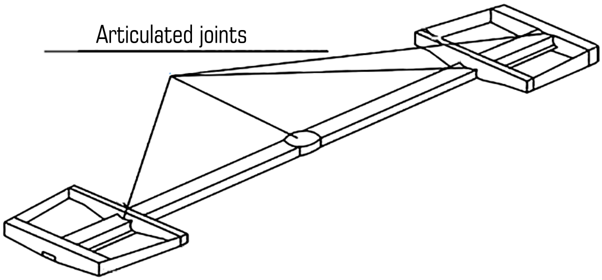


Fig. 4.28 Multifunctional articulated concept of a railway tank frame

The introduction of new features in interaction with known ones provides the appearance of additional degrees of freedom of the structure and implements in it the principle of adaptive perception of operational loads in the loaded or unloaded states, which, as a result, improves the dynamics and strength of the railway tank for the transportation of liquid cargo, provides a reduction in material consumption and, accordingly, increases the load capacity and increases the service life of the railway tank for liquid cargo.

4.21 PROMISING MULTI-MATERIAL CONCEPT OF A COVERED CAR

The promising multi-material concept of a covered car (**Fig. 4.29**) refers to car construction and can be used for railway transportation and is intended for the transportation of a wide range of piece, grain and other cargo that requires protection from atmospheric influences.

The concept is based on the task of improving the covered car to increase the efficiency of its use, namely: reducing material consumption, increasing the load capacity and loading volume of the body, and reducing the corrosion wear of the body module (**Fig. 4.30**), by improving its design, based on the execution of the body module as a solid composite material and cross-sectional configurations of equal resistance to the actions of the total corresponding operational loads, while meeting the conditions of strength and operational reliability.

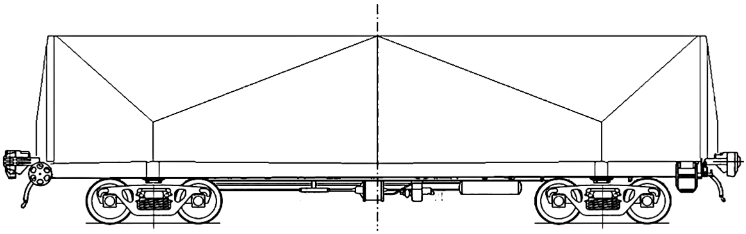


Fig. 4.29 Multi-material concept of a covered car

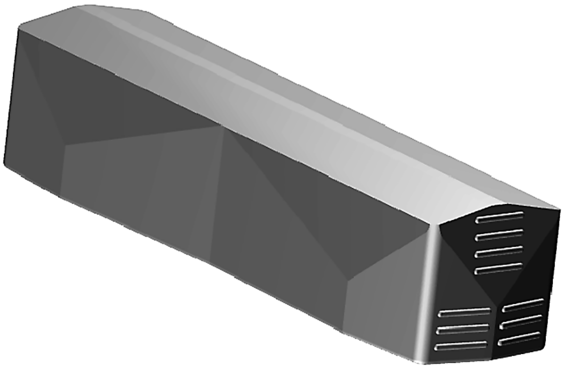


Fig. 4.30 Multi-material concept of a covered car body

The introduction of new features in interaction with known ones ensures a reduction in material consumption, an increase in the load capacity and loading volume of the body, an increase in the corrosion resistance of the body module and, as a result of all the above, a reduction in the cost of manufacturing and operating a covered car.

4.22 A PROMISING MULTI-MATERIAL CONCEPT OF A RAILWAY TANK CAR

A promising multi-material concept of a railway tank car (**Fig. 4.31**) belongs to railway transport, namely railway tanks and can be used for the transportation of liquid cargo.

The concept is based on the task of improving a railway tank car for transporting liquid cargo, namely: reducing material capacity, increasing the load capacity and loading volume of the body, and reducing the corrosion wear of the body module (**Fig. 4.32**), by improving its design, based on the continuous execution of the boiler from composite material and cross-sectional configurations of equal resistance to the effects of the total corresponding operational loads, while meeting the conditions of strength and operational reliability.

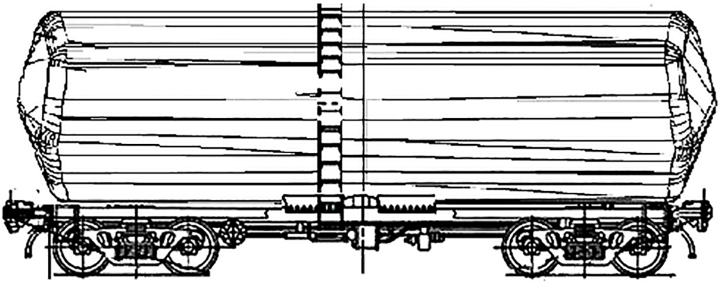


Fig. 4.31 Multi-material concept of a railway tank

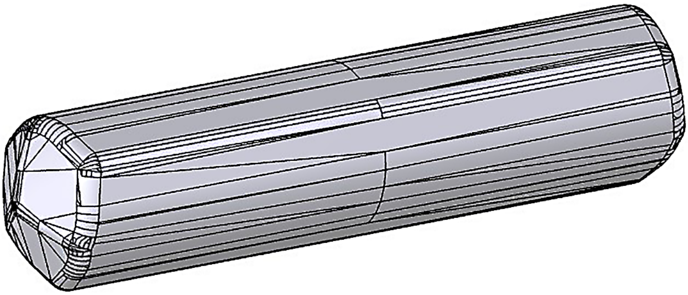


Fig. 4.32 Multi-material concept of a railway tank boiler

The introduction of new features in interaction with known ones ensures a reduction in material consumption, an increase in the load capacity and loading volume of the body, an increase in the corrosion resistance of the body module and, as a result of all the above, a decrease in the cost of manufacturing and operating a railway tank for transporting liquid cargo.

4.23 A PROMISING RAILWAY TANK WITH A MULTI-MATERIAL CONCEPT OF SUPPORTS

A promising railway tank with a multi-material concept of supports belongs to railway transport, namely railway tanks and can be used for transporting liquid cargo.

The concept is based on the task of improving the railway tank by replacing the supports located between the boiler and the frame with rubber-metal elements that absorb vibration energy, which, as a result, improves the dynamics of the railway tank.

The task is achieved by the fact that in a railway tank car, which contains bogies, a frame, braking equipment, automatic coupling devices, a boiler, fastening of the boiler to the frame and supports of the boiler on the frame, according to the concept, the supports of the boiler on the frame are made in the form of rubber-metal elements (**Fig. 4.33**).

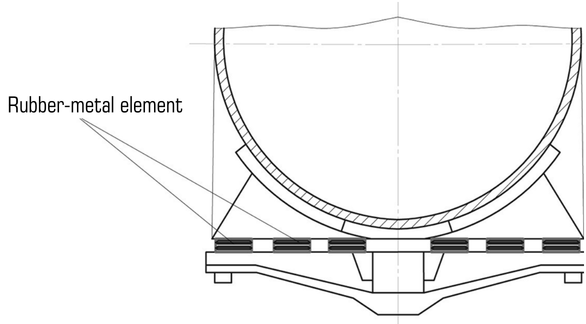


Fig. 4.33 Cross-section of a railway tank with a multi-material support concept

CONCLUSIONS

1. The creation and development of multifunctional components of freight cars is a promising direction for improving their designs. Today, there are a significant number of ways to create multifunctional components of freight cars. In general, among them it is possible to distinguish: a combination of elements that are separate in terms of their functions; transformation of a functional element or functional grouping of elements; identification and implementation of additional functions on the same resource base; identification and implementation of additional functions on a new resource base.

2. Most often in the practice of creating multifunctional technical means, a combination of elements that are separate in terms of their functions is used. Its main directions include: connection of different levels of the constructive hierarchy (modules, nodes, basic elements) of components without changing their forms and properties, and with mutual coordination of forms and properties;

introduction of new principles of functioning to car constructs on the existing element base and on a new element base; consideration at the design stage of the prerequisites for the constructive implementation of future innovative design solutions.

3. Today, the most promising from the point of view of practical creation of multifunctional components of freight cars are the following directions identified and presented in detail in the article: elastic-dissipative, non-rigid articulated and multi-material.

4. The expected results of the development and implementation of multifunctional components of freight cars include: reducing their own mass; improving operational properties; reducing the number of elements and redundant connections; increasing reliability and safety of movement; increasing the permissible values of the speeds of cars in empty and loaded states; reducing the costs of their: manufacturing, operation, maintenance, repairs, etc.

5. The presented directions for creating multifunctional components of freight cars will allow obtaining positive results in their manufacture and operation. Such positive results include: increasing the life cycle of the studied means, reducing their material consumption and increasing load capacity, improving maintainability, increasing crack resistance, reducing/completely eliminating stresses of different signs.

6. The possibilities of constructive and technological implementation of prestressed and/or deformed components of freight cars, structured in a graphical form and presented in the work, should be used in further research and development work on the creation of new generation freight cars, as well as increasing the systemic efficiency of their existing models.

7. The proposed theoretical provisions for the implementation of prestressed and/or deformed components in the design of freight cars in accordance with possible cases of loading at the stages of the life cycle should be used in solving similar scientific and applied problems for other types of rolling stock, as well as objects of transport engineering.

8. When introducing a directed stress-strain state into the components of freight cars, it is advisable to use the given mathematical notation.

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