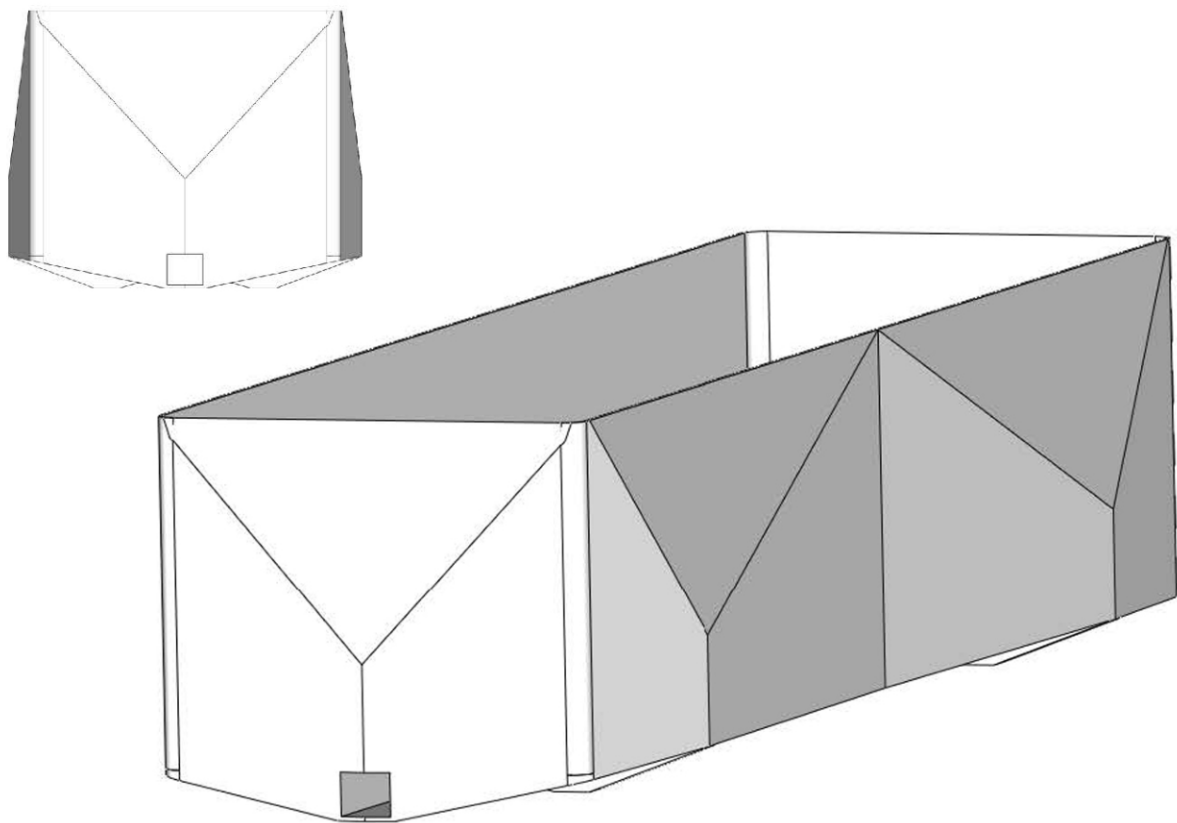


Oleksij FOMIN
Anna FOMINA

CONCEPTUAL SOLUTIONS FOR THE MANUFACTURE OF CARGO WAGON BEARING SYSTEMS FROM COMPOSITES

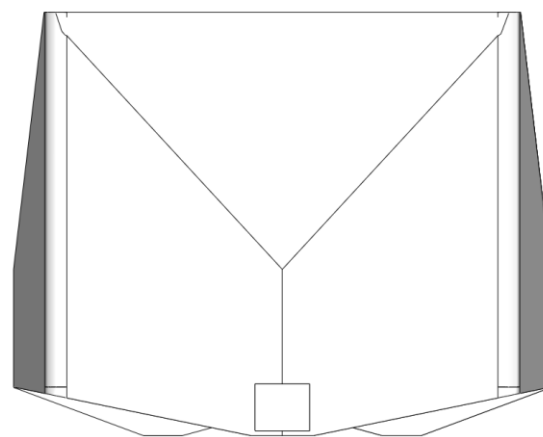
(PART 1)

Monograph



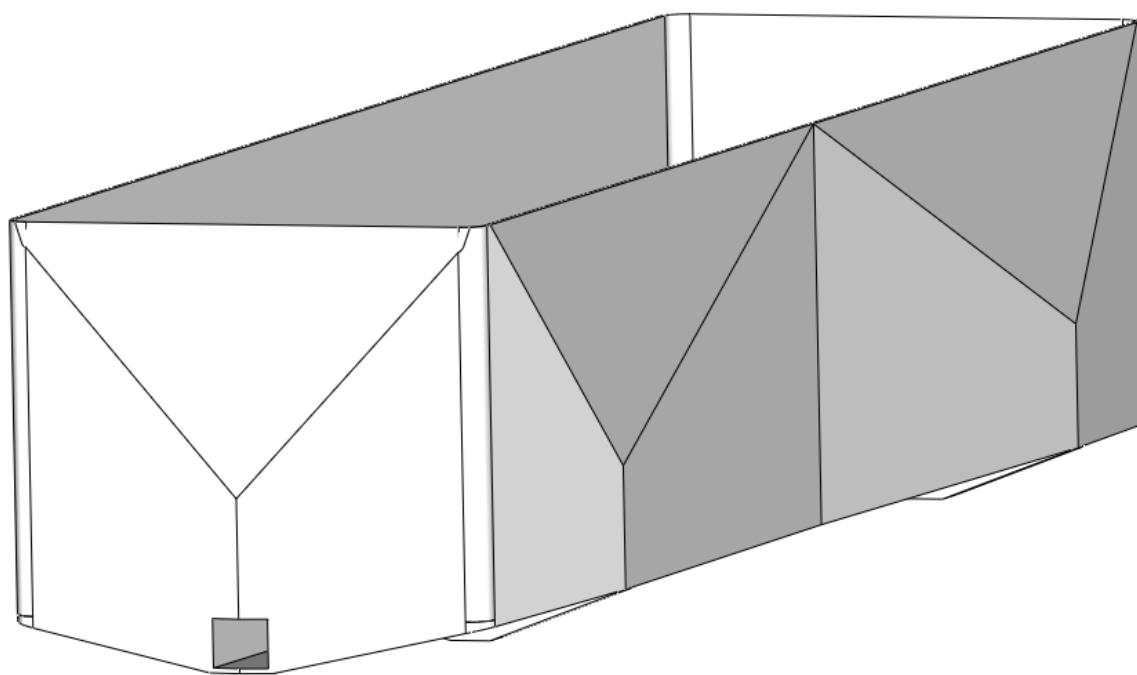
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Monograph



2023

UDC 629.4.02.001.76

F 71

Fomin, O. , and A. Fomina. *Conceptual solutions for the manufacture of cargo wagon bearing systems from composites (Part 1)*. Dallas, USA: Primedia eLaunch LLC, 2023. 356 p.

ISBN 979-8-89217-814-3

DOI 10.36074/fomins-monograph.2023

*This monograph is recommended for printing by the Science Council
of Volodymyr Dahl East Ukrainian National University
(protocol No 03 dd 27.10.2023)*

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The monograph will be useful for scientists, designers, engineers whose activities are related to the improvement of technical, economic and operational indicators of non-traction rolling stock at various stages of its life cycle.

In particular, the issue of the possibility and expediency of introducing various types of constructive hierarchy of components in the design of wagons. What can happen when creating new models of them or modernizing existing ones.

To date, the traditional approach to creating a structure of freight wagons from steel has almost completely exhausted the potential for improving their technical, economic and operational indicators. At the same time, the experience of the development of composite materials and technologies for their creation in other branches of light and heavy engineering and instrument building indicates the prospect of deploying relevant research and development works on the use of such materials in railcar construction.

The purpose of the monograph is to highlight the results obtained from the creation of conceptual solutions for the manufacture of component load-carrying systems of freight wagons from composites. The book also presents the results of previous works of a theoretical and practical nature. In particular, given. Analysis of the constructive perfection of truck wagons of the modern domestic vehicle by type. Features of calculations of conceptual solutions for manufacturing non-sowing systems cargo wagons made of composites. Concepts for freight wagons made of composites.

The book can be used as a study guide for the preparation of bachelors, masters, doctors of philosophy and doctors of sciences in various specialties of transport mechanics. Including from specialties: railway transport, transport technologies, mechanical engineering, materials science and others.

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INTRODUCTION

The urgent need to significantly increase the efficiency of freight transportation by railways requires solving the scientific and technical problem [2-5, 16-31, 41-49] of creating a fundamentally new generation of freight wagons from composite materials.

Today, the technical facilities of domestic railway transport are in a critical state of wear and tear. Obsolete freight wagons cause a negative impact on the infrastructure and, accordingly, create a direct threat to the safety of train traffic. They do not meet modern requirements for the level of transportation efficiency. The urgent need to significantly increase the efficiency of freight transportation by Ukrainian railways requires solving the scientific and technical problem of creating a fundamentally new generation of freight wagons [18, 21, 92, 124-131] from composite materials.

The key components of the specified problem, the solution of which is aimed at the task of the project, are:- unsatisfactory state of technical, economic and operational characteristics of railway freight wagons; - unsatisfactory level of characteristics of the load-carrying components of domestically produced freight wagons; - inconsistency of load-carrying structures of freight wagons with modern global trends in the development of transport structures; - lack of technical solutions for the creation of load-bearing components of freight wagons from composites; - significant material costs for the technical service of the existing non-sewing component freight wagons and an unreasonably short period of their operation;

The practical creation of composite concepts of freight wagons will ensure that their constructions achieve technical, economic and operational indicators of a new generation level. For this purpose, it is proposed to generate non-sewing structures of wagons from completely new progressive composites. The

implementation of such solutions will allow to reduce the weight of the wagon, correspondingly increase the carrying capacity, increase the speed of movement in the loaded and empty states, improve the dynamic qualities, anti-corrosion properties, reduce the costs of maintaining the wagons, improve the interoperable properties, etc.

Improvement of the specified characteristics will also allow: to increase traffic safety and environmental friendliness of cargo transportation, which is currently a primary problem in transport; to reduce empty runs due to the possibility of forming trains from different types of wagons, provided that they are excluded from derailment and thereby improve the efficiency of freight transportation; to ensure improvement of their fatigue strength due to significantly better characteristics and reduction of dynamic load in the case of cyclic disturbances caused by the peculiarities of the operation of wagons, and accordingly, increase (by 2-4 times) the design service life, improvement of the efficiency of the transportation process due to the availability of serviceable rolling stock, etc. . What will ultimately allow to significantly improve the profitability and competitiveness of domestic rail freight transportation and wagon production.

The obtained results of the work consist in obtaining new functional dependences of the loading of load-bearing structures of freight wagons made of composite materials under operational modes. Also, the results of the work will make it possible to create models of optimization and strength of load-bearing structures of freight wagons with improved technical and economic indicators. The conducted research will allow to create fundamentally new concepts of removable bodies with improved intermodal and interoperable properties.

Therefore, the use of composites in the creation of modern designs of freight wagons is an urgent and important scientific problem not only for the wagon industry, but also for the transport industry as a whole.

SECTION 1

ANALYSIS OF THE CONSTRUCTIVE PERFECTION OF TRUCK WAGONS OF THE MODERN DOMESTIC VEHICLE BY TYPE

The section presents analysis of the constructive perfection of truck wagons [23, 24, 27, 30-40, 47, 90, 140,141] of the modern domestic vehicle by type.

1.1 Design features of semi-wagons

Semi-wagons are intended for transportation of loose, bulk and artificial cargoes that do not require shelter and protection from atmospheric precipitation. This ensures the convenience of carrying out loading and unloading operations with the help of effective means of mechanization (overhead cranes, wagon transfers, etc.). In addition, many bodies of semi-wagons have unloading hatches in the floor or side walls, which ensure unloading of bulk cargo by gravity.

Using the example of a wagon with a load capacity of up to 125 tons, we will consider the design of the body of a universal eight-axle semi-wagon of the 12-124 model. It is equipped with unloading hatches in the floor. At the ends, the body is equipped with doors that open inside the wagons.

The body frame has a backbone beam consisting of two Z-shaped profiles welded to each other with a longitudinal seam, covered at the joint with a I-beam. Brackets for hinges are attached to the I-beams, for hinged hanging of the covers of the unloading hatches.

In the cantilever part of the backbone beam, the front and rear stops of the auto coupling are installed. The front stop is cast integrally with the impact socket. Pivot beams of a closed box cross-section have hinges and slides from below. Thresholds are welded from above to the frame beams, limiting the opening of the doors to the outside of the body. On the end surfaces of the end beam, the lever of the uncoupling drive of the auto coupling and the stacker handrails are fixed. Cross beams of the frame -I-beam section, their upper shelves have corrugations. Similar protruding parts have pivot beams. Hatch covers are corrugated, they have special locks. The lids are also equipped with torsion devices that facilitate lifting when closing. To ensure tight pressing with the help of the cover lever, there are staples on the lower strap .

The side walls of the body have metal cladding with trough-like stampings, supported by a frame consisting of upper and lower straps, as well as corner, pivot and intermediate racks.

Pivot and intermediate struts of a closed Ω -shaped profile. Corner struts (closed transverse profile) are welded from two Z-shaped elements, fixed to the upper strapping with overlays. The upper binding between the racks is reinforced with overlays. The cladding is attached to the frame by spot welding.

The doors are hingedly connected to the corner pillars of the body with the help of hinges. Each leaf of the door consists of a metal corrugated sheathing, reinforced with a frame consisting of upper and lower straps, as well as vertical elements of a closed cross-section, welded from Ω - and Z-like profiles. In the closed position, the door is held by locks - lower and upper, consisting of a wedge and a guide with stops for the wedge. In the open position, the doors are located along the side walls and are held by special rotating brackets that are installed in the holes on the upper body straps. At the ends, the body is equipped with external and internal splints, footboards and handrails.

The bodies of universal four-axle semi-wagons have a similar design of individual elements and are built in different versions.

The bodies of universal four-axle semi-wagons of models 12-119 and 12-753 are all-metal, made of typical profiles and differ in some structural properties. So, the semi-wagon model 12-753 is equipped with end doors, and model 12-119 has blind end walls.

The body of the universal four-axle semi-wagon model 12-119 is made with hollow end walls, has great strength, as the side walls are firmly connected to each other. In addition, it made it possible to increase the internal useful length without changing the longitudinal dimensions of the frame and increase the volume of the body by 2 m³.

The end beams of the box section, the corner posts are made in the form of plates made of rolled sheet thickness 8 mm. The nodes of the ends of the racks in the frame are reinforced with slats 160×100×12 mm.

The body of the semi-wagon model 12-757 with a carrying capacity of 75 tons has a reinforced structure. The backbone beam of the body frame is made of two reinforced zetas No. 31(U) and a height I-beam 190 mm, welded together. An increase in the technical level of the wagon fleet of the CIS railways is achieved by increasing the share of specialized semi-wagons, as well as those with hopper-type bodies.

The specialized four-axle semi-wagon with a hollow body of the 12-1505 model is developed on the basis of a universal semi-wagon, in which the unloading hatches are replaced by a solid floor, the end doors are tightly welded. There are two hatches in the floor for draining water and cleaning the body when preparing the wagon for loading. The frame of the body differs from the frame of the universal semi-wagon by the fact that an additional longitudinal I-beam No. 19 is installed in it to support the floor covering between the backbone beam and the lower ties of the side walls. The difference of the semi-wagon

model 12-1580 is that the frame does not have a I-beam spinal beam This made it possible to increase the internal height and volume of the body to 83 m³, and the carrying capacity is up to 71 tons.

The body of a specialized four-axle half-wagon with a hollow body with a carrying capacity of 71 tons, model 12-1592, is an all-metal welded structure. Its frame includes a backbone beam of two typical No. 31 zetas, two pivot beams of box section, two end, four transverse intermediate beams of the I-beam type, and two intermediate support beams.

The body of the specialized four-axle semi-wagon model 12-4004 is designed for the transportation of technological chips and short-sized wood (up to 2 m long) from production sites to pulp and paper industry enterprises. The frame of the body includes a backbone beam welded from two typical zetas No. 31, a I-beam No. 19 and a hump, pivot beams of a box section made of sheets of thickness 10 mm and 12 mm (lower), middle intermediate transverse beams, composed of vertical (7 mm), upper (8 mm) and lower (10 mm) letters. The end beams are of a box section, made of two channels No. 27. Currently, the leading wagon-building plants of Ukraine are producing semi-wagons of a new generation with increased technical and economic indicators. Let's consider the design features of the latest models of semi-wagons developed by the plant.

The universal semi-wagon model 12-7039 (Figure 1.1) is made of high-strength steel and has an axial load of 25 t/axle. It is intended for the transportation of artificial, loose, including small and packaged cargoes that do not require protection from atmospheric precipitation on the railways of Ukraine, the CIS countries and the Baltic States with a track width of 1520 mm with the possibility of unloading through the unloading hatches located in the floor of the wagon, as well as on wagon tippers The main technical characteristics of the wagon are given in table 1.1.



Figure 1.1 - Universal semi-wagon model 12-7039

The semi-wagon model 12-7023 (Figure 1.2) and its modifications is a universal four-axle with a welded body, increased volume and made of low-alloy steel 09G2S. It is intended for the transportation of loose, artificial, packaged goods. The open-top body has fourteen unloading hatches, the covers of which form the floor. The wagon is unloaded through the unloading hatches or on the wagon tipper. The main technical characteristics of the wagon are given in table 1.2.

Table 1.1 - Main technical characteristics of the semi-wagon model 12-7039

Parameter name	Value
Carrying capacity, i.e	75.5
Mass of the wagon, i.e	24.5
Calculated wheel load. pairs on the rail, kN	245.25
The length of the wagon along the coupling axes of auto couplings, mm	13920
Base, mm	8650
Internal dimensions of the body	
- length, mm	12790
- width, mm	2990
- height, mm	2362
Dimensions	1-VM
Height to the clutch axis from the level of the rail heads, mm	1060±20
Track width, mm	1520
Design speed, km/h.	120
Service life, years	32



Figure 1.2 – Universal semi-wagon model 12-7023

Universal four-axle semi-wagon model 12-783 (Figure 1.3) all-metal, with a welded body, intended for transportation of bulk, packaged, artificial cargo.

The floor of the wagon is formed by fourteen hatch covers. The wagon is equipped with automatic pneumatic, manual and parking brakes, and a T1 class absorption device.

The main technical characteristics of the wagon are given in table 1.3.

Table 1.2 – Main technical characteristics of the semi-wagon model 12-7023

Parameter name	Value
Carrying capacity, i.e	70.3
Mass of the wagon, i.e	23.7
Calculated wheel load. steam on the rail, kN(ts)	230.5
The length of the wagon along the coupling axes of auto couplings, mm	13920
Base, mm	8650
Internal dimensions of the body	
- length, mm	12790
- width, mm	2990
- height, mm	2362
Dimensions	1-VM
Height to the clutch axis from the level of the rail heads, mm	1060±20
Track width, mm	1520
Design speed, km/h.	120
Service life, years	22



Figure 1.3 – Universal semi-wagon model 12-783

Table 1.3 – Main technical characteristics of the semi-wagon model 12-783

Parameter name	Value
Carrying capacity, i.e	70.0
Mass of the wagon, i.e	24.0
Calculated wheel load. steam on the rail, kN(ts)	230.5
The length of the wagon along the coupling axes of auto couplings, mm	13920
Base, mm	8650
Internal dimensions of the body	
- length, mm	12790
- width, mm	2990
- height, mm	2045
Dimensions	1-VM
Height to the clutch axis from the level of the rail heads, mm	1060±20
Track width, mm	1520
Design speed, km/h.	120
Service life, years	22

A four-axle, all-metal half-wagon of the EAOS model with a welded body and a "deaf" floor (Figure 1.4).



Figure 1.4 – Universal semi-wagon of the EAOS model

The semi-wagon is intended for the transportation of bulk, packaged and artificial cargo. The undercarriage of the wagon is represented by trolleys of the Y25 type. The main technical characteristics of the wagon are given in table 1.4.

A specialized semi-wagon with a removable roof and unloading hoppers (Figure 1.5) is intended for transportation on the railways of Ukraine, the CIS countries, and the Baltic States with 1,520 mm tracks in one direction of alumina in bulk, with loading through the upper hatches and unloading into the Interrail space through the lower hatches on special unloading devices , and in the other direction – aluminum blanks and other artificially packaged goods that require protection from atmospheric precipitation. The main technical characteristics of the wagon are given in table 1.5.

Table 1.4 – Main technical characteristics of EAOS model semi-trailer

Parameter name	Value
Carrying capacity, i.e	58.0
Mass of the wagon, i.e	20.8
Calculated wheel load. pairs on the rail, kN	200.5
The length of the wagon along the coupling axes of auto couplings, mm	14400
Base, mm	9000
Internal dimensions of the body	
- length, mm	12792
- width, mm	2792
- height, mm	1999
Dimensions	UIC 505
Height to the clutch axis from the level of the rail heads, mm	1060±20
Design speed, km/h.	120
Service life, years	22



Figure 1.5 – Semi-wagon model 12-9765

Universal four-axle, all-metal wagon model 12-757 EI-2 with a welded body of increased volume, made of low-alloy steel 09G2S or 09G2D. It is intended for the transportation of bulk, artificial, packaged cargoes that do not require protection from atmospheric precipitation (Figure 1.6).

Table 1.5 - Main technical characteristics of the semi-wagon model 12-9765

Parameter name	Value
Carrying capacity, i.e	65.0
Mass of the wagon, i.e	29.0
Calculated wheel load. pairs on the rail, kN	230.5
The length of the wagon along the coupling axes of auto couplings, mm	17040
Base, mm	12800
Internal dimensions of the body	
- length, mm	12400
- width, mm	2872
- height, mm	1965
Dimensions	1-T
Height to the clutch axis from the level of the rail heads, mm	1060±20
Track width, mm	1520
Design speed, km/h.	120
Service life, years	22



Figure 1.6 – Semi-wagon model 12-757 EI-2

The main technical characteristics of the wagon are given in table 1.6.

Table 1.6 – Main technical characteristics of the semi-wagon model 12-757 EI-2

Parameter name	Value
Carrying capacity, i.e	67.5
Mass of the wagon, i.e	22.5
Calculated wheel load. pairs on the rail, kN	220.5
The length of the wagon along the coupling axes of auto couplings, mm	13720
Base, mm	8700
Internal dimensions of the body	
- length, mm	12490
- width, mm	2660
- height, mm	2050
Dimensions	
-body	IIRR (RAI)
-cart	02-VM
Height to the clutch axis from the level of the rail heads, mm	1060±20
Design speed, km/h.	120
Service life, years	22

Four-axle, all-metal wagon with a welded body and a semi-cylindrical model bottom 12-791 (Figure 1.7) intended for the transportation of loose and small cargoes that do not require protection from atmospheric precipitation. The body of the wagon without unloading hatches with rounded surfaces at the junctions of the frame with the side and end walls ensures the unloading of the wagon with the minimum possible residual cargo using the wagon tipper. The main technical characteristics of the wagon are given in table 1.7.



Figure 1.7 – Semi-wagon model 12-791

Table 1.7 – Main technical characteristics of the semi-wagon model12-791

Parameter name	Value
Carrying capacity, i.e	71.0
Mass of the wagon, i.e	22.9
Calculated wheel load. pairs on the rail, kN	231.5
The length of the wagon along the coupling axes of auto couplings, mm	13920
Base, mm	8650
Internal dimensions of the body	
- length, mm	12460
- width, mm	3070
- height, mm	2235
Dimensions	1-VM
Height to the clutch axis from the level of the rail heads, mm	1060±20
Design speed, km/h.	120
Service life, years	22

Universal four-axle, all-metal wagon with a welded body of increased volume, model 12-7019, made of low-alloy steel 09G2S or 09G2D. The wagon is intended for transportation of bulk, packaged and artificial cargoes that do not require protection from atmospheric precipitation (Figure 1.8). The main technical characteristics of the wagon are given in table 1.8.



Figure 1.8 – Semi-wagon model 12-7019

Table 1.8 – Main technical characteristics of the semi-wagon model 12-7019

Parameter name	Value
Carrying capacity, i.e	72.0
Mass of the wagon, i.e	22.0
Calculated wheel load. pairs on the rail, kN	230.5
The length of the wagon along the coupling axes of auto couplings, mm	13920
Base, mm	8650
Internal dimensions of the body	
- length, mm	12690
- width, mm	2950
- height, mm	2050
Dimensions	1-VM
Height to the clutch axis from the level of the rail heads, mm	1060±20
Design speed, km/h.	120
Service life, years	22

The four-axle, all-metal wagon with a welded body, a hollow floor and two hatches in the side walls of the 12-764 model is designed for the transportation of bulk, packaged and artificial cargoes that do not require protection from atmospheric precipitation (Figure 1.9).



Figure 1.9 – Semi-wagon model 12-764

The main technical characteristics of the wagon are given in table 1.9.

The four-axle, all-metal wagon model 12-1704-03 is intended for the transportation of bulk, packaged and artificial cargoes that do not require protection from atmospheric precipitation (Figure 1.10). The wagon has a welded body, the floor of which is formed by hatch covers. The main technical characteristics of the wagon are given in table 1.10.

Table 1.9 – Main technical characteristics of the semi-wagon model 12-764

Parameter name	Value
Carrying capacity, i.e	70.0
Mass of the wagon, i.e	23.5
Calculated wheel load. pairs on the rail, kN	229.3
The length of the wagon along the coupling axes of auto couplings, mm	13720
Base, mm	8700
Internal dimensions of the body	
- length, mm	12490
- width, mm	2660
- height, mm	2050
Dimensions	1-VM
Height to the clutch axis from the level of the rail heads, mm	1060±20
Design speed, km/h.	120
Service life, years	22



Figure 1.10 – Semi-wagon model 12-1704-03

Table 1.10 – Main technical characteristics of the semi-wagon model 12-1704-03

Parameter name	Value
Carrying capacity, i.e	70.5
Mass of the wagon, i.e	23.0±0.5
Calculated wheel load. steam on the rail, kN(ts)	229.3
The length of the wagon along the coupling axes of auto couplings, mm	13720
Base, mm	8650
Internal dimensions of the body	
- length, mm	12490
- width, mm	2660
- height, mm	2050
Dimensions	0-VM
Height to the clutch axis from the level of the rail heads, mm	1060±20
Design speed, km/h.	120
Service life, years	22

1.2 Design features of covered wagons

Covered wagons were used to ensure the transportation of goods by rail that needed protection from atmospheric precipitation. At the moment, there is a great variety in the design features of covered wagons. Let's consider the main models of covered wagons, which are produced by the leading wagon-building enterprises of Ukraine.

The covered wagon of model 11-7094 is intended for transportation along the entire network of railways with a gauge of 1520 mm of artificial, tar-no-artificial and packaged goods of a wide range that require protection from atmospheric precipitation (Figure 1.11). It is possible to equip the wagon with upper loading hatches and ventilation hatches in the side walls. Brake - automatic pneumatic, manual and parking. The chassis is two two-axle carts of mods. 18-7055 type 2 GOST 9246 or other interchangeable carts type 2 GOST 9246. SA-3 auto clutch. Absorbent apparatus of class T1. The main technical characteristics of the wagon are given in table 1.1.



Figure 1.11 – Covered wagon model 11-7094

Covered wagon model 11-7045 developed by PJSC "KBBZ" is shown in Figure 1.12.

Table 1.11 – Main technical characteristics of the covered wagon model 11-7094

Parameter name	Value
Carrying capacity, i.e	68.0
Mass of the wagon, i.e	26.0
Calculated wheel load. steam on the rail, kN(ts)	230.3 (23.5)
The length of the wagon along the coupling axes of auto couplings, mm	18720
Base, mm	13500
Internal dimensions of the body	
- length, mm	17492
- width, mm	2794
- height, mm	3106
Dimensions	1-VM
Height to the clutch axis from the level of the rail heads, mm	1040 - 1080
Track width, mm	1520
Design speed, km/h.	120
Service life, years	32



Figure 1.12 - Covered wagon model 11-7045

The main technical characteristics of the wagon are given in table 1.12.

In 2014, PJSC "KBBZ" began serial production of model 11-7038 covered wagons (Figure 1.13). The supporting structure of the wagon provides for the possibility of equipping it with upper loading hatches.

The main technical characteristics of the wagon are given in table 1.13.

Table 1.12 – Main technical characteristics of the covered wagon model 11-7045

Parameter name	Value
Carrying capacity, i.e	67.5
Mass of the wagon, i.e	26.5
Calculated wheel load. steam on the rail, kN(ts)	230.3 (23.5)
The length of the wagon along the coupling axes of auto couplings, mm	18720
Base, mm	13500
Internal dimensions of the body	
- length, mm	17492
- width, mm	2794
- height, mm	3106
Dimensions	1-VM
Height to the clutch axis from the level of the rail heads, mm	1060±20
Track width, mm	1520
Design speed, km/h.	120
Service life, years	32



Figure 1.13 – Covered wagon model 11-7038

The load-bearing structure of the covered wagon model 11-7139 (Figure 1.14) is of interest. The wagon has

- six unloading hatches in the floor with opening and closing devices, intended for partial unloading and cleaning of the wagon body from the remains of transported goods;
- doors inside the body to prevent cargo from piling up on the side sliding doors of the wagon;
- upper loading hatches, stairs and ladders on the roof;
- ventilation hatches in the side walls of the wagon body upon agreement with the customer.

Table 1.13 – Main technical characteristics of the covered wagon model 11-7038

Parameter name	Value
Carrying capacity, i.e	68.0
Mass of the wagon, i.e	26.0
Calculated wheel load. pairs on the rail, kN	230.5
The length of the wagon along the coupling axes of auto couplings, mm	18720
Base, mm	13500
Internal dimensions of the body	
- length, mm	17492
- width, mm	2790
- height, mm	3106
Dimensions	1-VM
Height to the clutch axis from the level of the rail heads, mm	1060±20
Track width, mm	1520
Design speed, km/h.	120
Service life, years	32



Figure 1.14 – Covered wagon model 11-7139

The main technical characteristics of the wagon are given in table 1.14.

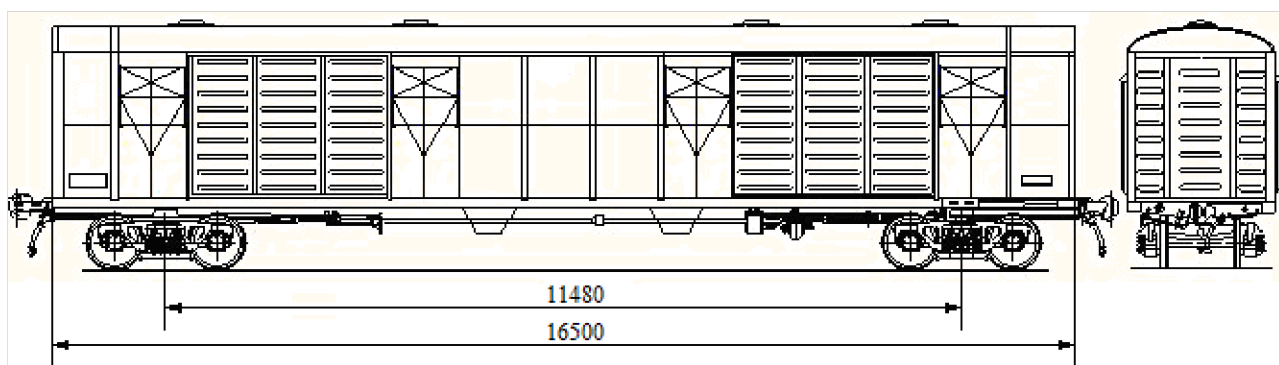


Figure 1.15 - Covered wagon model 11-950

Table 1.14 - Main technical characteristics of the covered wagon model 11-7139

Parameter name	Value
Carrying capacity, i.e	65.7
Mass of the wagon, i.e	28.3
Calculated wheel load. steam on the rail, kN(ts)	230.5 (23.5)
The length of the wagon along the coupling axes of auto couplings, mm	18720
Base, mm	13500
Internal dimensions of the body	
- length, mm	17492
- width, mm	2794
- height, mm	3106
Dimensions	1-VM
Height to the clutch axis from the level of the rail heads, mm	1040 - 1080
Track width, mm	1520
Design speed, km/h.	120
Service life, years	32

PJSC "Stakhaniv Carriage Construction Plant" created the first universal covered four-axle wagon (model 11-950) in size 03-VM of the "east-west" type in Ukraine (Figure 1.15).

The design of the wagon allows the transportation of goods in international traffic from Ukraine to the countries of Western Europe and back, or by transit through the territory of Ukraine as part of trains traveling along the railway network with a track width of 1520 mm and 1435 mm with a change from one track to another.

At the beginning of 2000, PJSC "Kryukiv Carriage Works" also developed a structure of a covered wagon for operation in the "east-west" direction (Figure 1.16), the feature of which is the presence of unloading bunkers in the middle part of the body, which allows for the transportation of bulk cargo in it. and the body space between the corner posts and the vertical walls of the central section has a movable door for loading taro-artificial loads.



Figure 1.16 - Sectional-type covered wagon

A feature of the developed structures is the use of modern methods of optimization theory at the stage of their design, which made it possible to significantly reduce the material volume of the body, as well as the use of new materials in the load-bearing structures.

One of the most common models of covered wagons, which found use on the railways of the CIS, is the 11-217 model (Figure 1.17).



Figure 1.17 – Covered wagon model 11-217

The universal covered wagon model 11-217 (Figure 1.8) built by the Altai Wagon-Building Plant is designed according to the dimensions of 1-VM (0-T) GOST 9238-83 and is intended for operation on the railways of the CIS and Baltic countries with a gauge of 1520 mm [35]. It can also be operated on reconstructed railway lines of REV member countries with a gauge of 1435 mm after appropriate replacement of running parts. The body of such wagons has a metal outer skin and wooden inner lining, and is also equipped with double-leaf doors that have an increased width of the door opening (3825 instead of 2000 mm of wagons model 11-066). The use of metal body cladding increases its reliability in operation. An increase in the width of the door opening ensures a faster loading and unloading process, and therefore, a reduction in downtime during cargo operations and an acceleration of the wagon circulation.

The wagon is loaded through doors 3 and hatches in the roof 2 and side walls. The widened doorway is reinforced, the strength of the body floor is increased, based on the calculation of the work of forklift trucks with an axial load of up to 43 kN. The model 11-217 wagon has the characteristics given in table 1.15.

Table 1.15 - Technical characteristics of the covered wagon model 11-217

Indicator	Value
Carrying capacity, i.e	68
Tara, t	24
Body volume, m ³	120
Length, m	
Behind the axles of autocouplings	14.73
Behind the end beams of the frame	13.87
Height to floor level, m	1,286
The maximum height of the wagon, m	4,692
Width, m	3,249
Internal dimensions, m	
Width	2.77
Length	2,737
Baza, m	10
Width of the doorway, m	3,825
Tare factor	0.35
Axial load, kN/axle	228
Running load, t/m	6.2
Design speed, km/h.	120
Dimensions	1-VM

All load-bearing elements of the frame, walls 1 and 4, and roof 2 are made of low-alloy steel 09G2D, and the cladding of the end 4 walls and the roof is made of low-alloy steel 10HNDP.

The frame (Figure 1.19) consists of a spinal beam 2, two side 3, two end 1, two pivot 4, two main 7 and seven intermediate 5 transverse beams, four braces 10, six longitudinal beams 6 to support the floor, one beam for fastening the brake cylinder and two legs. Spinal beam 2 is welded from two Z-shaped profiles No. 31. In its final parts, the rear stops of auto couplings, combined with the supra-heel box of the pivot unit, as well as sockets, cast together with the front stops of auto couplings, are installed. Side beams 3 are made of channels No. 20. In the area of the door opening, thresholds from special Z-shaped profiles are welded to the beams. End beams 1 are welded with a U-shaped cross-section and are made of 6 mm thick sheets. In the place where the outlet is installed, the beam has a niche with a depth of 180 mm, which made it possible to deepen the socket and reduce the overhang of the auto coupling from 610 to 430 mm. Such a solution made it possible to increase the internal length and increase the volume of the body without changing the dimensions of the wagon along the coupling axes of the couplings.

Handrails are installed on the end beam for the safe operation of train assemblers. Pivot beams 4 welded box section. Each of them consists of two vertical 6 mm thick, upper (8 mm) and lower (10 mm) horizontal sheets. At the points of intersection of the pivot beams with the backbone, steel pedicle boxes are installed, which connect the vertical walls of the backbone beam, and also strengthen the pedicle node of the frame. The hinges 12 and sliders 13 are riveted to the lower sheets of the pivot beams. The main transverse beams 7 are welded I-beam cross-section, made of sheets 6 mm thick. To ensure equal strength of the frame structure, the end, pivot and main transverse beams have a

variable height along their length. Braces 10 of the frame are made of channel No. 14, and transverse 5 and longitudinal 6 auxiliary beams for supporting the floor are made of bent channels 100x80x5 mm. Special clamps are welded to each end of the side beams of the frame for moving wagons with a winch.

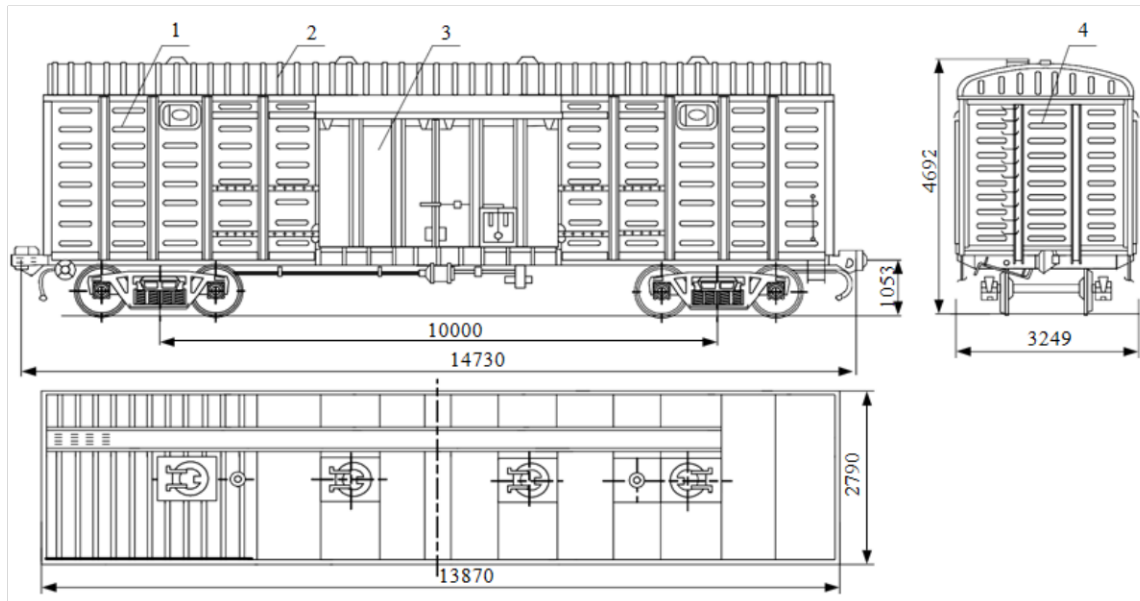


Figure 1.18 – Covered wagon model 11-217

A floor 9 of 55 mm thick boards joined in a quarter is laid on the frame. The perimeter of the floor is reinforced with angle 8. In the area of the door opening, where autoloaders work intensively, the wooden flooring is covered with metal sheets 4 mm thick.

The side wall (Figure 1.20) is of non-scraping design. The wall has a frame and cladding: metal 11 external and wooden 10 internal. For loading and unloading the wagon, self-sealing doors 6 and 7 and two hatches 4 equipped with ventilation grills are located in the middle part of the wall. The wall frame includes binding 1, two hinged 3, six intermediate 2 and two door 5 racks. Upper binding 1 (section A-A) is made of a corner 90x56x8 mm, pivot and intermediate posts – from a bent Ω -shaped profile 6 mm thick, and door posts 13

(section D-D) – from a Z-shaped profile measuring 100x75x6, 5 mm and a guide angle 15 with a size of 75x50x6 mm. The wall is welded to the longitudinal side beam of the frame 19 and to the end walls - to the corner posts 12 (section B-B). The outer cladding of 11 walls is made of corrugated sheets with a thickness of 3 mm from the bottom and 2.5 mm from the top, and the inner 10 is made of moisture-resistant plywood of the FSF brand with a thickness of 10 mm. The inner lining is attached to the frame with bolts and is framed at the joints with a corner 9. In each door opening with a width of 3825 mm, two door leaves 6 and 7 are installed, one of which has an unloading hatch in the lower part, 8. The opening mechanism of this hatch is locked with the opening mechanism and closing the door leaves and excludes its accidental opening. Sealing and self-sealing of the door leaves on the racks is ensured by the pressure of the bulk cargo and rubber elements 14, and between them in the beam - by binding 16 of the left doors of a special configuration, into the groove of which the binding of the 17 right doors enters. Sealing of the door from below is ensured by the pressure of the load and the pressing of the lower binding 21 to the threshold 20 of the door opening. Each of the door leaves 6 and 7 consists of a frame, sheathed on the outside with metal sheets 23 with a thickness of 1.4 mm, and on the inside with plywood 22 with a thickness of 8 mm. The door leaves move along a rail 26 attached above the doorway on rollers 25 with ball bearings.

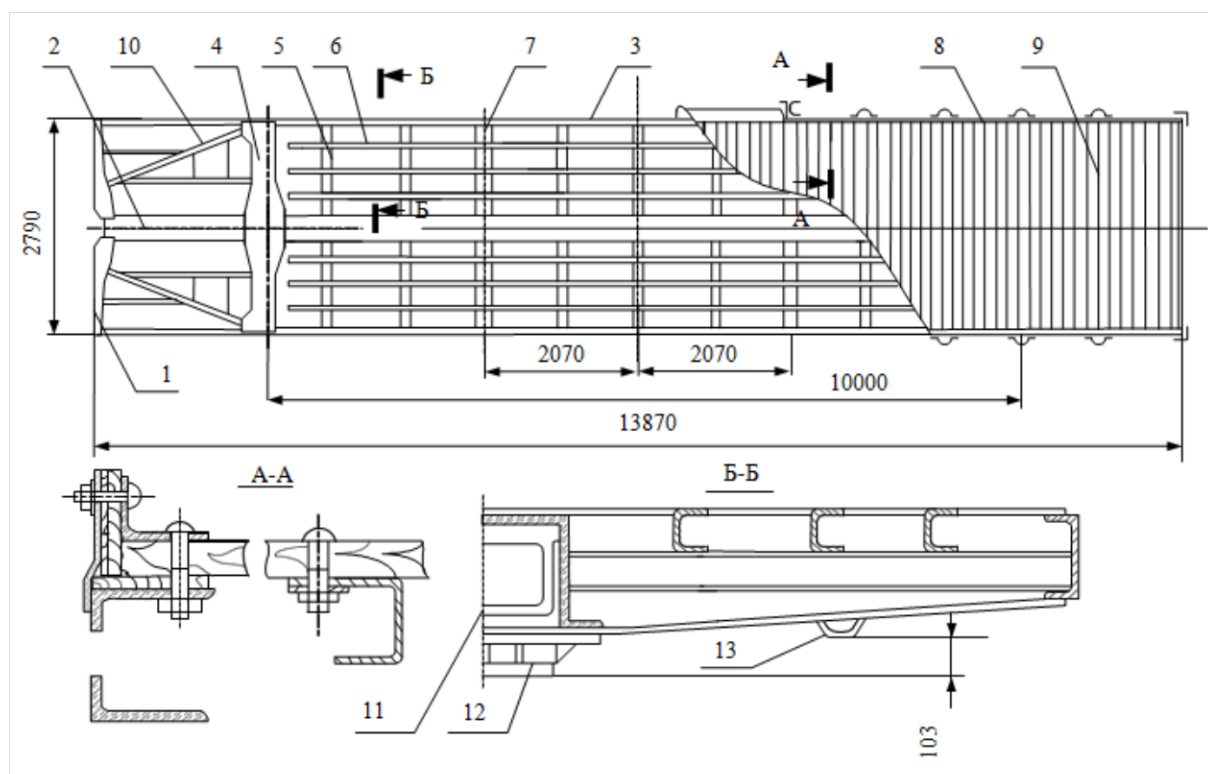


Figure 1.19 – Frame of the covered wagon model 11-217

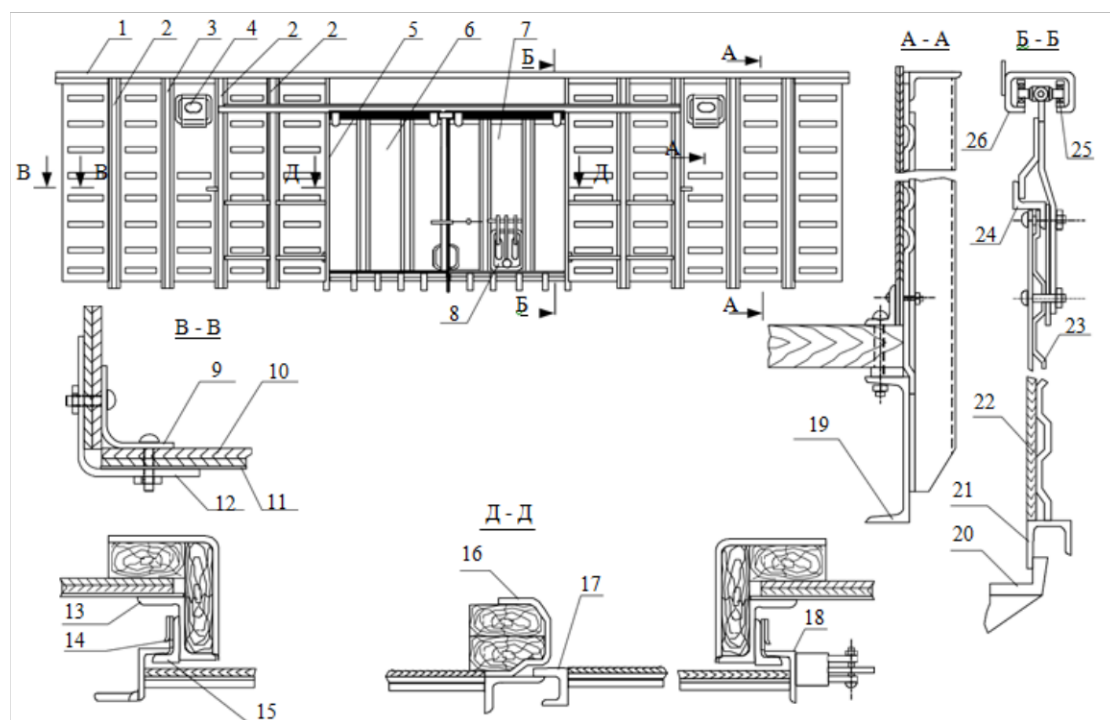


Figure 1.20 – Side wall of a covered wagon

Door leaf frames consist of upper, lower and side binding. The upper binding 24 has a Z-shaped profile, the lower 21 is U-shaped, and the side edge 18 has angles.

The middle binding, respectively, on the left door leaf has a special profile, welded from a corner and a bent element 16, inside which beams are inserted for rigidity, and on the right - a U-shaped profile. To protect the right door leaf from damage in the event of a sharp opening, a shock absorber is installed on the body strut second from the door opening, consisting (Figure 1.21) of body 1, spring 3, washer 4, and rod 2. Side hatch covers with a ventilation mesh are made of stamped steel sheets 2 mm thick and locks that keep the lids in the closed position. The locks can only be opened from inside the wagon.

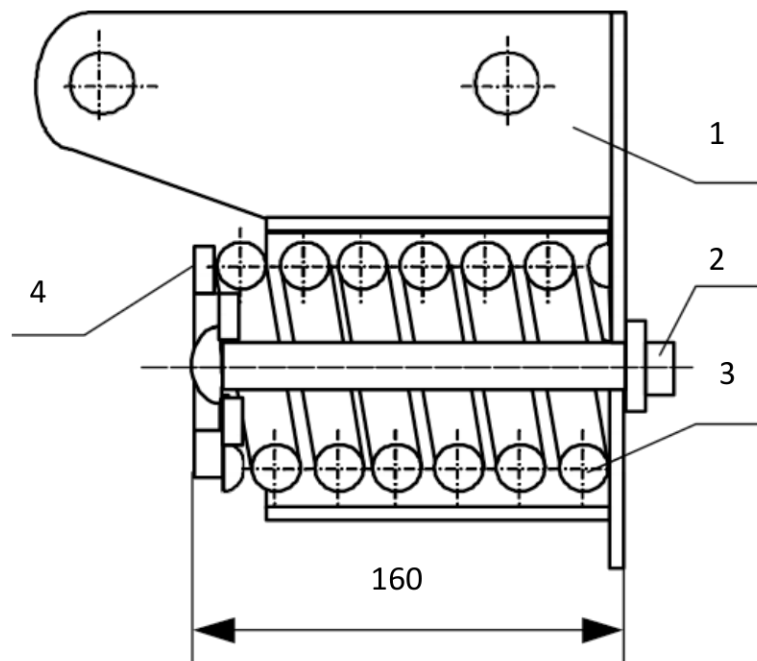


Figure 1.21 - Door shock absorber

The end wall (Figure 1.22) is made of a frame, outer metal 4 and inner wooden 5 skins, framed on the floor by a corner 6, and at the corners by a corner

8. The frame consists of two corner 2 and two intermediate racks 3, connected by the upper binding 1. The outer metal sheathing 4 is made of corrugated sheets 3 mm thick on the bottom and 2.5 mm on top, and the inner 5 is made of moisture-resistant plywood 10 mm thick. Corner posts 2 are made of a bent corner 80x80x6 mm, intermediate posts 3 are made of an Ω -shaped element 230x135x6 mm, and upper binding 7 is made of a special profile with a thickness of 6 mm. The end beam 7 of the frame serves as the lower binding of the wall.

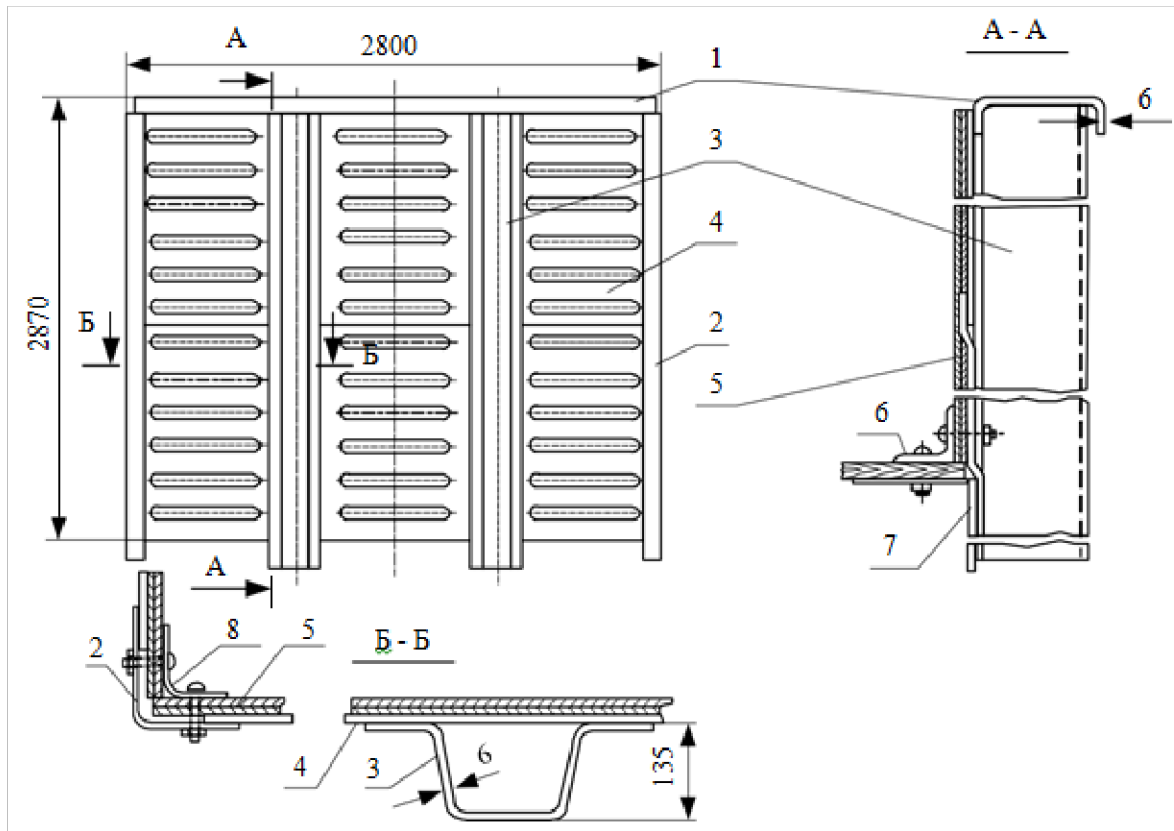


Figure 1.22 – End wall of a covered wagon

The roof of the body (Figure 1.23) is fully welded with four loading hatches 6 with a diameter of 400 mm and two typical pipe dividers 4. The roof is attached to the side and end walls of the body with rivets with a diameter of 10

mm and during repair can be dismantled from the body with less effort compared to the model wagon 11-066, in which it is attached to the walls by welding. Furnace treatments are provided for the installation of pipes of heating furnaces in case of human transportation. The roof to the loading hatches 6 and furnace treatment 4 can be climbed on the end chip and platforms 5. The roof has a metal frame, sheathed on the outside with corrugated sheets 3 1.5 mm thick, and two transoms 11, with the help of which the roof is attached to the end walls. Transoms are made of metal sheets 2 mm thick with stampings for rigidity and binding. The roof frame is formed by a set of arcs 1,

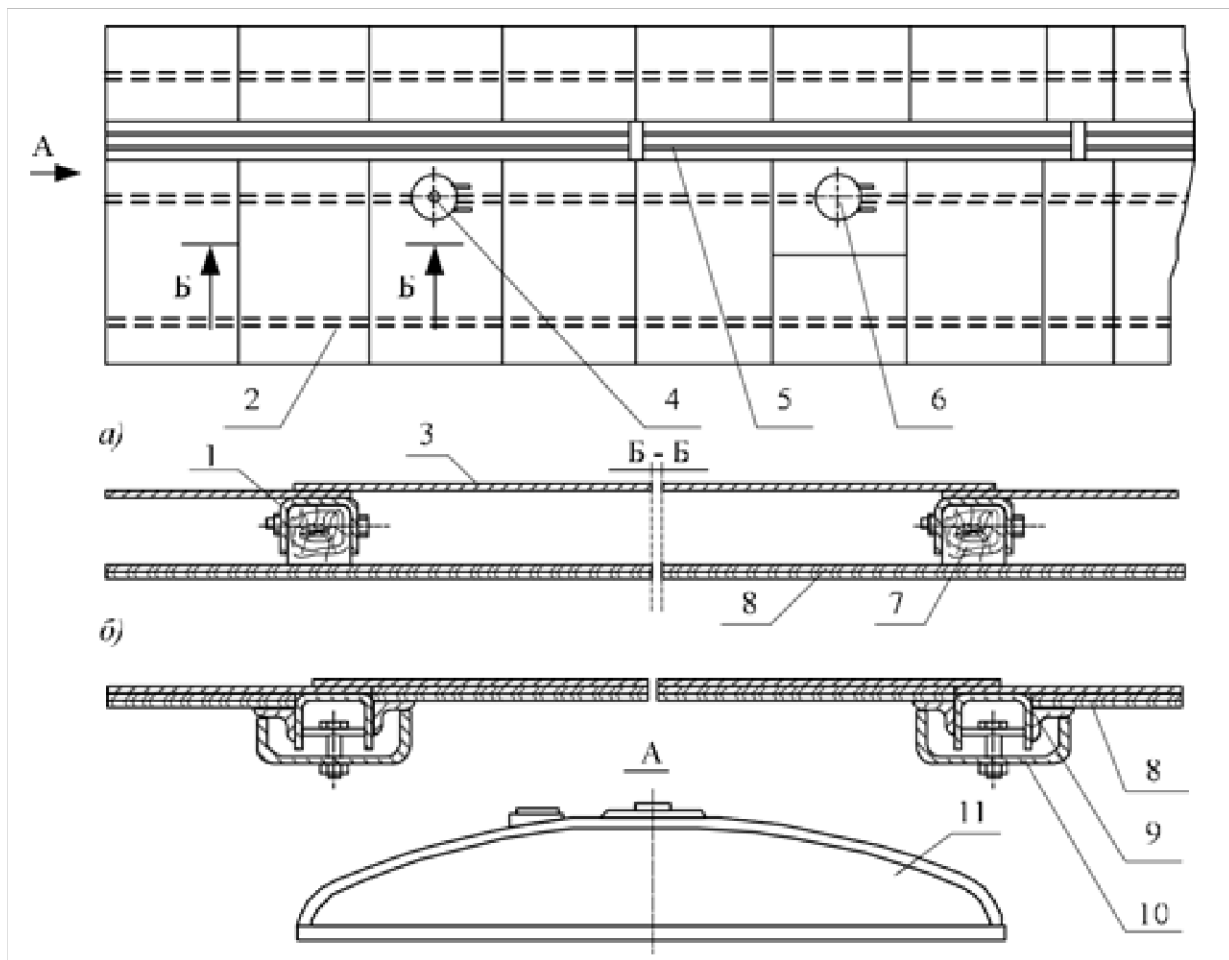


Figure 1.23 – Roof of a covered wagon

Arcs 1 are made of bent channels 60x50x3 mm, middle longitudinal elements 2 are made of bent angle 32x32xZ mm, and side bindings are made of two angles 56x56x5 mm. Sheets of the outer cladding are welded to the arcs of the longitudinal elements and the upper binding of the side walls. Between themselves, the sheets of the roof are welded in an overlap and, for greater rigidity, are made with transversely located corrugations with a height of 22 mm. From the inside (Figure 1.23, a) the roof is lined with moisture-resistant plywood 4 mm thick in two layers, which tightly adheres to the roof sheets from below, forming a ceiling. Plywood is attached to the sheathing with angles 9 and staples 10. This fastening of the lining practically excludes its damage during loading and unloading of the wagon. In the previous versions (Figure 1.23, b), the binding 8 was attached to wooden bars 7 with an air layer, which led to frequent damage to the binding.

Covers of the hatches 4 of the roof (Figure 1.24) are attached to the sheet 6 with two loops 5 and in the closed position are fixed with special locks 1 that open from the inside of the wagon.

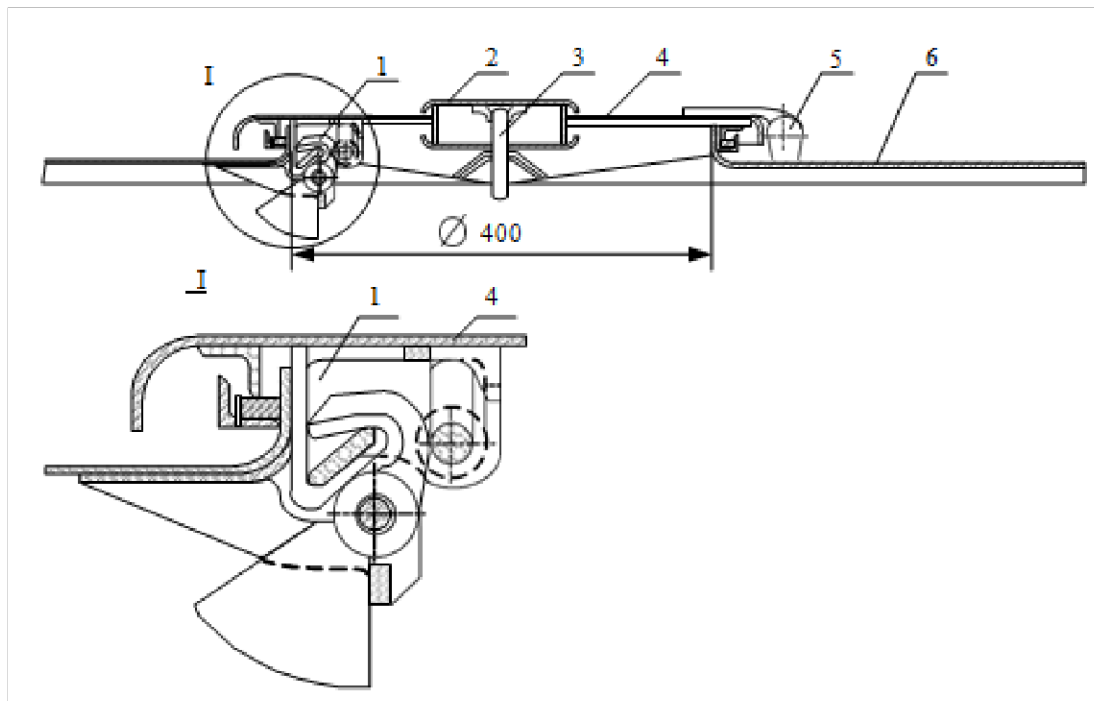


Figure 1.24 – The hatch cover of a covered wagon

Covers of 2 furnace divisions, which are installed on covers of hatches 4, are held in the closed position by screws 3.

The specialized covered hopper wagon for grain model 19-752 is produced by Kryukiv Wagon Building Plant. The wagon is designed according to the dimensions of 1-VM. Its characteristics are shown in table 1.2. The wagon has a metal frame (Figure 1.25), self-unloading, bunker type.

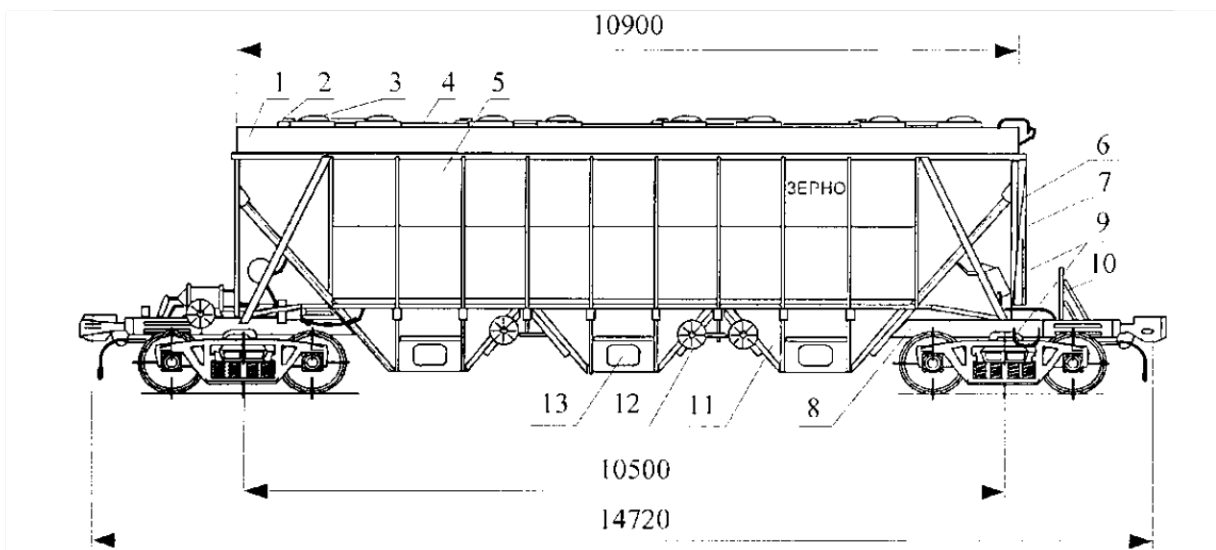


Figure 1.25 - Hopper wagon for transporting grain

Frame 8, side 5 and end walls 6, as well as roof 1 form the wagon body. The wagon has six bunkers 11, three on each side with mechanisms 12 for opening and closing the unloading hatches. Devices 13 for placing vibrators are provided to facilitate the dumping of cargo on the hoppers.

The wagon is loaded through four slotted loading hatches 2 located in the roof of the body. Hatches are closed with lids (1690x660 mm) with rubber seals.

Each cover is closed with two elastic flaps 3, which in the closed position go behind the gripping brackets welded to the roof and press the cover to the

neck of the hatch. The covers are equipped with a locking mechanism to prevent unintended release of casts from the gripping clamps. It is a shaft 4, placed along the hatch covers along the entire length of the roof, with staples welded to it. The shaft drive 7 is located on the end wall of the wagon. When the shaft is turned clockwise, its sectors close the open space of the gripping brackets and exclude the exit of the casters 3 from under them. When the shaft is turned counterclockwise, the sectors come out from under the gripping brackets, remove the casts from them and allow the covers to be opened. A ladder 9 is installed on the end side of the body and on the frame to climb up to the roof. The transition platform of the wagon is equipped with a fence 10.

The frame (Figure 1.26) consists of a spine 3, two side 2, two end 5, two pivot 1 and two middle 4 beams.

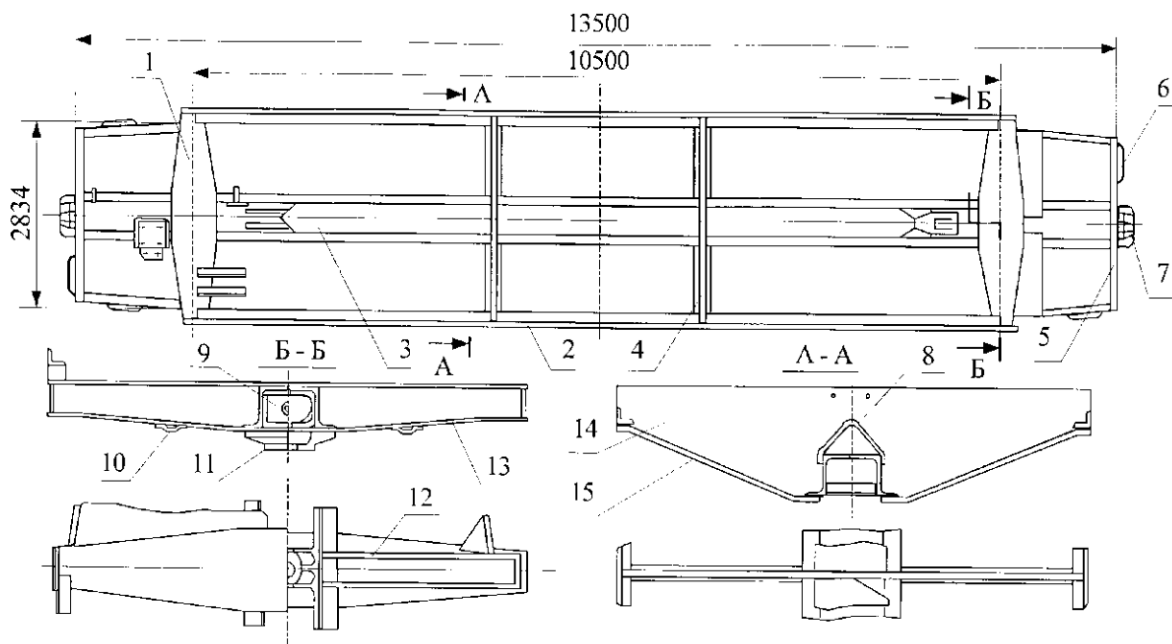


Figure 1.26 – Frame of a hopper wagon for transporting grain

The backbone beam is made of Z-shaped profiles No. 31, covered in the middle part with a ridge 8 (4 mm) for better unloading of the cargo. In the

cantilever part, the spinal beam is reinforced with a socket 7 and stops of autocouplings. The side beams are made of a corner 125x80x10 mm. The end beams of the L-shaped cross-section are welded from sheets 4 mm thick. Handrails 6 are installed on the end beam for the safe operation of assemblers. Pivot beams of box section consist of two vertical 12 (6 mm) and two horizontal 12 (10 mm) sheets. On the lower horizontal sheet of the beam, the sliders 10 and the heel 11 are fixed. To ensure the strength of the support unit and the rigidity of the joint of the pivot and spine beams, an over-heel box 9 is installed between them. The middle transverse beams consist of vertical 14 (6 mm) and lower inclined 15 (8 mm) sheets. The side walls (Figure 1.27) are made of corrugated metal sheets 6 with a thickness of 3 mm, reinforced for rigidity with ten racks 5, upper 4 and lower 7 straps.

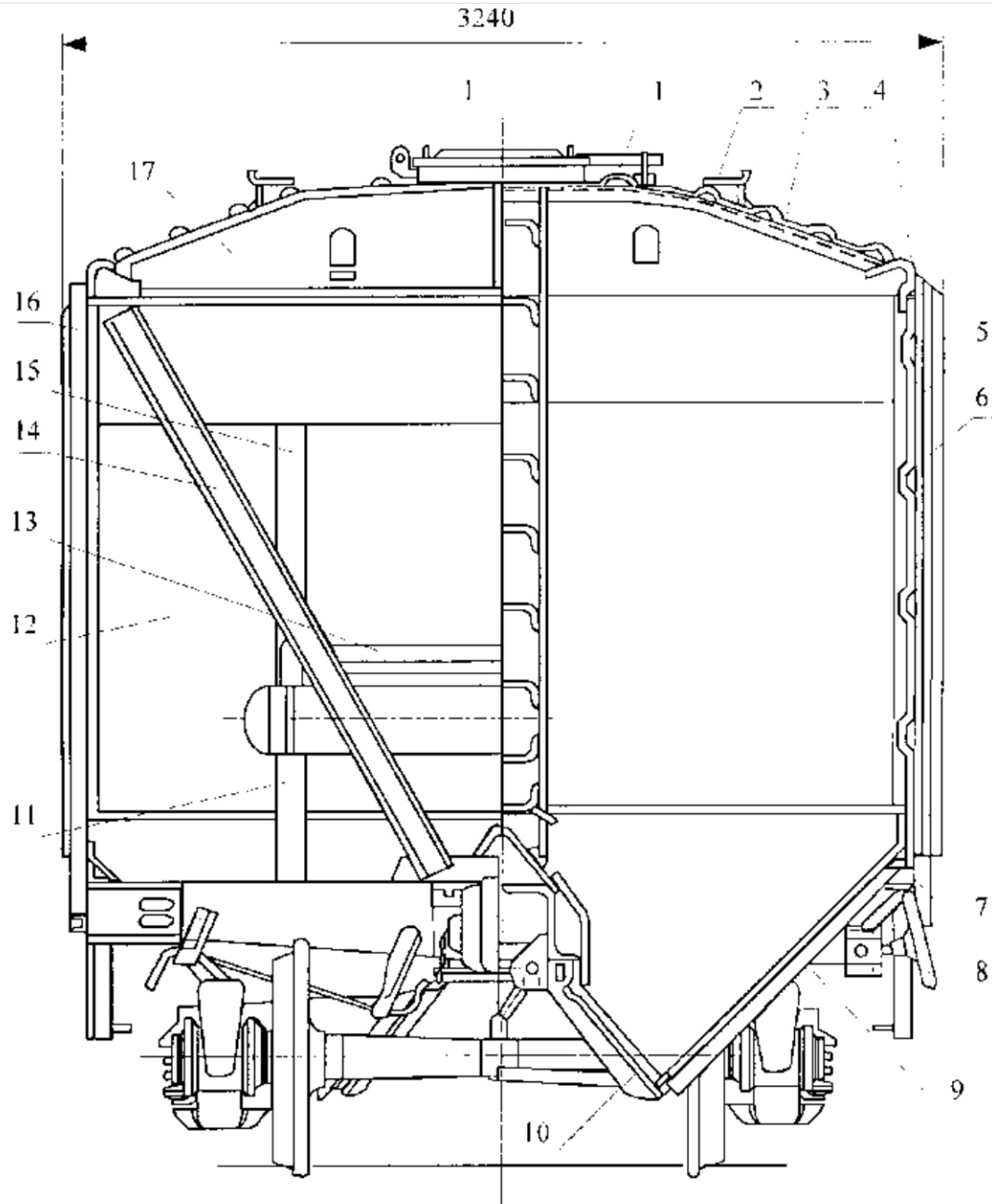


Figure 1.27 – Cross-section of the body of a hopper wagon for transporting grain

The racks are made of I-beam No. 10, the upper strap 4 is made of a bent special profile with a thickness of 6 mm, and the lower one is made of a rolled angle 125x80x10 mm. For greater rigidity, each wall is connected to the frame with two inclined channels No. 14. Bunkers 9 are welded from sheets 5 mm thick in the form of a truncated pyramid and have unloading covers 10 hatches

with rubber seals. Each two opposite hoppers is equipped with one unloading lever mechanism with a drive rudder 8. The unloading mechanism ensures opening and closing of the hatch covers of the hoppers in pairs. It consists of a screw drive with a rudder mounted on a bracket, and a system of hinged levers and rods with spacers connected in pairs to the covers of the unloading hatches. Closing the covers is ensured by the transition of the axes of the spacers past the "dead" point, which protects the lids from involuntary opening. For more complete unloading of the wagon, it is possible to install vibrators on the bunkers. The inclined end walls of the body 12 are located at an angle of 55° to the plane of the frame. They are welded from the upper and lower sheets with a thickness of 4 mm and two side straps of an angular profile with a section of 60x60x6 mm.

The upper sheet has a flanging, which acts as an upper binding. In the lower part, a shaped embossing is made, which, when connected to the inclined sheet of the wall, forms a transverse beam with a box section. The lower sheet of cladding is reinforced with two longitudinal 15 and one transverse 13 belts and braces 11. To give the cantilever body parts sufficient strength and rigidity, each end wall is reinforced with two racks-braces 14 and 16 from channel No. 14. The roof of the body is welded and consists of a corrugated sheet 1 with a thickness of 3 mm in the middle and 1.8 mm on the sides, supported by twelve arches 3, made of a 75x50x5 mm angle. There are four slot-type loading hatches on the roof. The roof is connected to the end walls by transoms 17, and to the side walls - directly by welding to the upper strapping of the wall 4.

The specialized covered hopper wagon for cement model 19-715 has the characteristics indicated. The bunker-type wagon is designed for bulk transportation of cement to places of mass consumption, where there are receiving devices located between the rails.

The body of the cement truck differs from the body of the grain truck only in its dimensions and the number of bunkers, of which there are four instead of six in the wagon. The end walls are inclined at an angle of 50° to the plane of the frame.

The wagon differs from the previously considered bunker types in that the loading hatches (1630x480 mm) in its roof are opened manually, as in all wagons, and the unloading hatches (2382x840 mm) are opened from the pneumatic main from the locomotive or from a stationary air supply source. In addition, the unloading hatches of the bunkers do not have bottom, but side unloading.

A feature of the bodies of universal covered wagons is the presence of sliding doors 1 figure 1.28, a, ventilation hatches 3 figure 1.28, a, in the side walls and loading hatches 2 in figure 1.28, a, in the roof. In such wagons, the presence of a roof prevents top loading with the use of cranes and other similar lifting and transport mechanisms, and the dimensions of the door opening limit the front of work when loading and unloading cargo with an auto or electronic loader.

Covered wagons with a removable roof are being developed to speed up loading and unloading operations and increase labor productivity, as well as for more efficient use of lifting and transport equipment during loading and unloading operations, but in real life such wagons have not been widely used. Some existing models of covered wagons theoretically (as an option ordered by the buyer of the wagon during its construction at the manufacturing plant) can have a removable roof, but in practice, again, this method of loading and such wagons is used extremely rarely, for example, it wagon model 11-280 manufactured by Altayvagon OJSC.

To speed up loading and unloading operations, hatches 4 in Figure 1.28 can be installed in the roof of the covered wagon. 1.28, b along the entire length

of the body, which will allow loading the wagons with bulk cargo during the movement of the wagons under the loading hopper 5 in figure 1.28, b. In this case, special folding aprons must be provided between the bodies to prevent the mass of the cargo from being thrown into the space between the wagons, the cargo hitting the coupling and tracks 6 in figure 1.28, b.

For more efficient use of auto - and electronic forklifts in loading and unloading operations of containers, packaged goods and other similar goods, bodies can be equipped with walls with sliding panels 7 and 8 in figure 1.28, v. By shifting, for example, panels 7 and 8 to the right, with the help of a loader it is possible to carry out (from the side platform) loading and unloading operations on the left side of the wagon body, and then, repeating the operations, on the right side of the body.

To ensure the possibility of using cranes and other lifting and transport mechanisms when loading and unloading oversized and heavy loads, the body can be equipped with a sliding (Figure 1.28, d) or folding (Figure 1.28, e) roof. With such a structural scheme, part of the roof 9 in figure 1.28, r shifts to the right, being located above another part of i 10 in figure 1.28, g. After loading the cargo in the left part of the body, both parts of the roof are shifted to the left and loading or unloading is carried out in the right part of the wagon body. With the variant of the body with an opening roof, the longitudinal parts 11 and 12 refer to 11 and 12 in figure 1.28, d are located along the side walls.

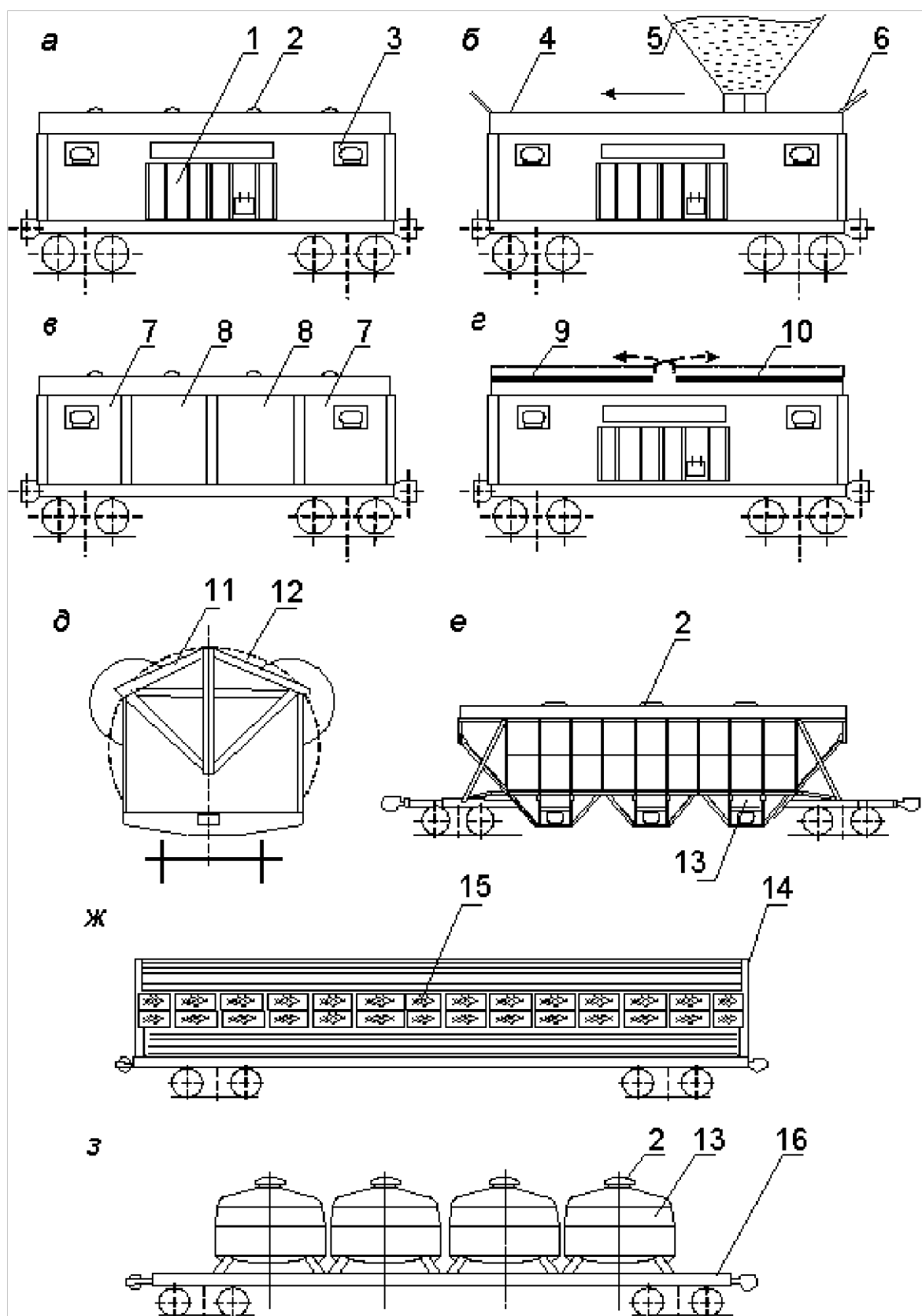


Figure 1.28 – Body of covered wagons

Specialized covered wagons include wagons for the transportation of livestock and poultry, passenger wagons, cold-rolled steel in rolls, granulated polymers, flour, as well as bunker-type structures (hoppers) for the transportation of grain, cement, and mineral fertilizers.

Hopper wagon model 19-7016 for transportation of bulk cargo. Wagon model 19-7016 manufactured by PJSC "KBBZ" (Figure 1.29) is intended for bulk transportation of non-toxic and non-toxic, corrosive-inactive bulk cargoes that do not depend on and require protection from atmospheric precipitation, with gravity loading through the upper hatches and unloading into the interrail space through lower hatches on special loading and unloading devices, on railways with a gauge of 1520 mm.

The wagon (Figure 1.30) includes body 1, frame 2 (with supports for lifting the body), roof 3 with loading hatches, bunkers 4, unloading device 5, automatic brake 6, parking brake 7, auto coupling device 8, two-axle trolleys 9 , as well as equipment for the installation of locking and sealing devices (hereinafter - ZPP) on loading and unloading hatches.



Figure 1.29 – General view of model 19-7016 wagon
for the transportation of bulk goods

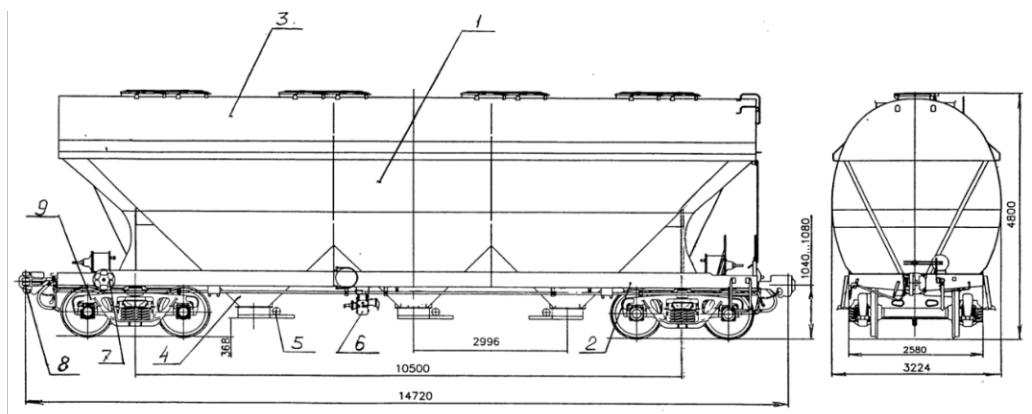


Figure 1.30 – The main structural elements of the model 19-7016 wagon

The body of the wagon (Figure 1.31) is an all-metal welded structure, which is formed by side walls 1, end walls 2 and internal partitions 3. The side walls have an arc-shaped profile, the upper strap 4 has a C-shaped section.

The inclined end walls are supported by two sheet braces 5, installed in a V-shape, and connected by the upper 6 and lower 7 G-shaped horizontal belts. The lining of the end walls of the wagon is made of a smooth sheet. The body is equipped with 8 stairs for climbing the service personnel to the roof of the wagon. Bunkers 9 close the lower part of the body. The walls of the bunkers are made of smooth sheet. In the lower part of each hopper there are unloading slots for pouring cargo.

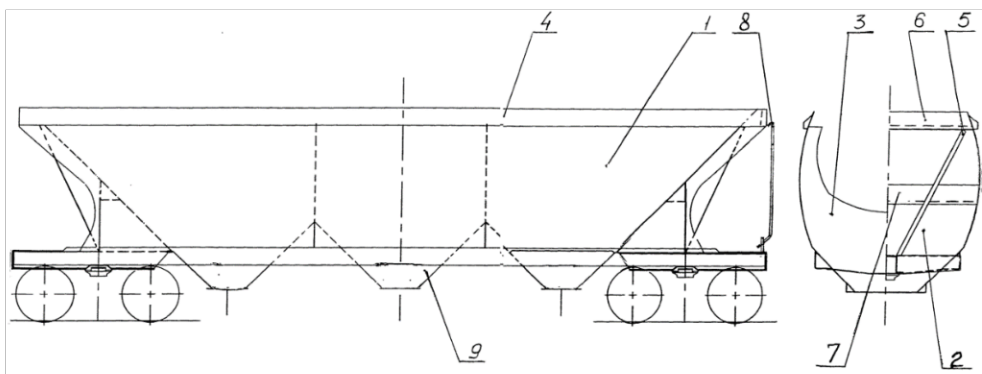


Figure 1.31 – Wagon body of model 19-7016

The frame of the wagon (Figure 1.32) consists of two cantilever spine beams 1, two pivot beams 2, two side beams 3, two intermediate beams 4 and two end beams 5 and decks 6,7. Each cantilever spine beam is made of two Z-profile beams. The end parts of the spinal beams are equipped with front and rear stops combined with heel pads.

Pivot beams have a box section. They are formed by the upper, lower and two vertical sheets and are made in the form of a beam of variable cross-section. For installation on carts, a hinge and slides are installed on the bottom sheet of

each pivot beam. Intermediate beams are installed between the bunkers and are made of lower and vertical sheets that form a T-shaped cross section. The end beams are made of an L-shaped sheet. Uncoupling levers with brackets, stacker handrails and signal lamp brackets are attached to the end beams.

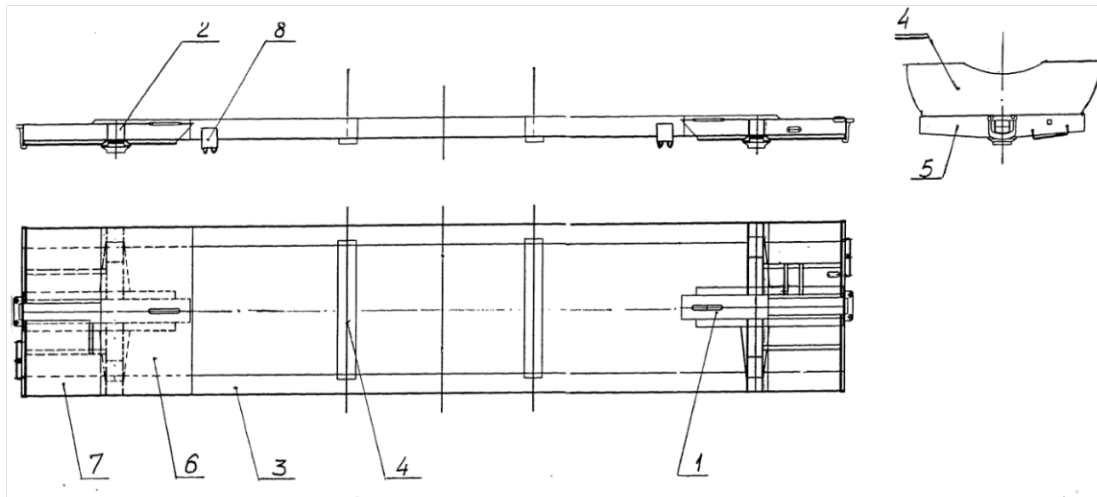


Figure 1.32 - The frame of the wagon model 19-7016

On the consoles of the frame there are decks 6, on the side of the transition platform - decks 7, made of corrugated sheets.

At the request of the customer, the wagon can be equipped with brackets 8, which are welded to the frame strapping, and are intended for lifting the body with the help of slings in order to unload the transported cargo directly into the receiving devices.

Hopper wagon model 19-7053 for transporting grain. Wagons model 19-7053 produced by PJSC "KBBZ" (Figure 1.33): 19-7053-01, 19-7053-02 are intended for bulk transportation of grain and similar food products, as well as other non-toxic, non-poisonous bulk cargoes that do not depend and require protection from atmospheric precipitation, on railways with a gauge of 1520 mm, with loading through the upper hatches and gravitational unloading into the

inter-rail space through the lower hatches on special loading and unloading devices.

The wagon consists of a body, a frame, a roof with loading hatches, bunkers, sliding-type unloading devices, an automatic brake, a parking brake, self-coupling devices and a chassis consisting of two trolleys.



Figure 1.33 - General view of the hopper wagon model 19-7053
for transporting grain

Wagons are equipped with ladders for service personnel to climb onto the roof of the wagon and descend into the body, a mechanism for sealing loading hatches, a mechanism for sealing unloading hatches (at the request of the customer), brackets designed to absorb shock loads from shock mechanisms when unloading the wagon, brackets intended for lifting the body from carts with the help of slings when unloading cargo through the lower unloading hatches.

The body (Figure 1.34) of each wagon model is an all-metal welded structure formed by side walls 1, end walls 2 and internal partitions 3. The cross section of the side walls has an arc-shaped profile. The side walls are made of 4 mm thick rolled steel of the 09G2S brand.

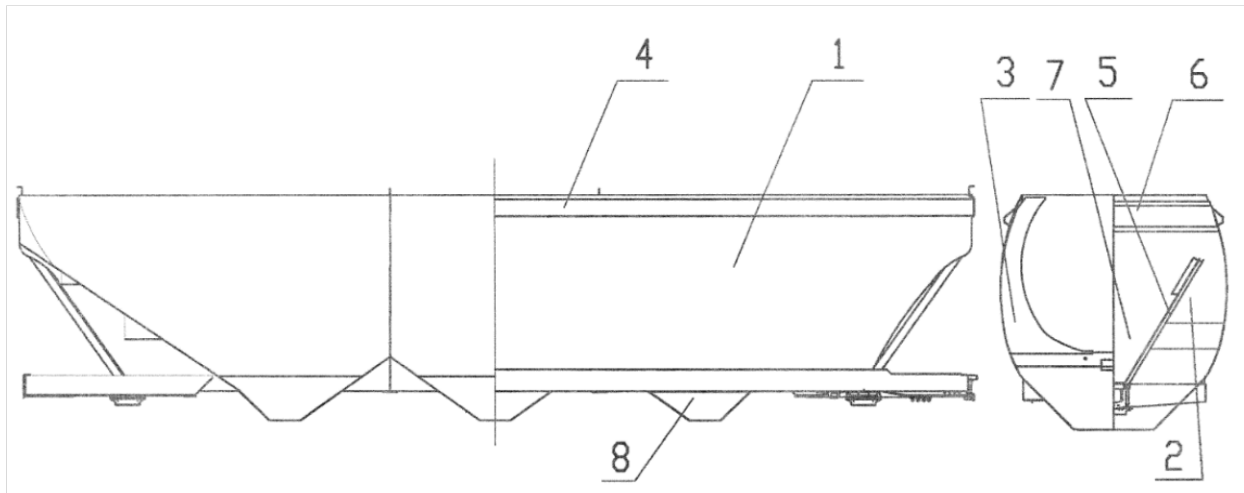


Figure 1.34 – Body of a hopper wagon model 19-7053

The upper strap 4 has a C-shaped cross-section and is made of 3 mm thick rolled steel from structural low-alloy steel of the 09G2S brand. The inclined end walls are supported by two braces 5 made of 6-mm-thick sheet steel made of 09G2S steel, reinforced at the edge with reinforcement made of 12P channel according to GOST 8240.

The braces are installed in a V-shape and are connected to the upper 6 and lower 7 G-shaped horizontal belts made of 6 mm-thick steel grade 09G2S. The cladding of the end walls of the wagon is also made of a smooth sheet of 6 mm thick steel grade 09G2S. Bunker 8 closes the lower part of the body. The walls of the bunkers are made of a smooth sheet with a thickness of 5 mm of steel grade 09G2S. In the lower part of each hopper there are unloading slots for pouring cargo.

The frame of the wagons (Figure 1.35) consists of two cantilever spine beams 1, two pivot beams 2, two side beams 3, two intermediate beams 4, four front sheets 5 and two decks 6.

Each cantilever spine beam is made of two Z-profile beams. The end parts of the spinal beams are equipped with cast front stops and rear stops combined with heel pads.

Pivot beams have a box cross-section, formed by two vertical sheets of 10 mm thick steel grade 09G2S and a bottom sheet of 12 mm thick steel grade 09G2S. The beams are made in the form of a beam of variable cross-section.

When assembling the frame, a 6 mm thick cantilever sheet made of 09G2S steel is welded from above to each beam. To install the frame on the carts, two sliders stamped from a 14-mm-thick sheet of 09G2 steel and a hinge are installed on the lower sheet of each pivot beam.

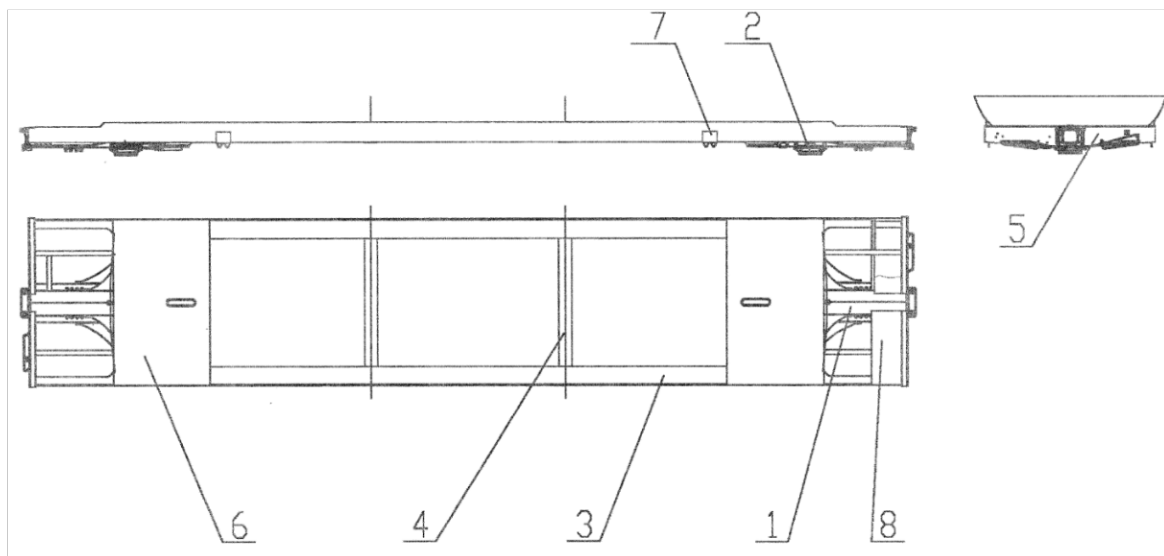


Figure 1.35 - The frame of the hopper wagon model 19-7053

The intermediate beams are installed between the bunkers and are welded from the lower and vertical sheets of 6 mm thick steel grade 09G2S, forming a T-shaped opening.

L-shaped end plates are made of 4 mm thick steel grade 09G2S. Uncoupling levers with brackets, folding handrails and signal lamp brackets are attached to the front sheets.

On the side of the transition platform, on the cantilever part of the frame, there are decks 8, made of cross-exhaust sheet. Brackets 7 are installed on the side beams 3 of the frame, designed for lifting the body from the carts with the help of slings, when unloading the transported cargo through the lower unloading hatches.

Hopper wagon model 19-6870 for transporting grain. "Zavod metalokonstruktsionii" CJSC (Engels, Russian Federation) manufactures bunker-type hopper wagons for grain transportation (Figure 1.36) model 19-6869 (axle load 230 kN) and 19- 6870 (axle load 245kN). These wagons have no fundamental structural differences.

The wagon body (Figure 1.37) is an all-metal welded structure, which includes a frame 1, two side walls 2, two end walls 3, a roof 4, six bunkers with unloading hatches 5, eight braces 7 and two diaphragms 9.

The side walls are connected to the internal diaphragms, frame and end walls, and through the upper strap to the roof of the wagon. Also, braces are installed inside the body, which additionally connect the side walls, frame and diaphragms.



Figure 1.36 – General view of the 19-6870 model hopper wagon for transporting grain

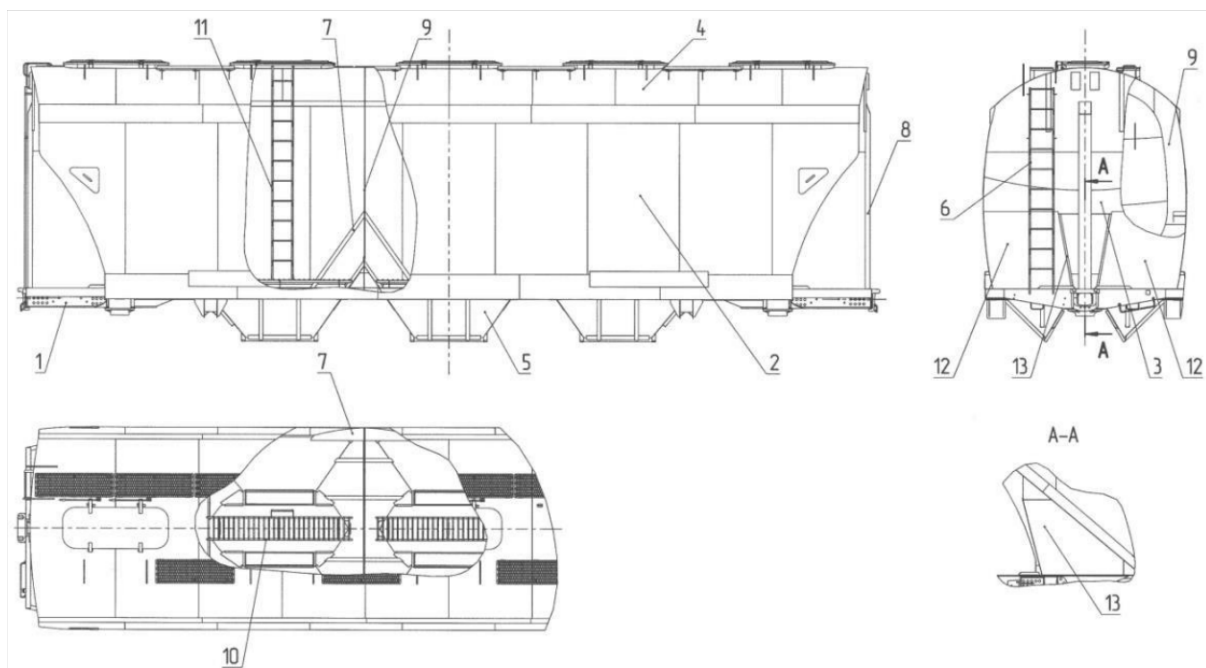


Figure 1.37 – Body of a hopper wagon model 19-6870

The end walls are connected along the contour with the side walls, frame, roof, bunkers and are additionally connected to the frame with vertical risers 8. To increase the rigidity of the body, the end wall is additionally reinforced with walls 12 and ribs 13.

The body inside is equipped with a ladder 10, which runs along the longitudinal axis of the wagon above the bunkers, which facilitates working conditions when servicing the wagon.

To ensure climbing to the roof and descent into the wagon through the manhole opening, the wagon is equipped with external 6 and internal ladders 11, located in the second hatch on the side of the transition platform.

The frame of the wagon (Figure 1.38) is an all-metal welded structure and consists of two spinal consoles 1, two pivot beams 2; two end beams 3; two side ties 4; four end ties 13. Spinal consoles are made of a Z-profile (material steel 345-09G2S or 345-09G2D) at the intersection with a pivot beam and kerfs 17, the backbone console forms a pivot node, which is closed with a reinforcing sheet 6.

For the installation of shock-traction equipment and the transmission of longitudinal tensile and compressive forces, a joint casting of the overheel box with the rear stop of the autocoupling 8 is placed in the pivot assembly.

In the area of intersection of the spinal beam with the end beam, there is a front stop 7 and anti-wear strips 11, riveted to the vertical walls of the spinal console.

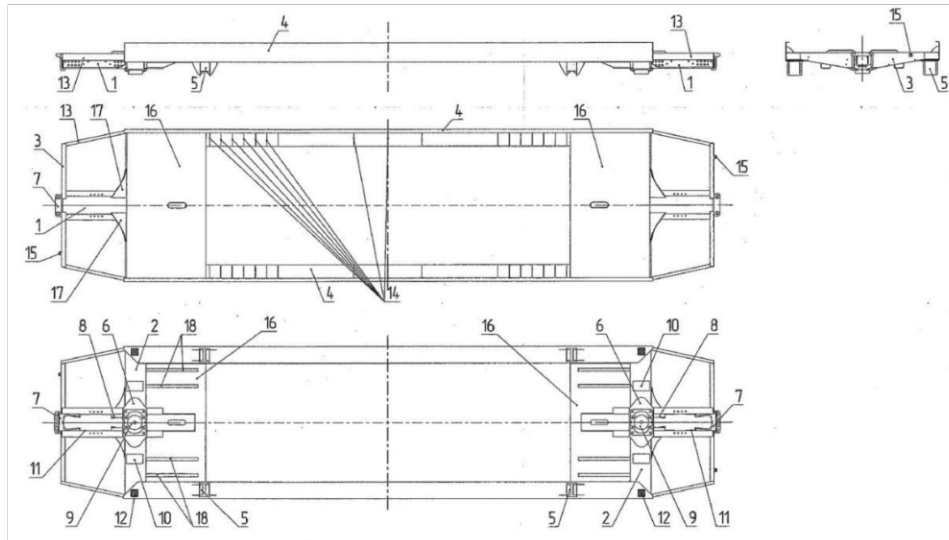


Figure 1.38 – The frame of the hopper wagon model 19-6870

Pivot beam 2 has a box section and consists of lower sheets that fit on both sides to the lower shelf of the spinal console (sheet 10 mm, material steel 325-09G2S), vertical sheets (sheet 8 mm, material steel 345-09G2S) and two diaphragms between them. The upper sheet 16 (sheet 6 mm, material steel 345-09G2S) connects the side straps, pivot and spinal console. Longitudinal beams 18, made in the form of a bent profile of a rectangular cross section, are installed on the top sheet butted against the vertical sheets of pivot beams.

For installation on carts, the frame is equipped with two stamped heels 9 with a diameter of 350 mm and a height of 110 mm and four ridges 10. The heels are attached to the frame using a riveted connection. The end beam 3 is a structure made of a bent profile. A bracket 15 for hanging train signals is placed on the end beam.

The side strapping of frame 4 is a bent channel with shelves of different lengths (sheet 6 mm, material steel 345-09G2S). The longitudinal walls of the bunkers rest on the lower shelf of the side trim 4, as well as the ribs 14 installed in it. In the area of the intersection of the pivot beam and the side strapping to

prevent the jacks from slipping when the wagon is lifted, plates 12 are installed for supporting the jacks. The end strapping 13 is made in the form of a bent channel. To raise the loaded body in the port, brackets 5 are installed on the side strap.

Hopper wagon model 19-3058 for transporting grain. The hopper wagon model 19-3058 for transporting grain (Figure 1.39) is manufactured by the Bryansk Machine-Building Plant, which is part of Transmashholding CJSC.

The wagon body is all-metal, welded structure. The design of the body provides protection of cargo from atmospheric precipitation, as well as full loading and unloading of cargo. Auto coupling devices and braking equipment are placed on the body frame.

The cargo is unloaded into the rail space through three unloading hatches located in the lower part of the body.

The wagon body (Figure 1.40) consists of a frame with bunkers 1, two side walls 2, two end walls 3 and a roof 4. The wagon frame consists of two cantilever beams 1, two pivot beams 2, four end beams 3, six transverse beams 4, two side beams 5, four end ties 6, four braces 7.



Figure 1.39 – General view of the 19-3058 model hopper wagon for transporting grain

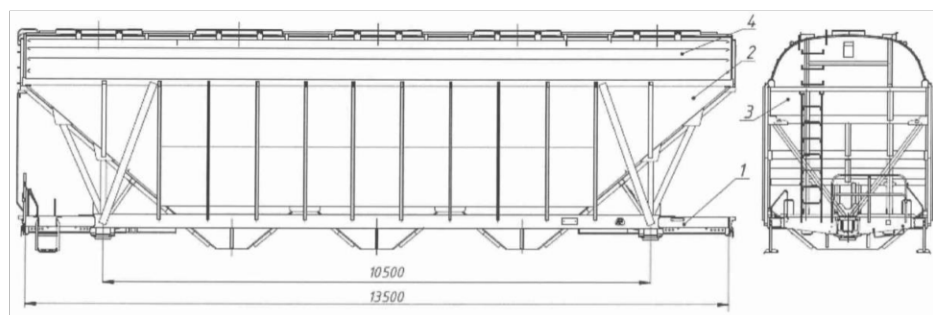


Figure 1.40 – Body of a hopper wagon model 19-3058

The wagon frame (Figure 1.41) accepts all types of loads. Cantilever beams are made of two zetas No. 31 of low-alloy steel 09G2S or 09G2SD, 10G2B, 10G2BD, 12G2F, 12G2FD. On the end parts of the cantilever beams,

the front and rear stops of the auto-coupling device, anti-abrasion strips are installed.

The hinged beam has a box cross-section, formed by upper, lower and vertical sheets and is made in the form of a bar of variable cross-section. Sliders are attached to the horizontal surface of the bottom sheet of the pivot beam. The end beams are made of a sheet with a thickness of 4 mm in the form of a channel of variable cross-section.

Transverse beams of triangular cross-section are made of 12 mm (two extreme) and 6 mm (four between bunkers) sheets. Side beams are made of welded pipe 250×150×7 mm.

The end straps are made of 4 mm thick sheet in the form of a channel.

At one end of the frame, average decking 8 for the transition platform is welded.

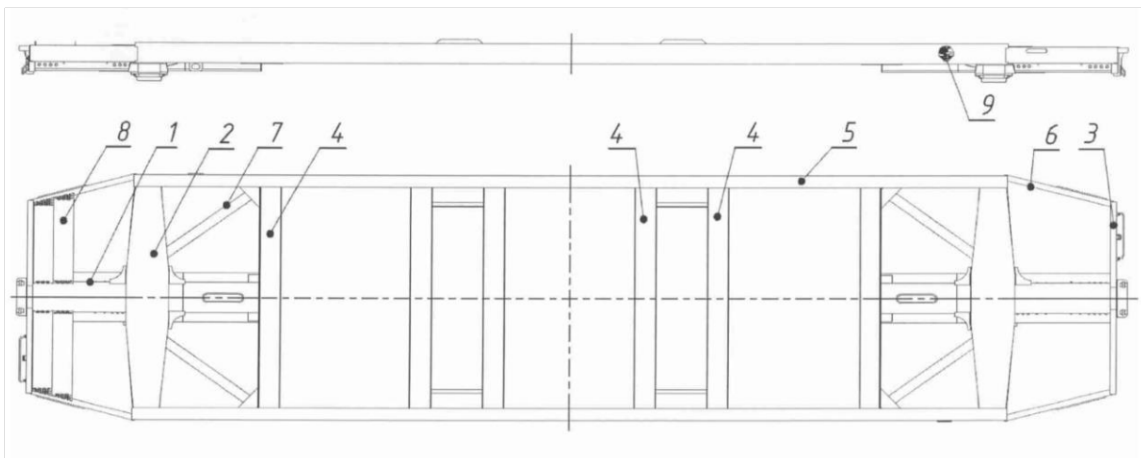


Figure 1.41 – Frame of the hopper wagon model 19-3058

There are three bunkers in the space between the pivot and side beams. Wagon bunkers consist of 5 mm-thick sheets of low-alloy steel grade 09G2S, inclined at an angle of 40°, with vertical reinforcing elements in the form of

channels. In the hoppers of the wagon, there are unloading hatches that ensure the unloading of cargo into the interrail space.

Table 1.16 Main technical characteristics of modern covered wagons

Model	19-7053	19-7053-01	19-7053-02	19-7053-03	19-7053-04
Carrying capacity, no more, i.e	76.0	70.5	70.5	71	76.5
Body volume, m ³	116	116	116	124	124
Tare weight, no more, t	24.0	23.5	23.5	23.0	23.5
Calculated static load from the wheel pair on the rails, kN(ts)	245.2 (25.0)	230.5 (23.5)	230.5 (23.5)	230.5 (23.5)	245.25 (25)
Wagon base, mm	10,500	10,500	10,500	10,500	10,500
The length of the wagon along the axles of the couplings, mm	14,720	14,720	14,720	14,720	14,720
Dimensions according to GOST 9238	1-T	1-T	1-T	1-T	1-T
Number of hatches: - loading - unloading	53	53	53	53	53
Cart	<u>18-7033</u>	<u>18-7020</u>	<u>18-7055</u>	<u>18-7055</u>	<u>18-7033</u>
Design speed, km/h	120	120	120	120	120
Mileage between repairs, km	500,000	500,000	210,000	210,000	500,000
Term of service, years	32	30	30	30	32

Hopper wagons for grain transportation of the new generation have a design that limits the load on the back support of the body frame, which is located separately from the pivot unit that receives vertical loads. And the rear stop itself has at least twice the surface area of the connection with the body frame compared to the structure of the model 19-752 grain wagon. This feature

of the design of the new generation grain wagons provides an even distribution of longitudinal loads on the rear and front supports, and the pivot unit separately ensures the distribution of vertical loads.

The effective use of hopper wagons in railway transport is determined by their good technical and economic parameters, the preservation of transported goods, which gives them an advantage over other types of wagons. In the CIS countries and Ukraine, a significant number of models of hoppers for grain transportation are operated and produced. Table 1.17 shows the characteristics of some models of hopper wagons for transporting grain from different manufacturers.

Having analyzed the market of hopper wagons for the transportation of grain, it can be concluded that the selected typical domestic prototype wagon loses to competitor wagons - it has a low carrying capacity. In order to solve this problem, it is proposed to design a body of a new generation of "drop-shaped" shape with an increased volume due to the maximum quality use of the calculated dimensions. At the same time, the prototype wagon has small linear dimensions, namely length and base, which can be considered an advantage compared to competitors. In the redesigned carriage, it is proposed to leave the length of the carriage and the base the same as in the prototype carriage. In combination with the increased volume of the body, carrying capacity and short length of the wagon, it will be possible to include a larger number of wagons in the train with the same length of the train as when using competitor wagons, which in general will allow transporting a larger amount of cargo. Such a characteristic will have a good effect on the competitiveness of the designed wagon.

Table 1.17 Technical characteristics of hopper wagons for grain transportation

Model	Carrying capacity, i.e	Axle load, t / axle	Body volume, m ³	Tare weight, i.e	Length along the axles of auto couplings, mm	Wagon base, mm	The number of loading / unloading hatches	manufacturing plant
19-756	76.5	25	111	23.5	14720	10500	4/6	JSC "Kryukiv Carriage Building Plant"
19-9549	76	25	120	23, 5	14720	10500	5/6	CJSC "Tikhvin Carriage Building Plant"
19-9870-01	76.5	25	101	23.5	14720	10500	4/6	CJSC "Tikhvin Carriage Building Plant"
19-6870	76.2	25	120	23.8	14720	10500	5/6	JSC "Metal Construction Plant"
19-9944-01	78.5	25	114	21.2	14720	10500	4/6	OJSC "Promtractor-wagon"

The main technical and economic parameters of hopper wagons, which characterize their efficiency, are carrying capacity, tare, volume of the body, and load from the wagon per 1 h.m. of the journey. When choosing these parameters in the process of designing hopper wagons, it is necessary to ensure the following compliance: hopper parameters - the nature of the cargo; dimensions and construction of the body - characteristics of loading machines and mechanisms; hopper design and equipment - operating conditions. Under the condition of matching the nature of the cargo, the ratio between the capacity of the body and its carrying capacity should be such that with normal loading of the

body, the carrying capacity of the wagon is fully used. Figure 1 shows the structural diagram of the prototype wagon.

The design of the designed hopper wagon should ensure:

- increase in carrying capacity and decrease in the tare ratio due to rational design, use of stronger and corrosion-resistant steels, aluminum alloys;
- increasing the adaptability of wagons to the complex mechanization of loading and unloading operations and the maximum reduction of heavy manual labor during these operations;
- reduction of material intensity and labor intensity of the production of wagons thanks to the improvement of the manufacturability of the design, the use of large blocks during assembly, and the maximum unification of nodes and parts;
- durability and reliability of the wagon in operation, etc.

Covered wagon designs produced by PJSC "Azovmash", PJSC can also serve as examples of the implementation of original technical solutions "Kryukiv Carriage Plant" and others, indicated in figures 1.42 and 1.43.

The hopper wagon with a body made of composite materials (Figure 1.43a) is intended for operation throughout the railway network of the 1520 mm gauge of the CIS countries, Latvia, Lithuania, Estonia for bulk transportation of safe mineral fertilizers and other loose safe cargoes that require protection from atmospheric precipitation. with unloading at points that have receiving and unloading devices.

The structure of the composite body of the hopper wagon is a self-supporting monocoque fiberglass skin, supported by an internal power set consisting of 7 transverse frames and a central backbone frame that overlaps the end walls.

Fiberglass is a very promising lightweight material with specified properties, which has a wide range of applications. Fiberglass has low thermal

conductivity, strength of steel, high corrosion and biological resistance. The service life of structures made of composite materials (fiberglass and carbon fiber) under the conditions of operation is up to 100 years. Thanks to these properties, products made of composite materials are widely used in civil and industrial construction, aviation, and from now on in carriage construction.



Figure 1.42. – Covered wagons



Figure 1.43. - Hopper wagons of the new generation: a - hopper wagon for goods that require protection from atmospheric precipitation; b - hopper wagon model 19-9549-01 with increased body volume; c - hopper wagon for grain transportation model 19-6870

The increased body volume of the hopper wagon model 19-9549-01 (figure 1.43b) makes it possible to transport all grain cargoes using the full carrying capacity of the wagon. This allows you to get the maximum economic effect on the wagon. The wagon has an optimal ratio of the angles of inclination of the unloading walls of the bunkers and the end walls for full unloading.

In Figure 1.43c, the bunker-type hopper wagon for grain transportation model 19-6870 is designed for the transportation of grain and other bulk food cargo with gravity loading and unloading of the wagon into inter-rail spaces. The carrying capacity of the grain wagon is 76.2 tons. The volume of the body is

120 cubic meters. This wagon model provides higher economic efficiency of transportation compared to existing analogues.

The covered hopper wagon of the bunker type (Figure 1.44) is designed to transport cement in bulk (without packaging) to places of mass consumption, where there are receiving and unloading devices located between the rails.

The all-welded wagon body consists of two vertical side walls and two end walls, installed at an angle of 50° to the horizontal, a frame and bunkers. The lining of the side and end walls is made of 09G2D steel. The end walls are reinforced with risers. The backbone beam is made of two Z-shaped rolling profiles.

Inside the body, a ridge is installed on the backbone beam, which gives it additional strength and contributes to better dumping of cargo.



Figure 1.44 - General view of the wagon hopper model 19-758 for the transportation of cement

The lower part is closed by four bunkers with unloading hatches, which have rectangular openings measuring 500×400 mm. Stamped manhole covers have sealing gaskets made of rubber, which retains elastic properties in the range from -50 °C to 100 °C.

The unloading mechanism (Figure 1.45) ensures opening and closing of the hopper lids in pairs, and also allows you to dose the pouring of cement from the wagon and stop unloading at any time. The mechanism consists of a screw drive with a rudder, fixed on a bracket, and a system of hingedly interconnected levers and rods with spacers 7 and 8, connected in pairs to the covers 7 of the unloading hatches.

When the steering wheel 4 of the drive 6 mounted on the bracket 5 is rotated, the two-armed lever 3 turns around the axis 2, which leads to the raising or lowering of the rod 9. Therefore, with the help of spacers 7 and 8, the lids 1 are opened or closed.

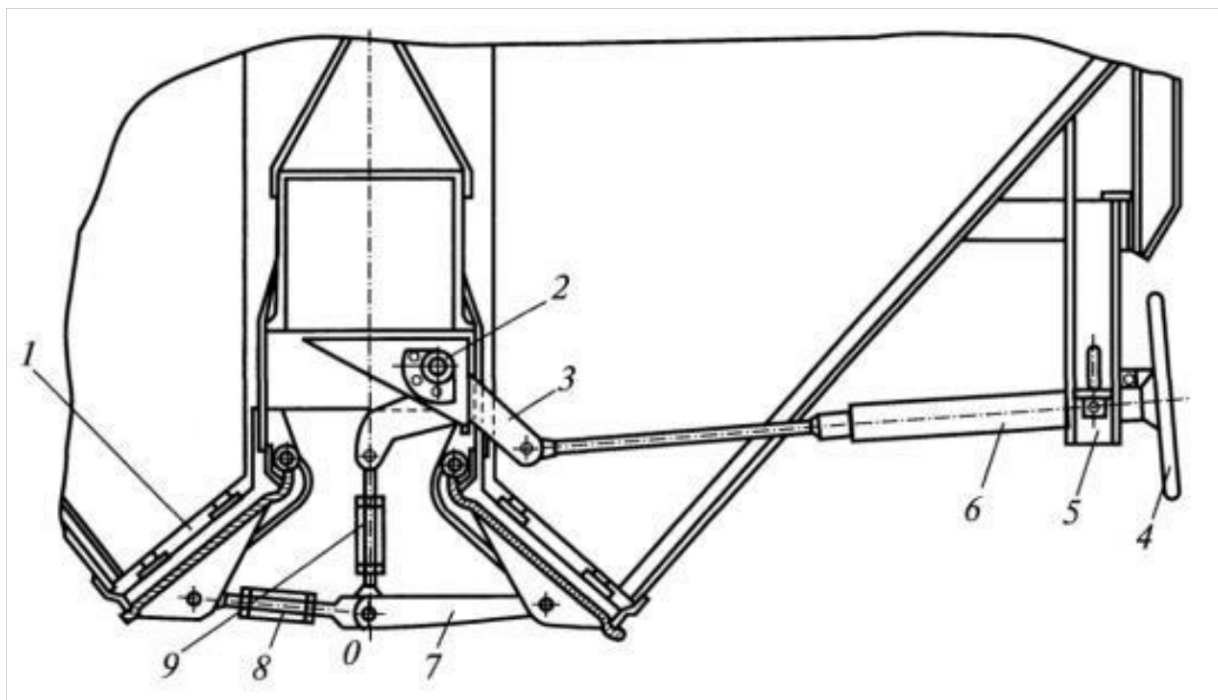


Figure 1.45 – Unloading mechanism of the 19-758 model hopper wagon for cement transportation

On the hoppers on the side of the unloading mechanism steering wheels, special clamps are installed for fastening vibrators, which are used to remove the cement remaining in the wagon.

The wagon has been manufactured since 1986 by PJSC "KrVBZ".

The four-axle hopper wagon model 19-7075 (Figure 1.46) is designed for bulk transportation of cement and other non-toxic and non-toxic construction and granular bulk cargoes.



Figure 1.46 - General view of the hopper wagon model 19-7075

The wagon (Figure 1.46) consists of the following components: body 1, frame 2, roof 3, hoppers 4, unloading mechanism 5, automatic brake 6, parking brake 7, self-coupling devices 8, two carts 9.

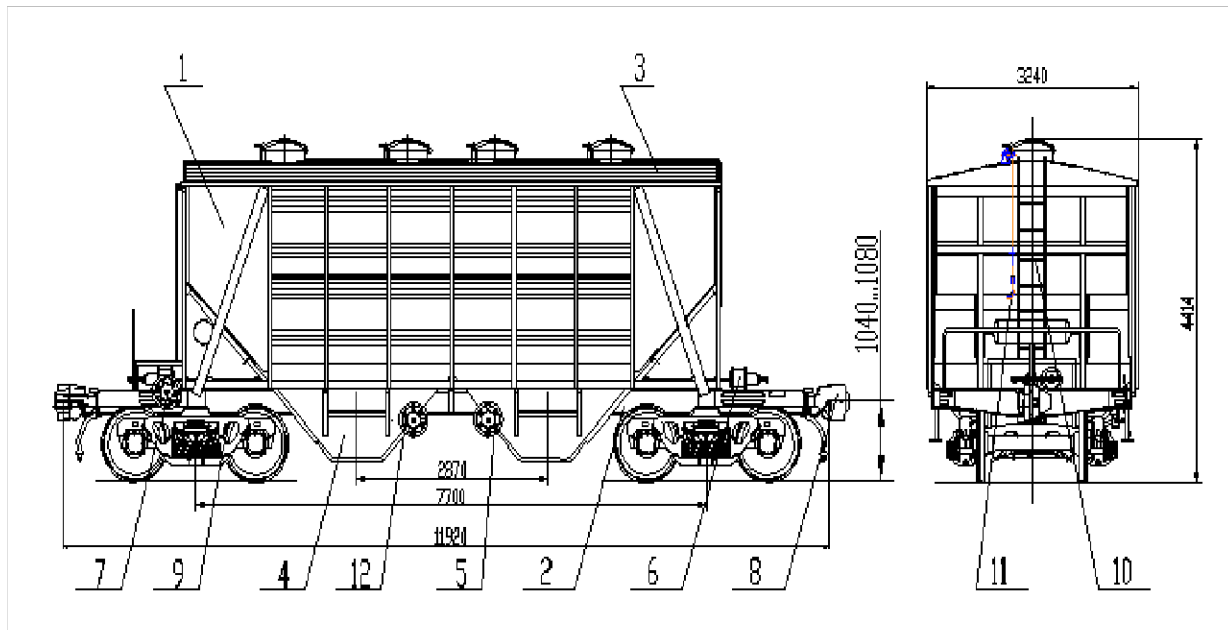


Figure 1.47 - The main structural elements of the wagon model 19-7075

The wagon is equipped with stairs 10 for climbing the service personnel to the roof of the wagon, devices 11 and 12 for installing locking and sealing devices (ZPP) on the loading and unloading hatches.

A ladder is installed on one of the roof hatches to allow service personnel to enter the wagon.

The wagon body (Figure 1.48) is an all-metal welded structure formed by two side walls and two end walls.

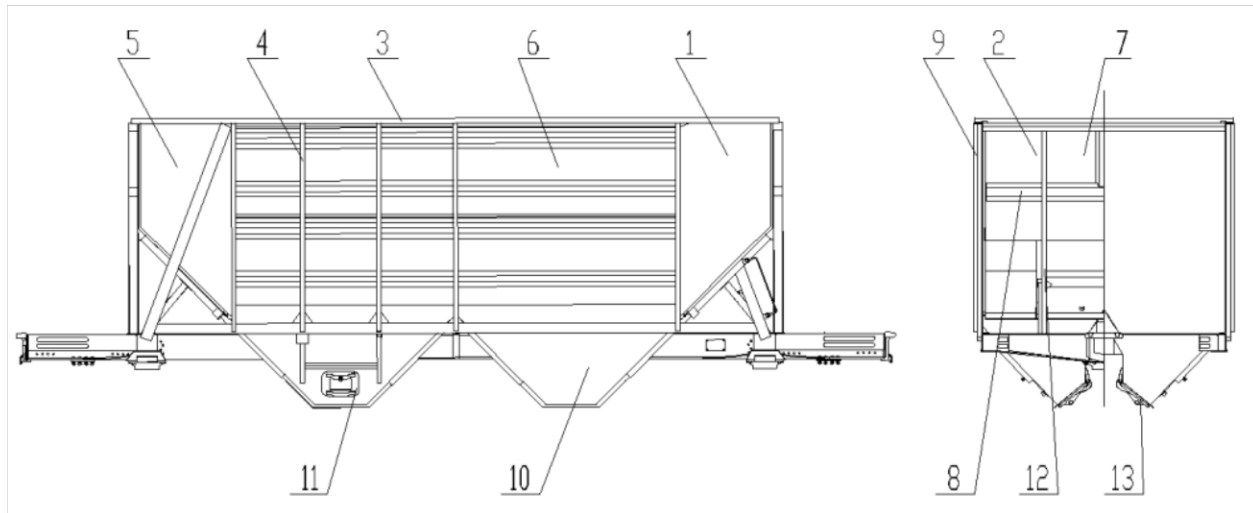


Figure 1.48 - Wagon body of model 19-7075

The side wall consists of the upper casing 3, made of an angular profile, vertical risers 4, made of I-beams, braces 5 of channel and sheathing 6, made of a bent profile with longitudinal corrugations.

The inclined end walls consist of smooth sheets of cladding 7, supported by a frame made of an Ω -shaped profile 8, two bent straps 9 made of an angular profile. The end walls are supported by two vertical risers 12, resting on the pivot beam of the frame.

Bunkers close the lower part of the body. The walls of the bunkers are made of a smooth sheet and reinforced with stiffening elements made of a bent channel.

In the lower part of each hopper there is a bottom 13 with a neck for pouring cargo and a welded plate 11 with brackets for installing a vibrating machine.

The frame of the wagon (Figure 1.49) consists of a backbone beam 1, two pivot beams 2, two side ties 3 made from a corner, one middle beam 4, two end beams 5 and four end ties 6 connecting the end and pivot beams. On one end part of the frame, decking 7 of the transitional platform is installed.

The spinal beam is made of two zeta profile beams.

The end parts of the spinal beam are equipped with front and rear stops combined with heel pads.

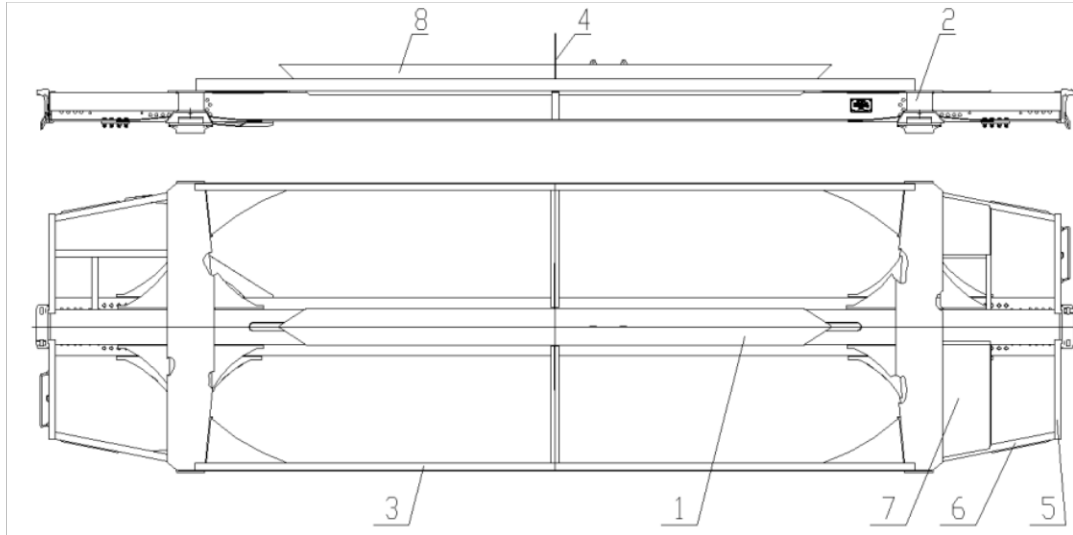


Figure 1.49 - Frame of the model 19-7075 wagon

Inside the wagon, a ridge 8 is installed on the backbone beam, which provides additional strength and contributes to better unloading of the cargo.

Pivot beams have a box cross-section, formed by the upper, lower and two vertical sheets, and are made in the form of a beam of variable cross-section. For installation on carts, a hinge and slides are installed on the bottom sheet of each pivot beam. The middle beam is installed between the bunkers and consists of a vertical and two lower sheets forming a T-shaped section.

The L-shaped end beams are made of sheet metal. Uncoupling levers with brackets, stacker handrails and signal lamp brackets are attached to the end beams.

The roof of the wagon (Figure 1.50) consists of transverse arcs 1 of an angular profile, cladding consisting of two end sheets 2 and one middle sheet 3, end transoms 4, with the help of which the roof is connected to the end walls of the body.

The outer sheets of the cladding are made of a bent profile with four longitudinal corrugations. The middle sheet is made of a bent profile with two longitudinal corrugations.

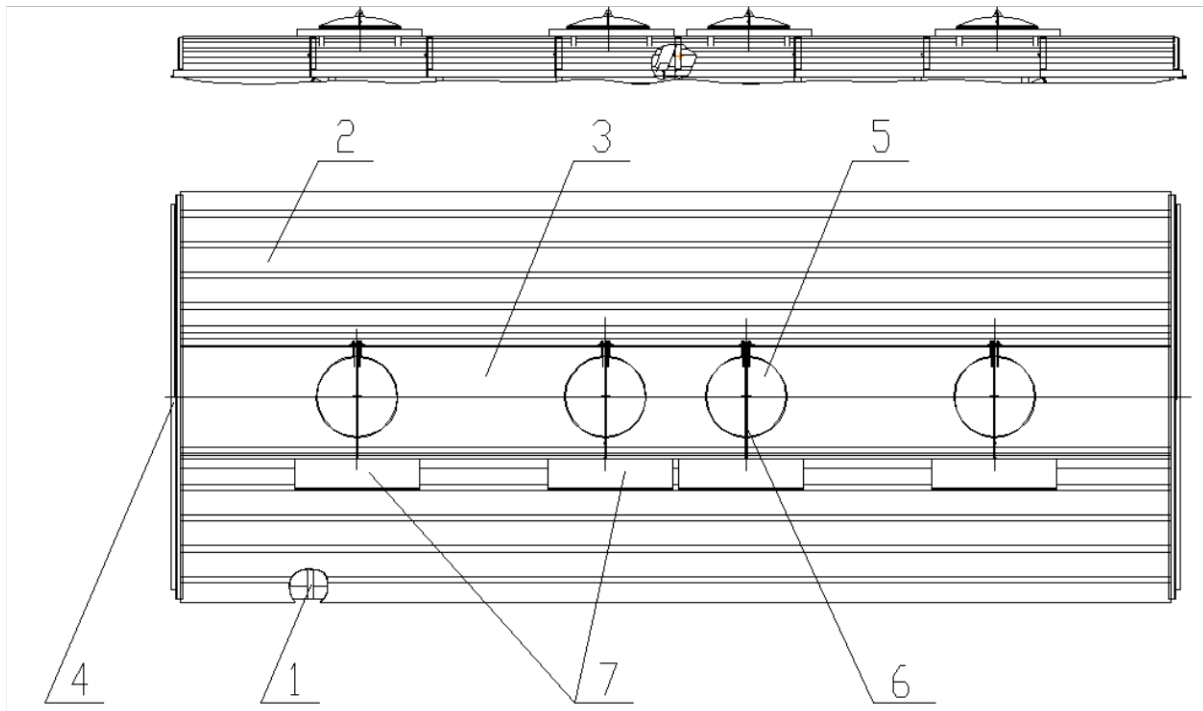


Figure 1.50 - Roof of the model 19-7075 wagon

Along the axis of the roof there are four round loading hatches, which are closed by covers 5 with elastic levers 6. For the lifting of service personnel, the roof of the wagon is equipped with handrails located on the end of the roof.

For the work of service personnel, the roof of the wagon is equipped with decking 7 made of corrugated sheet.

The wagon is equipped with an unloading mechanism and a mechanism for sealing the loading hatch covers.

The hopper wagon for the transportation of cement model 19-9862 (Figure 1.51) is manufactured by the joint-stock closed joint-stock company "Mogilovsky Carriage Plant" (Republic of Belarus).

The wagon body is an all-welded structure formed by a roof, two side walls and two end walls mounted on a frame. Each side wall is supported from the inside by three risers made of sheet metal. The side wall is made of 4-mm-thick sheathing sheets and the upper longitudinal reinforcement in the form of a bent corner from a 4-mm-thick sheet. Each end wall is supported by six uprights of rectangular section. The end wall consists of 4 mm-thick sheathing sheets with three crossbars and six vertical reinforcements.



Figure 1.51 – General view of the 19-9862 model hopper wagon for transporting cement

Inclined plates are installed inside the body to connect the sideboard with the hoppers and ensure full unloading. Transverse bent sheets ensure the

connection of the side wall with the bunkers, longitudinal bent sheets ensure the connection of the end walls with the bunkers.

The frame with hoppers (Figure 1.52) consists of a spinal beam 1, two pivot beams 2, eight crossbars 3,4 connected to two longitudinal beams 5, four end beams 6, 7, four connecting beams 8 and four hoppers 9 , 10.

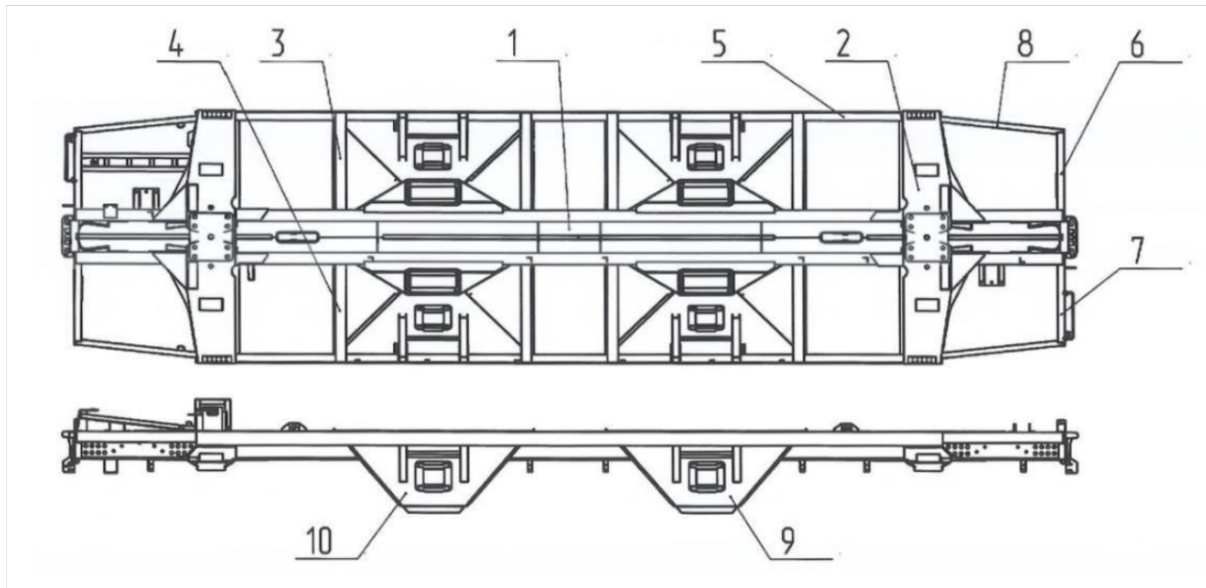


Figure 1.52 – Frame with hoppers of the hopper wagon model 19-9862

Spinal beam 1 is zeta profiles No. 31, connected to each other, between which the front and rear stops of the auto-coupling device are installed.

Pivot beam 2 of box section consists of upper, lower and four side sheets with diaphragms. A heel and sliders are installed on the bottom sheet.

Transverse beams 3,4 are made of a bent corner profile.

Lateral longitudinal beams 5 consist of two channels connected in a rectangular profile, end and inner plates.

The end beams 6, 7 are made in the form of a bent corner profile of variable cross-section. On them are the release lever, folding handrail, automatic and handbrake brackets, signal lamp bracket.

The end beams are connected to the pivot beam by connecting beams 8, to which the folding legs are attached.

Bunkers 9, 10 are made of smooth sheets 5 mm thick, reinforced with amplifiers. The bunkers have unloading hatches.

The roof (Figure 1.53) consists of: a roof frame 1, four hatch covers 2 and fourteen service platforms 3. The roof frame includes two end walls, seven crossbars connected to each other by sheets 3 mm thick, forming the necks of loading hatches, and four rings welded into the necks.

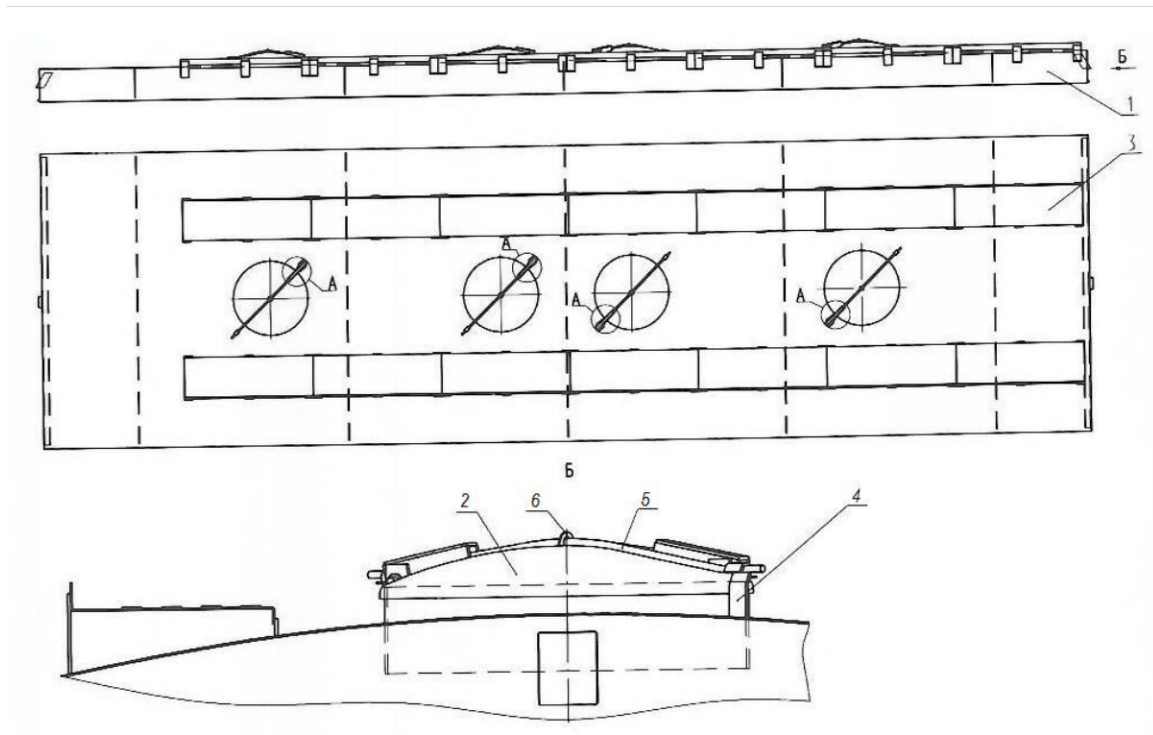


Figure 1.53 - The roof of the hopper wagon model 19-9862

Valves are installed in the end sheets of the roof frame to ensure ventilation of the interior space of the body and to prevent the formation of a vacuum during unloading.

There are four loading hatches on the roof of the wagon.

Hatch covers are closed through clamp 5 and hook 4 with latch 6. Opening and closing of covers is carried out manually.

The roof is attached to the body by welding.

Transportation of the planned volumes of cargo will be ensured by the working fleet of Ukrzaliznytsia and its own working fleet of private wagons, provided that the deficit is eliminated, by replenishing the inventory fleet of Ukrzaliznytsia, extending the service life of wagons with an expired service life, and renewing the fleet through procurement.

Indicators of perspective volumes of transportation in Ukraine 2006...2020 are given in table 1.18.

Thus, the priority in rolling stock renewal should be to provide railways of Ukraine with mostly new generation rolling stock. This will improve the technical and economic indicators of railway transport, improve the safety and convenience of transportation, increase the competitiveness of Ukrainian railways, and make a leap in improving the efficiency of the industry.

Table 1.18 – Indicators of prospective volumes of transportation

Years	Shipments (million tons)	Percentage growth over the previous year	Departure (s/day)	
			thousand	wagons
2006	398	+5.0%	109	17603
2007	415.9	+4.5%	113	18359
2008	446.48	+7.3%	121	19676
2009	452.82	+ 1.4%	124	20010
2010	460.52	+ 1.7%	126	20351
2011	468.37	+ 1.7%	128	20697
2012	477.63	+2.0%	130	21048
2013	484.43	+ 1.4%	132	21406
2014	492.64	+ 1.7%	134	21770
2015	501.03	+ 1.7%	137	22140
2016	510.94	+2.0	139	22517
2017	518.23	+ 1.4	141	22899
2018	527.02	+ 1.7	144	23289
2019	535.97	+ 1.7	146	23685
2020	546.58	+2.0	149	24087

1.3 Design features of wagons of platform wagons

According to the classification, platform railcars belong to open-type freight wagons. This is a very popular type of transport for long-distance transportation [35]. Recently, there has been an increase in the volume of cargo for some types of cargo, such as containers, metals and timber, which can be transported on these platform wagons with their certain modernization. Therefore, the issues of choosing economically feasible and technically possible options for modernizing the structures of flatcars of 1435/1520 mm gauge and substantiating the directions of improving the structure of the fleet become relevant.

The platform wagon for the transportation of containers does not have a floor covering and sides, it is equipped with stops necessary for fastening containers. Railway wagons-platforms, intended for the transportation of wood, are equipped with floor coverings and end boards. Otherwise, it is impossible to transport such cargo. Platform wagons for transporting wheeled equipment are similarly equipped.

Universal flatcars of the past years were intended for the transportation of heavy tracked vehicles and construction materials. Due to the change in the structure of transported goods and the lack of demand for certain types of freight wagons, more than 20 thousand flatcars were withdrawn from operation and sent to the reserve.

Platform wagons for transporting wagons over long distances have their own characteristics. Their body consists of specially fixed frames and metal flooring. Such a platform wagon has folding platforms-ramps on the ends, designed for racing wagons. Fixing of wagons in this case is done with the help of special stops.

Let us consider the design features of the new-generation flatcars manufactured by the leading wagon-building plants of Ukraine.

Consider the design features of the universal platform wagon (Figure 1.54).

The body of the platform consists of a frame 2 with a combined floor covering 10, eight side (four per side) and two end 7 boards.

The side boards are hinged on the side beams of the frame and each of them is held in the closed position by three wedge locks 3, and the end boards by two wedge locks 6.

Four support brackets 8 are installed on the end beams of the frame to keep the end boards in a horizontal position and use them when loading the wheeled machinery.

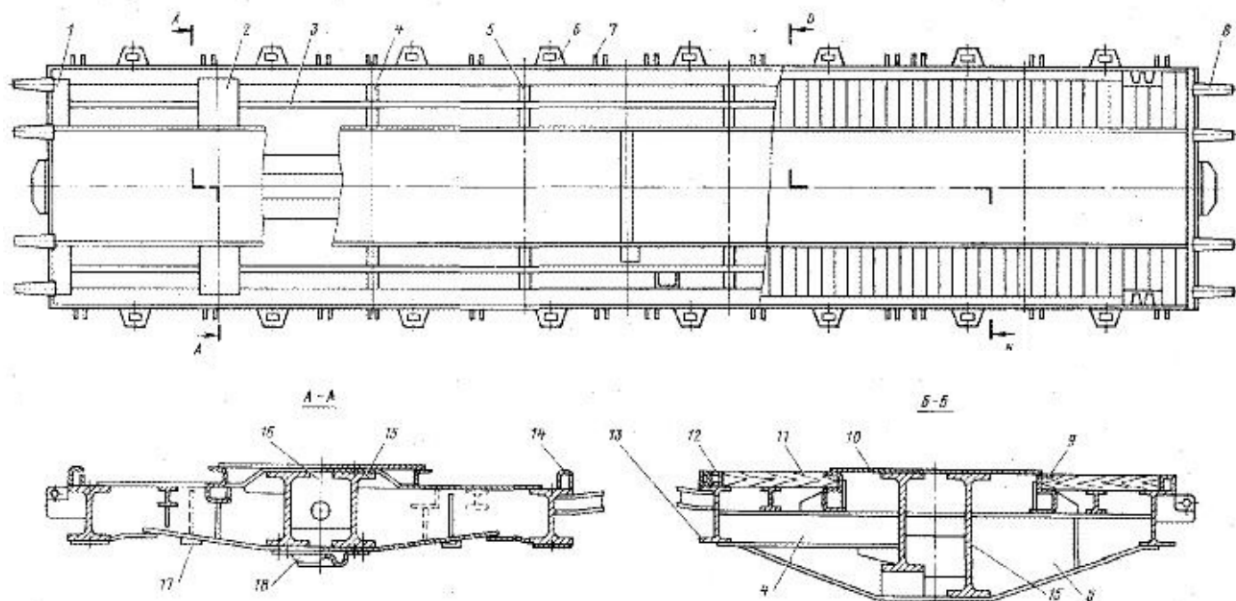


Figure 1.54 – Structural features of the load-bearing structure
universal platform wagon

For tying the cargo inside the body, staples 9 are provided, and tying rings 5 are provided outside. When transporting bulk cargo loaded above the sides, staples 4 are welded to the side beams of the frame for installing wooden rack.

The body frame is welded. It consists of a spine 15, two side 13, two end 1, two pivot 2, three main 5 and two intermediate transverse 4 beams, which, together with auxiliary longitudinal beams 3 and 9, serve to support the floor covering.

Two I-beams No. 70 of variable height along the length form a spinal beam 15.

I-beams are connected to each other by diaphragms and stops of autocouplings. The nodes of the intersection of the spinal and pivot beams are reinforced with supracalcaneal diaphragms 16.

Side beam 13 is made of I-beam No. 30 of constant height along its entire length. From the outside, wooden staples 6 and holders 7 of wedge locks are welded to it.

The end beams are welded, of constant height along the length and are made of an L-shaped sheet 8 mm thick and elements of its reinforcement: two corners (150x60x6 mm) and four ribs, welded from the inside of the beam at the places where brackets 8 are placed.

Pivot beams 2 welded, closed box section, variable height along the length. They consist of two vertical (8 mm), upper and lower horizontal sheets (10 mm).

Sliders 17 are riveted to the lower horizontal sheets of the pivot beams, and in the areas of connection with the backbone beam, hinges 18 are installed on the bolts.

The main transverse beams 5 are welded with a I-beam section, of constant height along the length and consist of a vertical sheet (8 mm) and two horizontal ones (10 mm).

Auxiliary transverse 4 and extreme longitudinal 3 beams, which serve to support the floor covering, are made of I-beam No. 10.

The transverse beams 4 are located in the frame below the floor level at the height of the auxiliary longitudinal beams 3 in order to ensure the location of their top in the same plane as the side ones and simplify the laying of the floor covering.

Let's consider the design features of some models of platform wagons.

The universal platform with wood-metal flooring is designed for the transportation of wheeled and tracked machinery, artificial and other loads, both with evenly distributed and concentrated load on the floor. The platform wagon model 13-4012 (Figure 1.55) differs in the structure of the floor: the central part is metal, and the edges are made of wood. The floor is reinforced with four stiffening beams.

The main technical characteristics of the platform wagon are given in table 1.19.



Figure 1.55 - Platform wagon model 13-4012

Table 1.19 – The main technical characteristics of the platform wagon model 13-4012

Parameter name	Value
Carrying capacity, i.e	72.0
Mass of the wagon, i.e	22.0
Calculated wheel load. steam on the rail, kN(ts)	230.5(23.5)
The length of the wagon along the coupling axes of auto couplings, mm	14620
Platform base, mm	9720
Internal dimensions of the body	
- length, mm	13300
- width, mm	2770
Dimensions	0-BM
Height to the clutch axis from the level of the rail heads, mm	1060±20
Track width, mm	1520
Design speed km/h.	120

The specialized flat car model 13-703102 (Figure 1.56) is designed for transportation of 40- and 20-foot universal high-tonnage containers, packaged artificial cargo, metal structures, long cargo and wheeled equipment.



Figure 1.56 - Flat wagon model 13-7031E2

The flat car is manufactured in the climatic version U for accommodation category I. The brake is automatic pneumatic, manual parking. Undercarriage - two two-axle bogies model 18-100 type 2 for a track of 1435 mm or two two-axle bogies model 18-7055 type 2. Self-clutch SA-3 is automatic, non-rigid. Absorption device of increased energy intensity class T1 or T2. The main technical characteristics of the flat car are given in table 1.20 .

The 13-4117 model flat wagon (Figure 1.57) is designed for transporting large-tonnage containers on main railways with a gauge of 1520 mm. When replacing the trolleys, the platform can be operated on railways with a gauge of 1435 mm.

Table 1.20 – The main technical characteristics of the flat wagon model 13-7031E2

Parameter name	Value
Carrying capacity, i.e	60.3
Mass of the wagon, i.e	29.7
Calculated load from the wheel pair on the rail, kN (ts)	22.5 (220.7)
The length of the wagon along the coupling axes of the auto clutches , mm	25670
Platform base, mm	18500
Dimensions: body carts	IIRR (RAI) 02-BM
Height to the clutch axis from the level of the rail heads, mm	1060±20
Track width, mm	1520 (1435)
Design speed, km/h	120



Figure 1.57 – Flat car model 13-4117

Features of the platform wagon:

- the weight of the container is reduced due to the use of new materials, which make it possible to reduce the material consumption of the structure while maintaining the strength parameters;

- standard sizes of transported containers: 1A, 1AA, 1AX, 1B, 1BB, 1BX, 1C, 1CC, 1CX.

The main technical characteristics of the flat car are given in table 1.21.

Table 1.21 – The main technical characteristics of the flat car model 13-4117

Parameter name	Value
Carrying capacity, i.e	72
Mass of the wagon, i.e	20
Height from the level of the rail heads to the load plane, mm	1290
The length of the wagon along the coupling axes of the auto clutches, mm	19720
Platform base, mm	14200
Dimensions with a submerged container	0-BM
Width; mm	2930
The maximum calculated static load from the wheel pair on the rail, kN (ts)	227.1 (23.15);
Design speed, km/h.	120

The universal platform wagon of model 13-401 differs from model 13-4012 in the construction of the frame: instead of four longitudinal stiffness beams, two are used here, the floor is completely wooden (Figure 1.58). The sides of the platform wagon are metal. The platform wagon is used for the

transportation of wheeled and tracked machinery, artificial and other cargoes that do not require protection from atmospheric precipitation.



Figure 1.58 - Platform wagon model 13-401

The main technical characteristics of the platform wagon are given in table 1.22.

Platform wagon model 13-4085 (Figure 1.59) developed on the basis of the universal model 13-4012 platform wagon and intended for the transportation of wheeled and tracked machinery, large-tonnage containers, container loads, metal structures, long dimensions and other loads, both with evenly distributed and concentrated loads on the floor. Special supports mounted on the frame of the platform wagon ensure reliable fixation of containers and their preservation during transportation.

Table 1.22 - The main technical characteristics of the platform wagon model 13-401

Parameter name	Value
Carrying capacity, i.e	70.0
Mass of the wagon, i.e	20.92
Calculated wheel load. steam on the rail, kN(ts)	223.01(22.73)
The length of the wagon along the coupling axes of auto couplings, mm	14620
Platform base, mm	9720
Internal dimensions of the body	
- length, mm	13300
- width, mm	2770
Dimensions	0-BM
Height to the clutch axis from the level of the rail heads, mm	1060±20
Track width, mm	1520
Design speed km/h.	120



Figure 1.59 – Platform wagon model 13-4085

The platform wagon is designed for simultaneous transportation of two containers of standard size 1C, 1CC, 1X or one container of standard size 1AA, 1A, 1AX, as well as other universal and specialized large-tonnage containers with a length of 6096 mm (20 feet) with a gross weight of up to 36 tons and a length of 12192 mm (40 ft) with a gross weight of up to 40 tons.

The main technical characteristics of the platform wagon are given in table 1.23.

Table 1.23 - The main technical characteristics of the platform wagon model 13-4085

Parameter name	Value
Carrying capacity, i.e	72.0
Mass of the wagon, i.e	22.0
Calculated wheel load. pairs on the rail, kN	230.0
The length of the wagon along the coupling axes of auto couplings, mm	14620
Platform base, mm	9720
Internal dimensions of the body	
- length, mm	13300
- width, mm	2770
Dimensions	0-BM
Height to the clutch axis from the level of the rail heads, mm	1060±20
Track width, mm	1520
Design speed km/h.	120

Specialized flat wagon model 13-785-01 (Figure 1.60) is designed for transportation of packaged piece cargoes, various types of rolled metal products

in the form of plates and profiles, in particular steel in coils, universal large-capacity containers and other cargoes that do not require protection from atmospheric precipitation.

The main technical characteristics of the flat wagon are given in Table 1.24.



Figure 1.60 – Flat wagon model 13-785-01

Brake - automatic pneumatic, manual parking. Running gear – two two-axle trolleys mod. 18-100 type 2 for a track of 1435 mm or two two-axle trolleys mod. 18-7055 type 2. Self-clutch SA - 3 automatic, non-rigid. Absorption device of increased energy intensity class not lower than T1 or T2 .

Table 1.24 – The main technical characteristics of the flat wagon model 13-785-01

Parameter name	Value
Carrying capacity, t, no more	63.0
Mass (tare), t	27.0
The calculated static load from the wheel pair on the rails, kN (ts), no more	220.7 (22.5)
Cargo characteristics of the floor: area, m ² length, m width, m height from the level of the rail heads of the empty platform, m	49 18.52 2.67 1.25
Design speed, km/h: loaded empty	100 120
The length of the wagon along the coupling axes of auto couplings , m	19,880
Dimensions: body carts	IRR(RA1) 02-BM
Track width, mm	1435
Height from the level of the rail heads to the clutch axis of auto clutches , m	1.04...1.08
The minimum radius of the iron curve. ways, passing single platform, m	75

The specialized flatcar model 13-7043 (Figure 1.61) is designed for transportation of large-capacity universal containers, as well as packaged piece cargoes, various types of metals in the form of plates and profiles and other types of cargoes that do not require protection from atmospheric precipitation, on the network of railways of Ukraine and CIS countries with a gauge of 1520 mm.



Figure 1.61 - Flat wagon model 13-7043

Brake - automatic, pneumatic, parking brake. Running gear - two two-axle bogies of the model 18-100 type 2 or two two-axle bogies of the model 18-7055 type 2. Auto clutch CA-3 automatic, non-rigid. Absorption apparatus of increased energy intensity of class T1. The main technical characteristics of the flatcar are given in Table 1.25.

Table 1.25 - Main technical characteristics of the flatcar model 13-7043

Parameter name	Meaning
Carrying capacity, t	68.5
Wagon weight, t	25.0
Design load from wheel pair on the rail, kN(tf)	230,5(23.5)
The length of the wagon along the axes of the coupling of the couplings, mm	19 600
Platform base, mm	14 600
Internal dimensions of the body	
- area, m ²	48.6
- length, mm	18270
- width, mm	2660
Dimension	1-BM
Height to the axis of coupling from the level of rail heads, mm	1060±20
Track width, mm	1520
Design speed, km/h.	120
Service life, years	32

Platform wagon model 13-9004 (Figure 1.62)intended for transportation of large-tonnage containers and wheeled equipment: front-end loaders, trucks, various construction equipment, transportation of mobile buildings and houses. A platform wagon with end sides, equipped with hinged fitting stops (the stop is included in the container lock). The frame is of welded construction.



Figure 1.62 - Platform wagon model 13-9004

The main technical characteristics of the platform wagon are given in table 1.26.

The specialized flatcar model 13-9004M (Figure 1.63) is intended for transportation of packaged artificial cargo, wheeled machinery, as well as 40- and 20-foot universal high- tonnage containers. The main technical characteristics of the flatcar are given in table 1.27.



Figure 1.63 – Flat wagon model 13-9004M

Table 1.26 – Main technical characteristics of the platform wagon models 13-4085

Parameter name	Value
Carrying capacity, i.e	65.0
Mass of the wagon, i.e	26.0
Calculated wheel load. pairs on the rail, kN	223.0
The length of the wagon along the coupling axes of auto couplings, mm	19620
Platform base, mm	14720
Internal dimensions of the body	
- length, mm	18300
- width, mm	2870
Dimensions	0-BM
Height to the clutch axis from the level of the rail heads, mm	1060±20
Track width, mm	1520
Design speed km/h.	120

Table 1.27 – Main technical characteristics of the 13-9004M model flat wagon

Parameter name	Value
Carrying capacity, i.e	40/54.5
Tare weight, i.e	24.5
The length of the flat along the clutch axes of auto clutches , mm	19620
Platform base, mm	14720
Dimensions	0-BM
The height of the clutch axis above the level of the rail heads, mm	1060 ± 20
Static load from the wheel pair on the rails, kN	230.5
Design speed, km/h.	120



Figure 1.64 - Platform wagon model 13-4012-09

The platform wagon model 13-4012-09 (Figure 1.64) is intended for the transportation of tank containers. On the frame of the platform wagon, two containers of standard size 1C, 1CC, 1CX or one container of standard size 1AA, 1A, 1AX can be placed at the same time.

The main technical characteristics of the platform wagon are given in table 1.28.

Table 1.28 – Main technical characteristics of the platform wagon models 13-4012-09

Parameter name	Value
Carrying capacity, i.e	72.0
Mass of the wagon, i.e	18,24
Calculated wheel load. steam on the rail, kN(ts)	221.1 (22.56)
The length of the wagon along the coupling axes of auto couplings, mm	14620
Platform base, mm	9720
Internal dimensions of the body	
- length, mm	13300
- width, mm	2770
Dimensions	0-BM
Height to the clutch axis from the level of the rail heads, mm	1060±20
Track width, mm	1520
Design speed km/h.	120

Specialized flatcar model 13-7024 (Figure 1.65) is designed for transportation of 40- and 20-foot universal large-capacity containers on the network of railways of Ukraine and CIS countries with a gauge of 1520 mm.



Figure 1.65 - Flat wagon model 13-7024

Brake - automatic pneumatic, manual parking. Running gear - two two-axle bogies of the model 18-100 type 2 or two two-axle bogies of the model 18-7055 type 2. Auto clutch CA - 3 automatic, non-rigid. Absorption apparatus of increased energy intensity of class not lower than T1. The main technical characteristics of the flat wagon are given in Table 1.29.

Table 1.29 - Main technical characteristics of the flat wagon model 13-7024

Parameter name	Meaning
Carrying capacity, t, not more than	71.2
Tare weight, t	22.3
The length of the wagon along the axes of the coupling of the couplings, mm	25 620
Wagon base, mm	18 500
Dimension	03-BM
Height from the level of rail heads to the axis of coupling of automatic couplings, mm	1060 ± 20
Design static load from wheelset on rails, kN (tf), not more than	230.5 (23.5)
Design speed, km/h.	120
Service life, years	32

The 13-4012-10 model platform wagon (Figure 1.66) with fixed equipment is designed for the transportation of cast slabs. The design of the wagon was developed taking into account the convenience of carrying out loading and unloading operations, the compactness of cargo placement and the maximum use of the carrying capacity of the platform wagon. The original solution used in the design of the support beams allows you to change the length of the cargo opening and obtain 12 options of fixed lengths for different sizes of cargo, ensuring its reliable fastening on the platform wagon without the use of temporary (one-time) fastening props.



Figure 1.66 - Platform wagon model 13-4012-10

The main technical characteristics of the platform wagon are given in table 1.30.

The platform wagon with removable equipment model 13-4012-11 (Figure 1.67) is intended for the transportation of rolled steel. The wagon is developed on the basis of the universal model 13-4012 platform wagon and is a specialized vehicle for the transportation of rolled steel on the network of main railways with a gauge of 1520 mm.

Table 1.30 - Main technical characteristics of the platform wagon model 13-4012-10

Parameter name	Value
Carrying capacity, i.e	68.0
Mass of the wagon, i.e	26.0
Calculated wheel load. steam on the rail, kN(ts)	230.0 (23.5)
The length of the wagon along the coupling axes of auto couplings, mm	14620
Platform base, mm	9720
Internal dimensions of the body	
- length, mm	13300
- width, mm	2770
Dimensions	0-BM
Height to the clutch axis from the level of the rail heads, mm	1060±20
Track width, mm	1520
Design speed km/h.	120

The design was developed taking into account the convenience of carrying out loading and unloading operations, the compactness of the placement of cargo on the frame of the platform wagon and the maximum use of the carrying capacity of the wagon. Detachable equipment ensures reliable fastening of the load without the use of temporary (disposable) fasteners and allows the transportation of rolled steel of the following sizes: length from 3000 to 12700 mm; width from 1500 to 2500 mm; thickness from 8 to 30 mm.



Figure 1.67 - Platform wagon model 13-4012-11

The main technical characteristics of the platform wagon are given in table 1.31.

The specialized flat car model 13-7031 (Figure 1.68) is designed for transportation of packaged artificial cargo, wheeled equipment, as well as 40- and 20-foot universal high- tonnage containers .

Table 1.31 – Main technical characteristics of the platform wagon model 13-4012-11

Parameter name	Value
Carrying capacity, i.e	68.0
Mass of the wagon, i.e	26.0
Calculated wheel load. steam on the rail, kN(ts)	230.0 (23.5)
The length of the wagon along the coupling axes of auto couplings, mm	14620
Platform base, mm	9720
Internal dimensions of the body	
- length, mm	13300
- width, mm	2770
Dimensions	0-BM
Height to the clutch axis from the level of the rail heads, mm	1060±20
Track width, mm	1520
Design speed km/h.	120

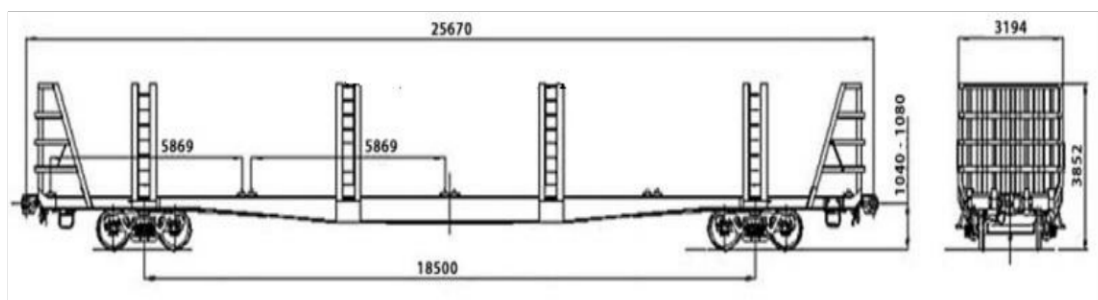


Figure 1.68 – Vagon-platform model 13-7031

Brake - automatic pneumatic, manual parking Running gear - two two-axle trolleys model 18-100 type 2 or two two-axle trolleys model 18 - 7055 type 2.

Autoclutch SA - 3 automatic, non-rigid. Absorption device of increased energy intensity class T1 or T2. The main technical characteristics of the flat car are given in table 1.32.

Table 1.32 – Main technical characteristics of the 13-9004M model flat wagon

Parameter name	Value
Carrying capacity, i.e	63.8
Mass of the wagon, i.e	30.2
Calculated load from the wheel pair on the rail, kN (ts)	23.5 (230.5)
The length of the wagon along the coupling axes of the auto clutches , mm	25670
Platform base, mm	18500
Dimensions: body carts	1-VM 02-VM
Height to the clutch axis from the level of the rail heads, mm	1060±20
Track width, mm	1520
Design speed, km/h.	120
Service life, years	32

The platform wagon model 13-H451 (Figure 1.69) is designed for the transportation of wheeled and tracked machinery, artificial and other cargoes that do not require protection from atmospheric precipitation. The platform wagon is equipped with metal folding sides: longitudinal – 8, transverse – 2. The model uses a frame from the serial model of the universal platform wagon.



Figure 1.69 - Platform wagon model 13-H451

The main technical characteristics of the platform wagon are given in table 1.33.

Table 1.33 - Main technical characteristics of the platform wagon model 13-H451

Parameter name	Value
Carrying capacity, i.e	63.0
Mass of the wagon, i.e	21.3
Calculated wheel load. pairs on the rail, kN	206.78
The length of the wagon along the coupling axes of auto couplings, mm	14620
Platform base, mm	9720
Internal dimensions of the body	
- length, mm	13300
- width, mm	2770
Dimensions	0-BM
Height to the clutch axis from the level of the rail heads, mm	1060±20
Track width, mm	1520
Design speed km/h.	120

The flat wagon model 13-785 (Figure 1.70) is designed for transportation of packaged piece cargoes, various types of metals in the form of plates and profiles, universal large-tonnage containers (three containers 20 feet long or one 40 feet long and one 20 feet long), wheeled equipment and other cargoes that do not require protection from atmospheric precipitation.

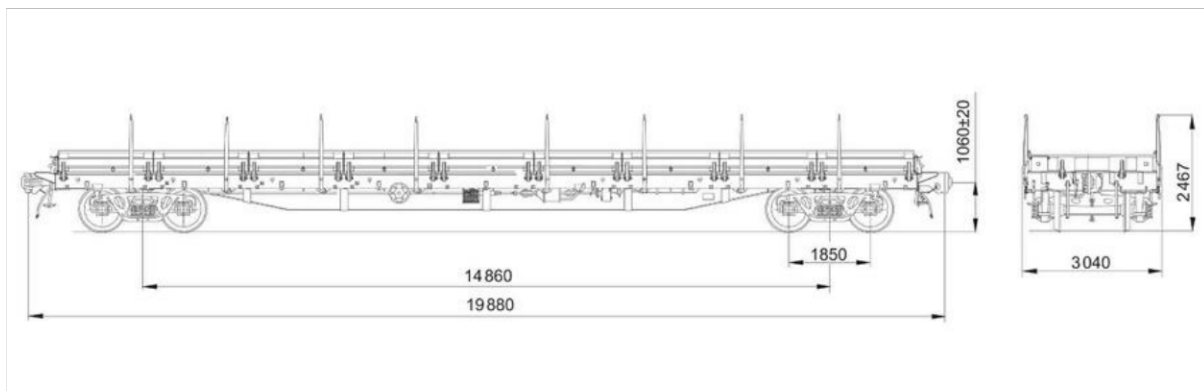


Figure 1.70 - Flat wagon model 13-785

It is equipped with two ends and eighteen longitudinal tilting sides, swivel racks for securing cargo. The design of the wagon allows for mechanical loading and unloading using cranes and forklifts. For the convenience of performing such works, the sides of the wagon can be tilted: longitudinal with a 180° turn, and end - 90°. Brakes - automatic pneumatic, manual parking. Running gear - two two-axle bogies of model 18-100 type 2 for 1435 mm gauge or two two-axle bogies of model 18-7055 type 2. Auto clutch CA - 3 automatic, non-rigid. Absorbing apparatus of increased energy intensity of class not lower than T1.

The main technical characteristics of the flatcar are given in Table 1.34.

Table 1.34 - Main technical characteristics of the flat wagon model 13-785

Parameter name	Meaning
Carrying capacity, t, not more than	64.0
Tare weight, t	26.0±2%
Length of the platform along the axes of the coupling of the couplings, mm	19880
Wagon base, mm	14860
Size: bodies carts	IIRR(RAI) 02-BM
Height from the level of rail heads to the axis of coupling of automatic couplings, mm	1060 ± 20
Cargo characteristics of the floor: area, m length, mm width, mm	49 18520 2670
Design static load from wheelset on rails, kN (tf), not more than	220.7(22.5)
Height from the level of rail heads to the axis of coupling of automatic couplings, mm	1060 ± 20
Design speed, km/h.	120

The 13-926 model platform wagon is designed for the transportation of wheeled and tracked machinery, artificial and other cargoes that do not require protection from atmospheric precipitation (Figure 1.71).



Figure 1.71 - Platform wagon model 13-926

The main technical characteristics of the platform wagon are given in table 1.35.

The frame of the platform wagon is a welded structure with a backbone beam, equipped with rear and front supports. The wagon has a combined floor covering, 12 longitudinal and 2 transverse sides. The sides are hinged to the frame and held by wedge-shaped locks in the raised (closed) position. In the lowered position, the longitudinal sides are below the floor level. The end sides are equipped with torsion bars, which keep them in a raised position above the support brackets and ensure the rolling of rolling loads and wheeled equipment along the train.

Table 1.35 – The main technical characteristics of the platform wagon model 13-926

Parameter name	Value
Carrying capacity, i.e	71.0
Mass of the wagon, i.e	23.0
Calculated wheel load. steam on the rail, kN(ts)	230.0 (23.5)
The length of the wagon along the coupling axes of auto couplings, mm	19620
Platform base, mm	14400
Body dimensions	
- length, mm	18400
- width, mm	2930
Dimensions	1-BM
Height to the clutch axis from the level of the rail heads, mm	1060±20
Track width, mm	1520
Design speed km/h.	120

The flat car model 13-9744 is designed for transportation of heavy containers, long cargoes, packages of sheet metal and lumber (Figure 1.72). Two end walls, four stationary side racks , eight timber supports, eight removable side racks are attached to the supporting structure of the flat carframe , and stops for fittings are also installed.

The main ones technical characteristics of the flat car are given in the table 1.36.



Figure 1.72 - Flat wagon model 13-9744

The 13-935 model platform wagon is designed for the transportation of tracked and wheeled equipment, as well as large-tonnage containers (Figure 1.73). The wagon is equipped with end boards, hinged fitting stops, a wooden floor with a metal strip (575 mm).

Table 1.36 – Main technical characteristics of the flat car model 13-9744

Parameter name	Value
Tara, t	24
Carrying capacity, i.e	70
Axle load, t/ axle	23.5
Wagon base, mm	9720
The length of the wagon along the axles of the couplings, mm	14620
Dimensions	1-T
Height from the level of the top of the rail heads to the upper planes of the shelves of the longitudinal beams of the frame, mm	1240
Width along the side beams of the frame, mm	3100
Height of end walls, mm	2890
Height of longitudinal racks , mm	2640
The number of hinged fitting stops	8
Design speed, km / h.	120



Figure 1.73 - Platform wagon model 13-935

The main technical characteristics are presented in table 1.37.

Table 1.37 – The main technical characteristics of the 13-935 model platform wagon

Parameter name	Value
Carrying capacity, i.e	73.0
Mass of the wagon, i.e	27.0
Calculated wheel load. pairs on the rail, kN	245.0
The length of the wagon along the coupling axes of auto couplings, mm	19620
Platform base, mm	14400
Body dimensions	
- length, mm	18300
- width, mm	2950
Dimensions	1-BM
Height to the clutch axis from the level of the rail heads, mm	1060±20
Track width, mm	1520
Design speed km/h.	120

Thrall _ Wagon " developed and tested prototypes of the " EuroSpine " sectional wagon (Figure 1.74), which is an articulated platform (maximum of 5 units) on standard trolleys. Such wagons can transport both counter-trailers and containers. The wheels of the semi-trailer installed on the platform are located in the pockets at a height 330 mm from the level of the rail head, which ensures the full height of the wagon with a trailer when the air suspension is lowered no more than 4,13 m.



Figure 1.74 - Flat wagon "EuroSpine" of the company " Thrall Wagons »

Platform wagons with a lowered loading platform are used for the transportation of road trains under the "RoLa" system (Figure 1.75).



Figure 1.75 – A flat wagon with a lowered loading platform for the transportation of road trains according to the "RoLa" system

Model 13-785 platform wagon (Figure 1.76) is designed to transport packaged artificial cargo, various types of metal in the form of plates and profiles, universal heavy-duty containers (three 20-foot containers or one 40-

foot container and one 20-foot container) and other cargo , which do not require protection from atmospheric precipitation.



Figure 1.76 - Platform wagon model 13-785

The main technical characteristics are presented in table 1.38.

The wagon is equipped with 2 end and 18 longitudinal folding sides, swivel racks for securing cargo. The design of the wagon allows for mechanical loading and unloading using lifting cranes and loaders. For the convenience of carrying out such work, the sides of the wagon can be folded: longitudinal ones with a 180° turn, and end ones - by 90°. Brake - automatic pneumatic, manual brake. The chassis is two two-axle carts of mods. 18-100 type 2 for a track of 1435 mm. The wagon's harness is equipped with a T1 class absorbing device.

At present, the use of flat wagons for contrarail transportation has become relevant.

Mixed transportation advantageously combines the two dominant types of land transport - road and rail - in a single transport chain. In this way, high mobility and speed of cargo delivery is ensured - thanks to road transport, and high productivity, economy and environmental cleanliness - thanks to railway transport. Simultaneously with the introduction into the regular operation of

counter-trailer trains composed of modernized platform wagons, the development of fundamentally new types of rolling stock for the railways of the CIS countries was started.

Table 1.38 - The main technical characteristics of the platform wagon model 13-785

Parameter name	Value
Carrying capacity, i.e	68.0
Mass of the wagon, i.e	26.0
Calculated wheel load. steam on the rail, kN(ts)	230.5 (23.5)
The length of the wagon along the coupling axes of auto couplings, mm	19880
Platform base, mm	14860
Body dimensions	
- length, mm	18520
- width, mm	2670
Dimensions	IIRR (RAI)
Height to the clutch axis from the level of the rail heads, mm	1060±20
Track width, mm	1520
Design speed km/h.	120

By definition, trailer transportation is combined transportation (Figure 1.77), which is mainly carried out by road and rail transport . Motor vehicles - road trains and semi-trailers (contra-trailers) act as cargo units of semi-trailer transportation. The essence of the trailer transportation technology is the integration of road and rail vehicles into a single transport system.



Figure 1.77 - Trailer transportation

During the formation of a fleet of wagons for cross-trailer transportation by railways of Ukraine, the concept of maximum use of the existing technical base of railway transport was adopted at the first stage. In order to solve the priority tasks of carrying out contrail transportation, the option of creating a specialized rolling stock by modernizing platforms from the operating fleet was chosen as the most effective.

Several types of counter-trailer trains are widely used in the USA. For example, the "Trailer-Train" train (Figure 1.78) consists of four-axle platforms. The advantages of this train are a low loading platform and a reduced cargo mass compared to a train made up of autonomous platforms.. Train "Santa Fe" contains articulated sections that include 10 platforms. The fastening system allows the installation of trailers of any size using almost the entire length of the train. Wagons of the train "Iron Highway" form a single loading platform with a length of approx 715 m.

Such a platform, subject to additional equipment with fastening devices, can also be used for transporting containers. In the countries of Western Europe, the transportation technology of counter-trailers according to the "Kangaroo" system on platforms that have a deep loading platform in the intercar space, on which the wheels of semi-trailers are located, has become widespread.



Figure 1.78 - "Trailer-Train" train for counter-trailer transportation

During the transportation of containers, removable beams are installed on the frame so that the fastening devices are located on top. When transporting counter-trailers, the beams are located along the frame, in its lower part. The technical parameters are as follows: tare - 28 tons, base - 19 m, frame length - 24,5 m, length behind buffers - 25,74 m. In the middle part of the long platform wagon, 12,4 m10 removable fastening beams are installed. On one side, the removable beams have devices for fastening containers, and on the other side - support grooved surfaces for the installation of wheeled counter-trailers. The four-axle platform of the German Railways with a carrying capacity of 52 tons is intended for the transportation of counter-trailers and containers.

The platform is equipped with movable stops for fixing semi-trailers. Axle articulated platform wagon, which is manufactured by the company "Talbot" for the transportation of containers and semi-trailers, consists of two sections connected by a through harness. When loading, the buffer bars are lowered using a hydraulic mobile ramp.

1.4 Design features of tank wagons

Tank wagons are designed for the transportation of liquid, gaseous and dusty cargoes. The significant variety of transported goods has led to significant changes in the designs of tank wagons, and therefore the latter can be classified as:

- general purpose - for the transportation of a wide range of petroleum products;
- special purpose - for the transportation of certain types of cargo.

Today, a large percentage of general-purpose tank wagons are in circulation (Figure 1.79). Therefore, let's consider their construction.



Figure 1.79 – Tank wagon model 15-1443-06 for transportation of light petroleum products

A four-axle tank wagon with a carrying capacity of 60 tons has a boiler with a capacity of 71.7 m³ and a total of 71.3 m³. The internal diameter of the boiler is equal 3000 mm. The thickness of the armored sheet is 11 mm, upper and side -9 mm, bottom -10 mm. All sheets and bottoms are connected by butt seams. The container of the tank wagon is 23.2 tons.

The frame has lightened end and side beams, the latter being left only in the cantilevered parts of the frame. There are also no intermediate transverse beams.

Fixing of the boiler to the frame is carried out in its middle and end parts. Shaped legs are welded to the middle part of the armor sheet, connected by bolts, sharpened to the holes, with support bars, which are welded to the backbone beam of the frame.

At the ends, the boiler rests on wooden bars fixed by means of gutters, bolts with nuts and diaphragms on the pivot and spine beams of the frame.

The boiler is attached to the extreme supports by tension clamps designed to prevent its vertical and lateral movement relative to the frame. The length of the tension clamps is regulated by screw couplings.

The tank wagon is equipped with external breakers with platforms in the cap, a universal drain device and a safety inlet valve. To ensure complete draining of the cargo, the armored sheet is curved so that it has a slope to the draining device.

The four-axle tank with a carrying capacity of 60 tons of the construction of the Mariupol plant, model 15-1443 (Figure 1.80) has a boiler with a useful capacity of 71.7 m³, a total capacity of 73.1 m³ and an internal diameter of 3.0 m.

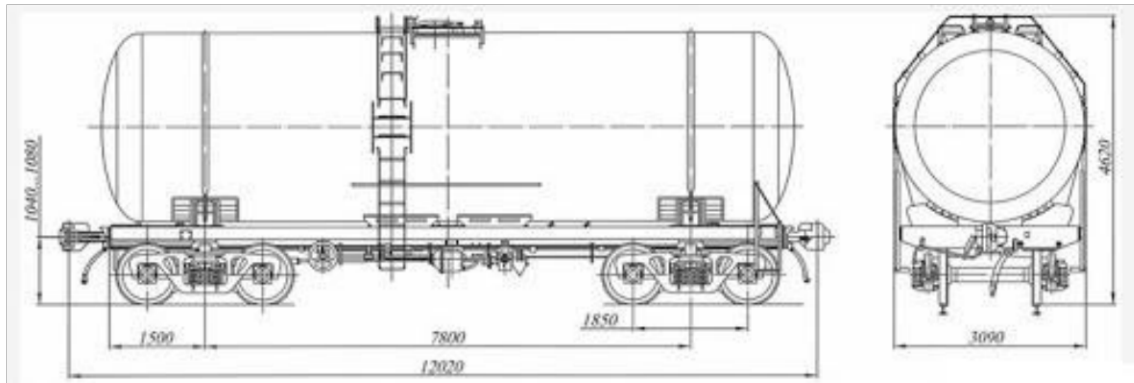


Figure 1.80 - Tank wagon model 15-1443

The boiler is attached to the frame in its middle and end parts. The boiler is attached to the extreme supports by tension clamps designed to prevent its vertical and transverse movements relative to the frame.

A feature of the tank frame design of the model 15-1443 is the absence of side longitudinal beams, the presence of powerful end beams and lightweight longitudinal side beams only at the ends of the frame. There are also no intermediate transverse beams. As a result, the tare mass of the tank decreased by 1.4 tons. With this design, the forces acting on the tank are absorbed by the boiler, the stiffness of which is much higher than the stiffness of the longitudinal side beams, and then transmitted to the trolleys through its extreme supports.

In recent years, 4-axle tanks with an increased base (7.8 m instead of 7.12 m) and shortened consoles (1.5 m instead of 1.84 m) have been built at the Mariupol Wagon Building Works, which improves the dynamic qualities of the tank, especially in horizontal plane, and increase the safety of the movement of freight trains, in which there are such tank wagons.

For the transportation of gasoline, a 4-axle tank with a specific boiler volume of $1.4 \text{ m}^3 / \text{t}$ is designed, inscribed in the 02-VM dimensions, which allows it to be operated on foreign railways with a track width of 1435 mm. The

carrying capacity of such a tank is 62 t, the tare weight is 25.3 t, the axial load is 216 kN, the running load is 64 kN / m.

A modern representative of tank wagons is the tank model 15-7076 (Figure 1.81) built by the Kryukovsky Wagon Building Plant. The tank wagon is designed for the transportation of petroleum products along the entire railway network with a track width of 1520 mm. The tank wagon has a frame of reinforced construction and a boiler of increased strength. The tank's resistance to climatic influences meets the requirements of GOST 15150, ensuring operational reliability at the lowest operating air temperature from -60 to +50 °C. The brake is automatic pneumatic with separate trolley braking and parking brake. The chassis is two two-axle carts of mods. 18-7055 type 2 GOST 9246 (an analogue of the cart mod. 18-100). Self-clutch CA-3. Absorbent apparatus of class T2.



Figure 1.81 – Tank wagon model 15-7076

Table 1.39 Technical characteristics of the modern tank wagon model 15-7076

Carrying capacity, no more, i.e	67.3
The volume of the boiler is full (useful), m ³	85.56 (83.91)
Tare weight, no more, t	26.7
Calculated static load from the wheel pair on the rails, kN	230.5 (23.5)
The length of the wagon along the axles of the couplings, mm	12020
Dimensions according to GOST 9238	1-VM
Height to the clutch axis from the level of the rail heads, mm	1060±20
Cart	<u>18-7055</u>
Track width, mm	1520
Mileage between repairs, years (thousand km)	3 (210)
Design speed, km/h	120

1.5 Design features of hopper wagons for transportation of hot pellets and sinter

One of the most common types of vehicles used to transport high-temperature cargoes by railway is hopper wagons.

Currently, there are a large number of designs of hopper wagons for the transportation of pellets and hot sinter. Let us consider the design features of this type of wagon on the example of the model 20-471.

Specialized hopper gondola wagon model 20-471 (Figures 1.82) is designed for the transportation of hot pellets and sinter with a cargo temperature of up to 700°C from production sites to the receiving hoppers of the blast furnace [2].



Figure 1.82 - Specialized hopper gondola wagon model 20-471

The body of the hopper gondola wagon has the frame 4, two vertical sides 2, two end walls 1 with an angle of 41 ° to the plane of the frame and two hoppers with two unloading hatches 3 size 3500x400x560 mm (Figure 1.83). The body frame consists of a ridge beam, two end, pivot and transverse beams.

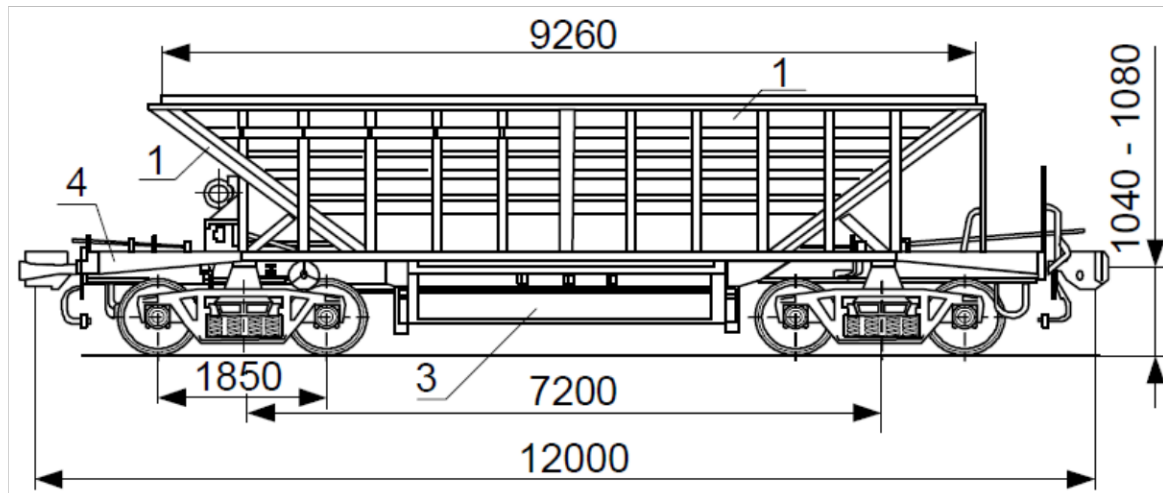


Figure 1.83 - Specialized gondola wagon for transportation of hot pellets and sinter

The main technical characteristics of the wagon are given in table 1.40 [8].

The ridge beam is made of two I-beams No 45, covered with sheets at the top and bottom. End, pivot and cross beams are welded respectively trough-shaped, box and I-beam sections.

The frame of the side wall is made of rolled and bent profiles: the upper belt of box section is made of channel No 14 and bent element, the lower belt and pivot rack - of closed rectangular profile of 160x80x7 mm box section. The lower and upper belts are interconnected with twelve racks. Intermediate racks are made of the channel No14. The end wall frame is welded using the channels No 10 and No 14. The wall cladding is a set of bent profile panels that do not have a rigid connection with the frame, which ensures their mobility during thermal expansions to prevent warping of the load-bearing elements of the body.

Table 1.40 - The main technical characteristics of the hopper model 20-471

Name of parameter	Value
Load capacity, not more than, t	65.0
Body volume, m ³	42.0
Wagon weight, t	23.7
Estimated load from the wheelset on the rails, kN (ts)	215.6
Wagone base, mm	7200
Length of the wagon on axes of autocouplings, mm	12000
Dimensions by the GOST	1-BM
Height to the coupling axis from the level of the rail heads, mm	1040 – 1080
Number of hatches: - for loading - for unloading	- 1
Design speed, km / h	120
Inter-repair mealage, km	210000
Service life, years	15

The covers of the hopper unloading hatches are opened and closed by means of a special unloading mechanism (Figure 1.84), which is located under the hoppers and is a system of levers actuated by pneumatic cylinders with remote control. The hatch cover has a frame design which is sheathed with goffer sheets.

A visor is welded to the lower belt, which in the closed position is under the lower strapping of the body, thus creating a reliable seal against spills of pellets. From the ends of the cover seal is created by protruding sheets, which

are placed in the grooves of the hatches in closed position. The unloading mechanism has a system of levers 2, 5, 6 connecting the hatch covers 1 with the shaft 7, which by means of a gear pair 3 under the action of two pneumatic cylinders 4 rotates to a certain angle, opening or closing the unloading hatch covers. The covers are closed due to the passage of the levers connecting them through the "dead point".

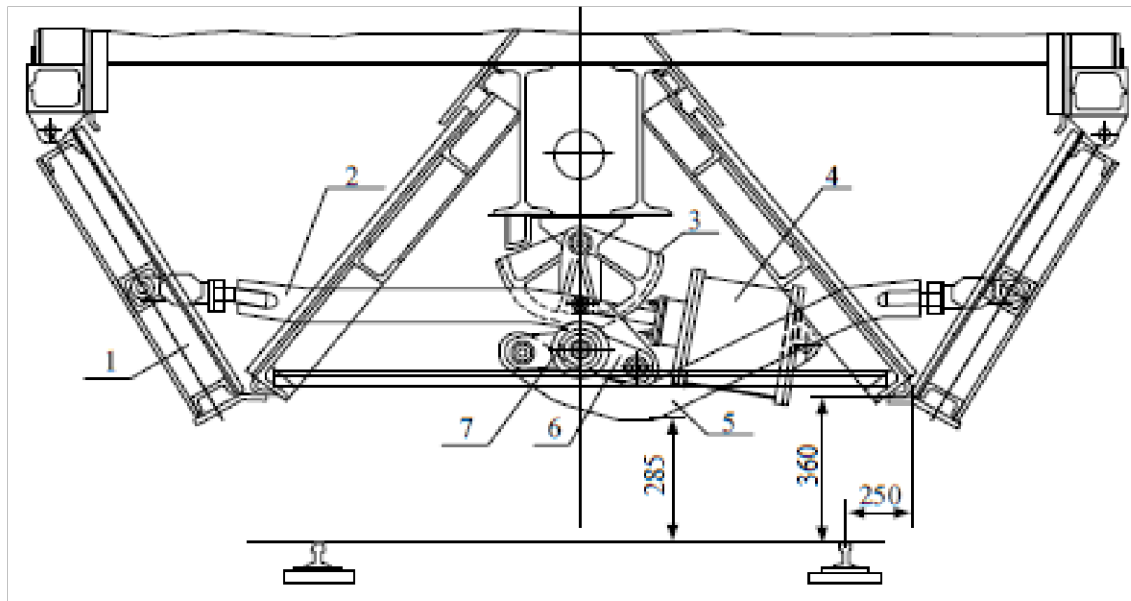


Figure 1.84 – The wagon unloading mechanism

The size of the opening of the hatch covers can be adjusted from 300 to 570 mm by setting the sector to different heights. All bearing elements of a body are made of low-alloy steel 09G2D.

Hopper wagon model 20-7032 (Figure 1.85) is designed for transportation of 1520 mm hot pellets and sinter by railway with a temperature not exceeding 700°C, as well as for their mechanical unloading. Unloading is carried out on both sides of the railway gauge through unloading hatches in special unloading devices. Brake is the automatic pneumatic, manual brake. Chassis is two two-axle carts model 18-7055 type 2 (GOST 9246-2013 / DSTU 7530-2014).

Autocoupling CA - 3. The wagon is equipped with an absorber of high energy consumption class T1 [3].



Figure 1.85 - Hopper wagon model 20-7032

The main technical characteristics of the wagon are given in the table 1.41.

The hopper wagon model 20-480 was serially launched since 1982 till 1986 by the PJSC “Dniprovagonmash” (Figure 1.86). It is designed to transport hot pellets and sinter, as well as other cargoes that do not require protection from precipitation.

Table 1.41 - The main technical characteristics of the hopper wagon model 20-7032

Name of parameter	Value
Load capacity, not more than, t	70.5
Body volume, m ³	45.0
Wagon weight, t	-
Estimated load from the wheelset on the rails, kN (ts)	23.5
Wagone base, mm	230.3 (23.5)
Length of the wagon on axes of autocouplings, mm	7 780
Dimensions by the GOST	12 000
Height to the coupling axis from the level of the rail heads, mm	1-BM
Number of hatches: - for loading - for unloading	1060±20
Design speed, km / h	- 2
Inter-repair mealage, km	120
Life time, years	210 000
Load capacity, not more than, t	15



Figure 1.86 - Hopper wagon model 20-480

The main technical characteristics of the wagon are given in the table 1.42.

Hopper wagon model 20-4015 is designed for transportation of pellets and sinter by main railway gauges of 1520 mm and gauges of industrial enterprises [5]. The wagon was built by the PJSC "Dniprovaonmash" (Figure 1.87).

Table 1.42 - The main technical characteristics of the hopper model 20-480

Name of parameter	Value
Load capacity, not more than, t	71.0
Body volume, m ³	42.0
Wagon weight, t	22.0
Estimated load from the wheelset on the rails, kN (ts)	228.0
Wagone base, mm	5870
Length of the wagon on axes of autocouplings, mm	10000
Dimensions by the GOST	1-BM
Height to the coupling axis from the level of the rail heads, mm	1040 – 1080
Number of hatches:	
- for loading	-
- for unloading	2
Design speed, km / h	120
Inter-repair mealage, km	210 000
Service life, years	15



Figure 1.87 - Hopper wagon model 20-4015

The design of the wagon provides mechanized loading through an open body and automated unloading on receiving devices (into the hoppers, on trestles). Non-rigid (floating) fastening of body panels allows to do loading of cargoes with a temperature of up to 700°C. The wagon is equipped with an unloading mechanism with pneumatic drive and automatic locking, which provides a reliable closure of the hatch covers, full unloading and automation of the unloading process. Angles of inclination of end walls provide effective dumping of the unloaded cargo. The wagon can be used to transport goods that do not require protection from the weather.

The main technical characteristics of the wagon are given in table 1.43.

Table 1.43 - The main technical characteristics of the hopper wagon model 20-4015

Name of parameter	Value
Load capacity, not more than, t	70.0
Body volume, m ³	45.0
Wagon weight, t	24.0
Estimated load from the wheelset on the rails, kN (ts)	230.5
Wagone base, mm	7780
Length of the wagon on axes of autocouplings, mm	12000
Dimensions by the GOST	1-BM
Height to the coupling axis from the level of the rail heads, mm	1040 – 1080
Number of hatches:	
- for loading	-
- for unloading	2
Design speed, km / h	120
Inter-repair mealage, km	210 000
Service life, years	15

Hopper wagon model 20-4015-01 is a modification of model 20-4015-01 (Figure 1.88) [6].

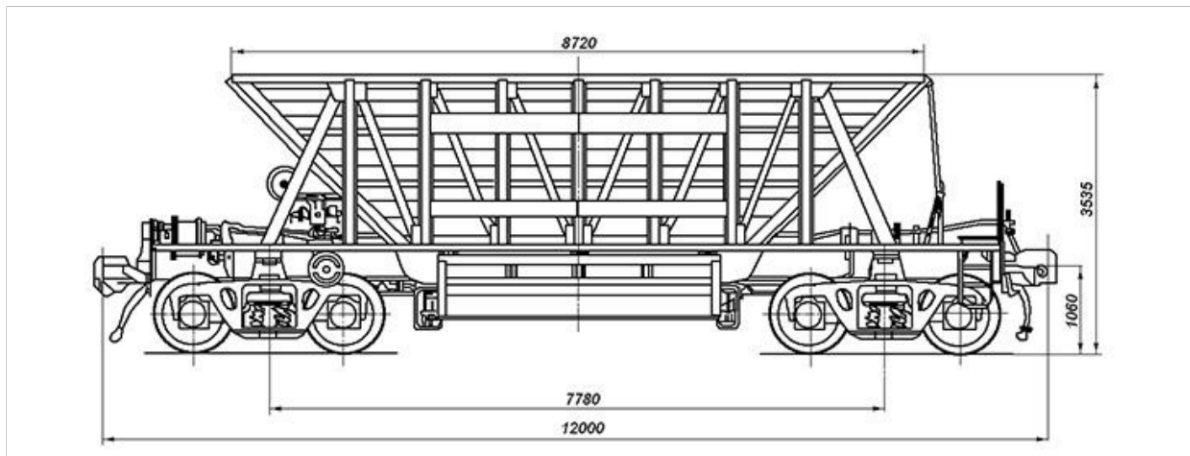


Figure 1.88 - Hopper wagon model 20-4015-01

The main technical characteristics of the wagon are given in the table 1.44.

The branch of Panyutyn Wagon Repair Plant of the JSC Ukrzaliznytsia has produced the hopper wagon model 20-9749 (Figure 1.89). The wagon has four unloading hatches with unloading on both sides [7].

Table 1.44 - The main technical characteristics of the hopper wagon model 20-4015-01

Name of parameter	Value
Load capacity, not more than, t	71.0
Body volume, m ³	44.0
Wagon weight, t	23.0
Estimated load from the wheelset on the rails, kN (ts)	230.5
Wagone base, mm	7780
Length of the wagon on axes of autocouplings, mm	12000
Dimensions by the GOST	1-BM
Height to the coupling axis from the level of the rail heads, mm	1060
Number of hatches: - for loading - for unloading	- 2
Design speed, km / h	120



Figure 1.89 - Hopper wagon model 20-9749

The main technical characteristics of the wagon are given in the table 1.45.

Table 1.45 - The main technical characteristics of the hopper wagon model 20-9749

Name of parameter	Value
Load capacity, not more than, t	69.0
Body volume, m ³	45.0
Wagon weight, t	25.0
Estimated load from the wheelset on the rails, kN (ts)	235.0
Wagone base, mm	7780
Length of the wagon on axes of autocouplings, mm	12000
Dimensions by the GOST	1-BM
Height to the coupling axis from the level of the rail heads, mm	1040 – 1080
Number of hatches: - for loading - for unloading	- 4
Design speed, km / h	120
Inter-repair mealage, km	210 000
Service life, years	15

Hopper wagon model 19-9982, manufactured by the State Machinery Plant "Karpaty", designed for reliable transportation of pellets or sinters with a temperature not exceeding 700°C, and other bulk and small loads that do not require protection from precipitation on public roads and industrial enterprises (Figure 1.90) [9].

Production of hopper wagons meets the requirements of the TU U30.2-37958251-005-2013, certified in the system UkrSEPRO UA 1.098.0011424-13 and meets the requirements of the DSTU ISO 9001: 2009.



Figure 1.90 - Hopper wagon model 19-9982

The main technical characteristics of the wagon are given in the table 1.46.

Hopper wagon model 20-793 is designed for transportation and mechanized unloading of hot pellets and sinter on main and industrial railway gauges with a width of 1520 mm (Figure 1.91) [10].

Table 1.46 - The main technical characteristics of the hopper model 19-9982

Name of parameter	Value
Load capacity, not more than, t	71.0
Body volume, m ³	45.0
Wagon weight, t	23.0
Estimated load from the wheelset on the rails, kN (ts)	230.5
Wagone base, mm	7800
Length of the wagon on axes of autocouplings, mm	12000
Dimensions by the GOST	1-BM
Height to the coupling axis from the level of the rail heads, mm	1060
Number of hatches: - for loading - for unloading	- 4
Design speed, km / h	120

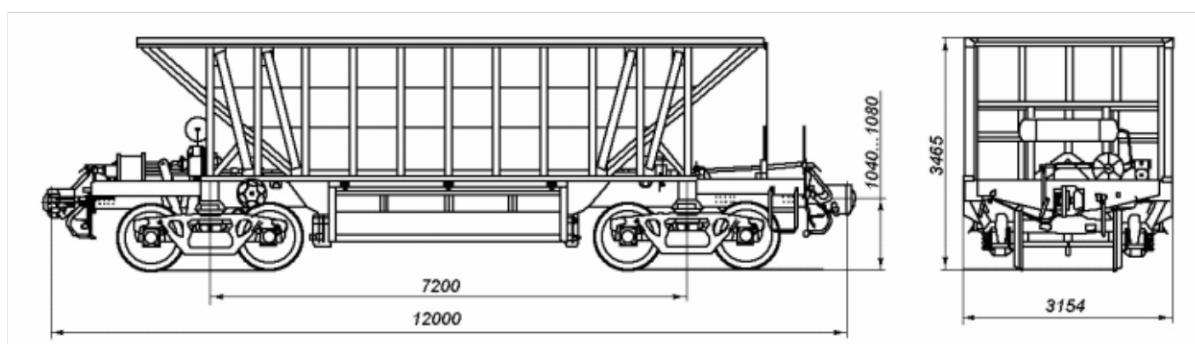


Figure 1.91 - Hopper wagon model 20-793

The main technical characteristics of the wagon are given in the table 1.47.

Table 1.47 - The main technical characteristics of the hopper wagon model 20-793

Name of parameter	Value
Load capacity, not more than, t	70.0
Body volume, m ³	42.0
Wagon weight, t	23±3%
Estimated load from the wheelset on the rails, kN (ts)	228.0
Wagone base, mm	7200
Length of the wagon on axes of autocouplings, mm	12000
Dimensions by the GOST	1-BM
Height to the coupling axis from the level of the rail heads, mm	1040 – 1080
Number of hatches:	
- for loading	-
- for unloading	2
Design speed, km / h	120

Four-axle gondola wagon model 20-9839 (Figure 1.92), designed for transportation bulk cargoes on main railway gauges with a rail gauge width of 1520 mm that requires shelter from precipitation, including hot pellets [19].

The gondola has an all-metal body with a volume of 45 m³, capable of withstanding loads up to 71 tons. The wagon is equipped with two carts model 18-1750 type 2, the size of the wagon is according to the GOST 9238 - 1-VM. The wagon for cargo unloading is equipped with two unloading hatches each of which has the size 562x1596 mm.



Figure 1.92 - Hopper wagon model 20-9839

The main technical characteristics of the wagon are given in the table 1.48.

Hopper wagon model 20-5197 with heat-resistant body cladding is designed for transportation pellets and sinter by railway with a temperature of up to $+400^{\circ}\text{C}$ and their mechanized unloading (Figure 1.93). The wagon cladding is movable, which allows to compensate for thermal expansion. Compared to similar wagons, the pellet truck of Ural designers has a larger body volume (48 m^3) and load capacity (75.5 tons).

Table 1.48 - The main technical characteristics of the hopper wagon model 20-9839

Name of parameter	Value
Load capacity, not more than, t	71
Body volume, m ³	45
Wagon weight, t	23
Estimated load from the wheelset on the rails, kN (ts)	230,5
Wagone base, mm	7780±5
Length of the wagon on axes of autocouplings, mm	12000±20
Dimensions by the GOST	1-BM
Height to the coupling axis from the level of the rail heads, mm	1060±20
Number of hatches:	
- for loading	-
- for unloading	2
Design speed, km / h	120

The hopper wagon is installed on innovative carts of the 18-194-1 model with the increased axial loading of 245 kN. The service life of the wagon has been increased from 15 to 24 years [31].



Figure 1.93 - Hopper wagon model 20-5197

The main technical characteristics of the wagon are given in the table 1.49.

through an open body and automated unloading on receiving devices (in hoppers, on trestles) [32].

Non-rigid (floating) fastening of body panels allows to do loading of freights with the temperature of up to 700°C. The wagon is equipped with an unloading mechanism with pneumatic drive and automatic locking, which provides a reliable closure of the hatch covers, full unloading and automation of the unloading process. Angles of inclination of end walls provide effective unloading of the cargo. The wagon can be used to transport cargoes that do not require protection from the weather.

Table 1.49 - The main technical characteristics of the hopper model 20-5197

Name of parameter	Value
Load capacity, not more than, t	75.5
Body volume, m ³	48.0
Wagon weight, t	24.0
Estimated load from the wheelset on the rails, kN (ts)	245.0
Wagone base, mm	6780
Length of the wagon on axes of autocouplings, mm	11000
Dimensions by the GOST	1-BM
Height to the coupling axis from the level of the rail heads, mm	1040 – 1080
Number of hatches:	
- for loading	-
- for unloading	2

The design of the hopper model 20-9916 provides mechanized loading

The main technical characteristics of the wagon are given in the table 1.50.

The hopper is roduced according to the TU U 30.2-05749336-004: 2012 "Wagons for pellets model 20-9916 and model 20-9916-01", developer and manufacturer is the PJSC "Verhniodniprovsk Machinery Construction Plant".

The hopper wagon model 20-9916-01 (Figure 1.94) is a modification of the hopper wagon 20-9916 [33].

Table 1.50 - The main technical characteristics of the hopper model 20-9916

Name of parameter	Value
Load capacity, not more than, t	71.0
Body volume, m ³	45.0
Wagon weight, t	23.0
Estimated load from the wheelset on the rails, kN (ts)	235
Wagone base, mm	7780
Length of the wagon on axes of autocouplings, mm	12000
Dimensions by the GOST	1-BM
Height to the coupling axis from the level of the rail heads, mm	1040 – 1080
Inter-repair mealage, km	210 000
Service life, years	15

The hopper is roduced according to the TU U 30.2-05749336-004: 2012 "Wagons for pellets model 20-9916 and model 20-9916-01", developer and manufacturer is the PJSC "Verhniodniprovsk Machinery Construction Plant".

The hopper wagon model 20-9916-01 (Figure 1.94) is a modification of the hopper wagon 20-9916 [33].



Figure 1.94 - Hopper wagon model 20-9916-01

The main technical characteristics of the wagon are given in the table 1.51.

The hopper model 19-9809 is designed for transportation of pellets and sinter by main railway gauges with a width of 1520 mm and railway gauges of industrial enterprises (Figure 1.95).

Table 1.51 - The main technical characteristics of the hopper model 20-5197

Name of parameter	Value
Load capacity, not more than, t	72.0
Body volume, m ³	45.0
Wagon weight, t	22.0
Estimated load from the wheelset on the rails, kN (ts)	235.0
Length of the wagon on axes of autocouplings, mm	10000
Dimensions by the GOST	1-BM
Height to the coupling axis from the level of the rail heads, mm	1040 – 1080
Inter-repair mealage, km	210000
Service life, years	15



Figure 1.95 - Hopper wagon model 19-9809

The main technical characteristics of the wagon are given in the table 1.52 [34].

Table 1.52 - The main technical characteristics of the hopper model 19-9809

Name of parameter	Value
Load capacity, not more than, t	70.0
Body volume, m ³	45.0
Wagon weight, t	24.0
Estimated load from the wheelset on the rails, kN (ts)	235.0
Wagone base, mm	7800
Length of the wagon on axes of autocouplings, mm	12020
Dimensions by the GOST	1-BM
Height to the coupling axis from the level of the rail heads, mm	120
Inter-repair mealage, km	210000
Service life, years	15

The wagon-hopper of model 19-1241 allows to transport practically all bulk types of cargoes (sinter, pellets, ores of ferrous and nonferrous metals, crushed stone, etc.), on the wagon small-sized brake elements are used that is much more compact, than on available analogs, it is applied a separate brake system and a reliable unloading system, reinforced visor and armor plates of the frame as the most burning parts of the body.

The main technical characteristics of the wagon are given in the table 1.53

Table 1.53 - The main technical characteristics of the hopper model 19-9809

Name of parameter	Value
Load capacity, not more than, t	69.0
Body volume, m ³	45.0
Wagon weight, t	24.0
Estimated load from the wheelset on the rails, kN (ts)	230.5
Wagone base, mm	7200
Length of the wagon on axes of autocouplings, mm	12000
Dimensions by the GOST	1-BM
Number of hatches:	
- for loading	-
- for unloading	2
Design speed, km / h	120
Inter-repair mealage, km	210000
Service life, years	15

It is important to say that the designs of hopper wagons are constantly being improved and updated. Therefore, the analysis of the designs of hopper wagons is applied to the existing wagon fleet.

SECTION 2

FEATURES OF CALCULATIONS OF CONCEPTUAL SOLUTIONS FOR MANUFACTURING NON-SOWING SYSTEMS CARGO WAGONS MADE OF COMPOSITES

The section presents features of calculations [6-16, 51-53, 68-88, 91, 141] of conceptual solutions for manufacturing non-sowing systems cargo wagons made of composites.

2.1 Wear in mechanisms and mechanical efficiency

Wear is the process of deterioration and detachment of material off the surface of a solid body manifesting in a gradual change in the size and form of a body. Wear decreases strength of details and accuracy of mechanisms, increases loads on bearings, leads to an increase in vibrations and noise.

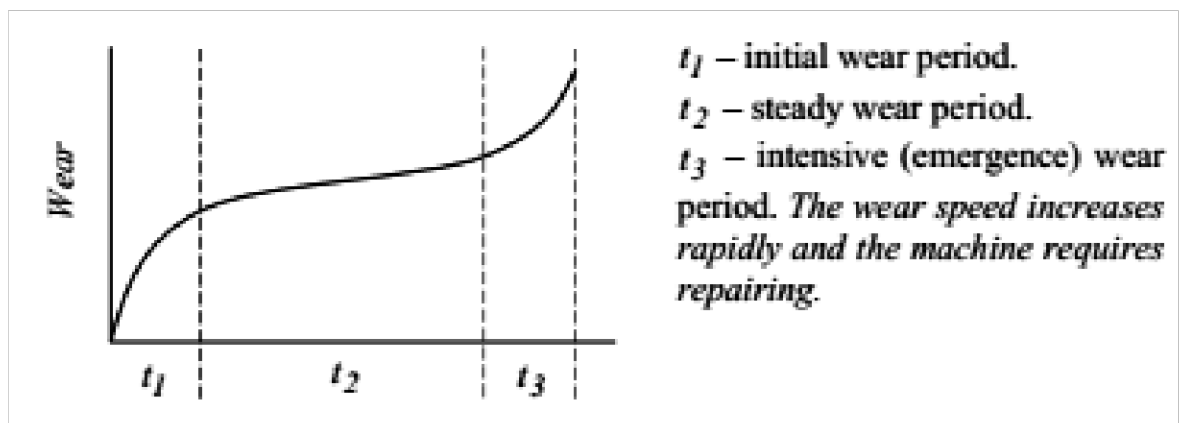


Figure 2.1 Wear curve

Types of wears:

1) Type I seizure. It occurs in rolling and sliding friction.

The basic cause is an actual load exceeding a permissible load.

Elastic deformations on the friction surface turning into plastic.

The top layer of material tears off and gets spread on the surface.

2) Type II seizure. It occurs in sliding friction.

The basic cause is high temperatures in the friction area.

The top layer of material tears off and gets spread on the surface.

3) Pitting wear. It occurs at rolling friction.

The basic cause is considerable specific loads changing by a cyclic law.

The particles of material tear off the surface of a detail where pits appear.

4) Abrasive wear. It occurs at sliding friction.

The basic cause is sand and dust into the contact area.

5) Oxidation wear.

It occurs in moist conditions.

Wear (measured in units of length, volume or mass) decreases the strength of details, changes the character of their mating, increases gaps in movable joints, and produces noise.

There exist:

- limiting wear – the wear corresponding to the limiting state of a product (or its part); and
- permissible wear – the wear at which a product keeps its workability.

Mechanical efficiency:

$$\eta = \frac{A_{n.c.}}{A_{d.c.}} < 1 \quad (2.1)$$

$$\eta = \frac{A_{\partial.c.} - A_{\partial.c.}}{A_{\partial.c.}} = 1 - \frac{A_{\partial.c.}}{A_{\partial.c.}} = 1 - \psi , \quad (2.2)$$

where ψ is the mechanical loss factor,

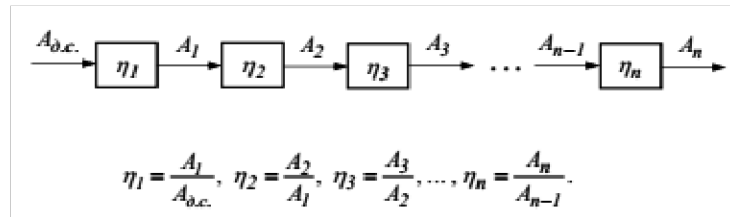
$$\psi = \frac{A_{\partial.c.}}{A_{\partial.c.}} , \quad (2.3)$$

$A_{\partial.c.}$ is the work of parasite resistance forces;

$A_{\partial.c.}$ is the work of moving forces;

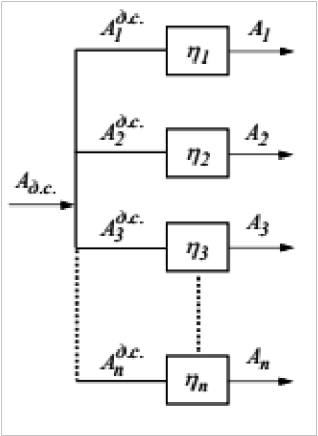
$A_{n.c.}$ is the work of useful resistance forces;

General efficiency of mechanisms connected in series



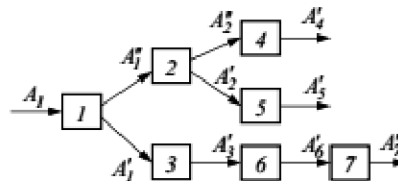
$$\eta_{\text{общ}}^{\text{носл}} = \eta_1 \cdot \eta_2 \cdot \eta_3 \cdot \dots \cdot \eta_n = \frac{A_n}{A_{\partial.c.}} \quad (2.4)$$

General efficiency of mechanisms connected in parallel

$$\eta_1 = \frac{A_1}{A_1^{\partial.c.}}, \quad \eta_2 = \frac{A_2}{A_2^{\partial.c.}}, \quad \eta_3 = \frac{A_3}{A_3^{\partial.c.}}, \quad \dots, \quad \eta_n = \frac{A_n}{A_n^{\partial.c.}} \quad (2.5)$$


$$\eta_{\text{общ}}^{\text{nap}} = \frac{A_{n.c.}}{A_{\partial.c.}} = \frac{\sum_{i=1}^n A_i}{\sum_{i=1}^n A_i^{\partial.c.}} = \frac{\sum_{i=1}^n A_i^{\partial.c.} \cdot \eta_i}{\sum_{i=1}^n A_i^{\partial.c.}} \quad (2.6)$$

$$\eta_{\text{общ}}^{\text{nap}} = \frac{A_1^{\partial.c.} \cdot \eta_1 + A_2^{\partial.c.} \cdot \eta_2 + A_3^{\partial.c.} \cdot \eta_3 + \dots + A_n^{\partial.c.} \cdot \eta_n}{A_1^{\partial.c.} + A_2^{\partial.c.} + A_3^{\partial.c.} + \dots + A_n^{\partial.c.}}, \quad (2.7)$$



When determining the general mechanical efficiency of complex engineering units the mechanical efficiencies of modules, as well as the character of their connection are considered.

For instance, for a combined connection of modules of engineering units, the general mechanical efficiency is defined as follows.

The efficiencies of modules 3-7 equal:

$$\eta_3 = \frac{A'_3}{A'_1}; \eta_4 = \frac{A'_4}{A'_2}; \eta_5 = \frac{A'_5}{A'_2}; \eta_6 = \frac{A'_6}{A'_3}; \eta_7 = \frac{A'_7}{A'_6}. \quad (2.8)$$

When modules are connected in parallel their total efficiency is determined as the product of efficiencies of these modules:

$$\eta_{3,6,7} = \frac{A'_7}{A'_1} = \frac{A'_3}{A'_1} \cdot \frac{A'_6}{A'_3} \cdot \frac{A'_7}{A'_6} = \eta_3 \cdot \eta_6 \cdot \eta_7. \quad (2.9)$$

When modules are connected in parallel the power flow is divided, and the total work is distributed by flows:

$$\eta_{4,5} = \eta_4 \cdot v_4 + \eta_5 \cdot v_5, \quad (2.10)$$

where v_4 and v_5 are the coefficients of distribution of the work by flows 4 and 5.

It should be mentioned that the sum of distribution coefficients for several modules connected in parallel is 1:

$$v_1 + v_2 + \dots + v_n = 1 \quad (2.11)$$

By applying the dependencies obtained, the equation for defining the overall mechanical efficiency of a compound engineering unit can be written:

$$\eta = \eta_1 \cdot [v_2 \cdot \eta_2 (v_4 \cdot \eta_4 + v_5 \cdot \eta_5) + v_3 \cdot \eta_3 \cdot \eta_6 \cdot \eta_7] \quad (2.12)$$

Strength is the capacity of a structure and its elements to bear certain loads without decay.

Rigidity is the capacity of a structure and its elements to resist deformation (change in form and size) under external loads.

Stability is the capacity of a structure and its elements to maintain a certain initial form of elastic equilibrium.

Basic forms of structural elements used in buildings and machines.

Bar (rod) is the body in which one size (length) considerably exceeds the other two (lateral) sizes. Bars are divided into: rectilinear, curvilinear, prismatic (of uniform and variable section) and thin-walled.

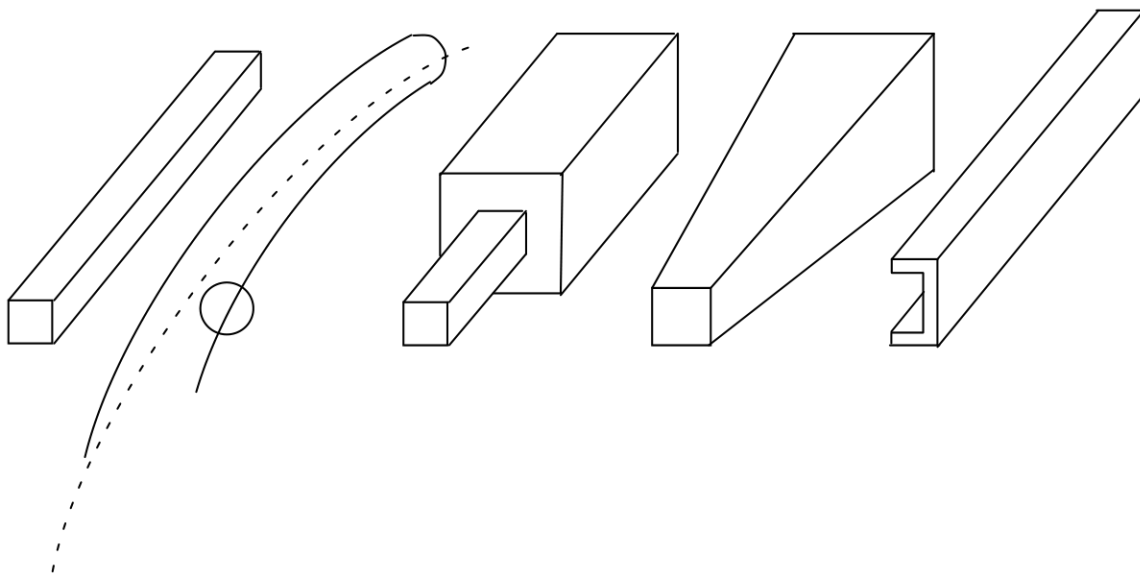


Figure 2.2

Shell is the body limited with curved surfaces located close to each other.

The surface dividing the shell-wall thickness into equal parts is called the midline.

By form of the middle surface there are cylinder, conical, spherical and toroidal shells.

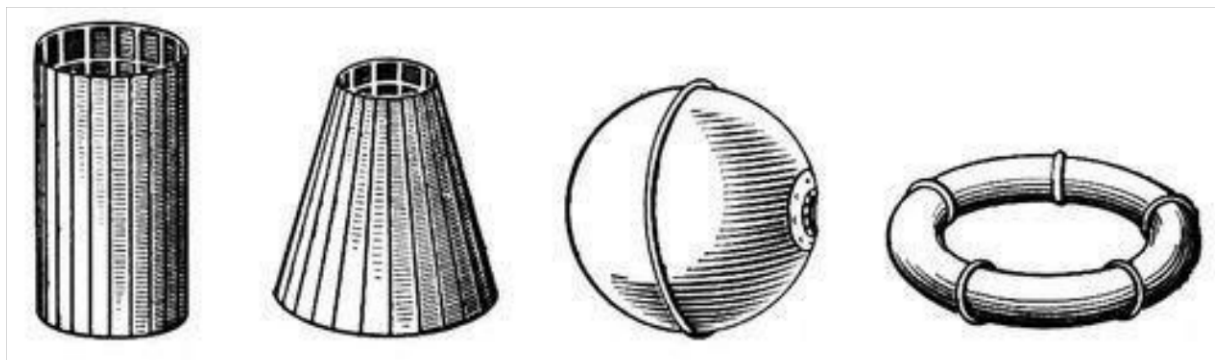


Figure 2.3

Plate is the shell, the middle surface of which is a plane.

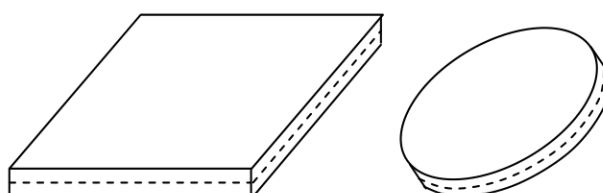


Figure 2.4

Solid body is the body, in which all three dimensions are of the same order.

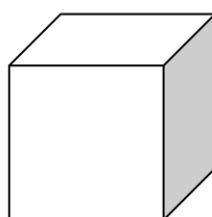


Figure 2.5

The loads applied to the structure (and taken by details of machines and structures in operation) are the external loads.

Loads on the element of a structure can be:

- applied to sections of its surface (surface loads); and
- distributed by volume (volumetric loads).

Surface loads are divided into:

- concentrated – the loads applied on a very small area in comparison with the overall dimensions of a detail and conditionally considered as applied in one point.

The dimension of concentrated loads is N .

- distributed – the loads applied to areas of a detail or a larger structure area and which, while building a design model, cannot be replaced with concentrated loads.

The dimension of distributed loads:

- by length N/m ,
- by area of the element of a structure N/m^2 ,

Volumetric loads are forces applied to each particle of the material of a detail (proper weight, inertia forces).

The dimension of volumetric loads is N/m^3 .

By lifetime loads are divided into:

- permanent – the loads applied to a structure during its whole lifetime (proper weight of a structure).
- temporary – the loads applied to a structure during a limited period (train weight).

By pattern of influence on a structure, loads are divided:

- static – the loads which increase slowly from zero to the limited values, and then maintain constant.
- dynamic – the loads which cause high accelerations in a structure or its certain elements, which cannot be neglected in calculations.

Dynamic loads are divided into:

- instantaneous – the loads which rapidly achieve a certain value (pressure of a locomotive wheel while entering a bridge);
- impact – the loads applied during a very short time period;
- intermittent-fluctuating – the cyclically changing loads.

The external forces on structural elements include not only loads, active forces, but also constant reactions, reactive forces.

Internal forces (method of sections).

When external forces are applied to actual bodies or temperature changes, the internal interaction forces (intermolecular interaction forces) appear in these bodies; the internal forces counteract the external forces and try to return the particles to their pre-deformation position.

Determination of internal forces emerging due to loading a body is the basic task of strength calculation.

For determination of internal forces the method of sections is used.

The method is based on a sequence of the following operations:

- a detail is conditionally cut in the place where the internal forces are determined;
- one of two parts of the detail dissected is conditionally cast out;
- effect of the part neglected is replaced with the internal forces (balanced with external forces applied to the remaining part).
- unknown internal forces are determined from the equilibrium equations.

Generally, for a spatial task, the system of internal forces is reduced to main vector of forces $\vec{R}$ applied to the center of figure, and main moment $\vec{M}$ which are resolved into constituents along the coordinate axis (internal power factors in the section):

$$\vec{R} = \vec{N}_x + \vec{Q}_y + \vec{Q}_z ; \quad \vec{M} = \vec{T}_x + \vec{M}_y + \vec{M}_z \quad (2.13)$$

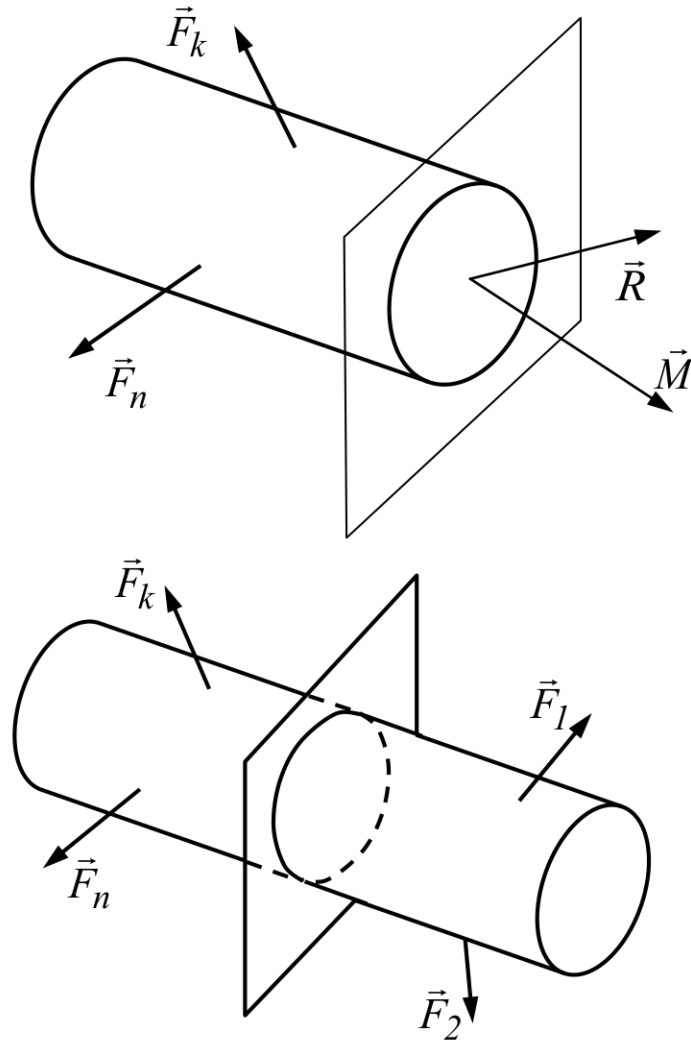


Figure 2.6

Internal power factors in the section:

$\vec{N}_x$ longitudinal (normal) force;

$\vec{Q}_y, \vec{Q}_z$ lateral (crosscutting) forces;

$\vec{T}_x$ torque moment;

$\vec{M}_y, \vec{M}_z$ flexure moment.

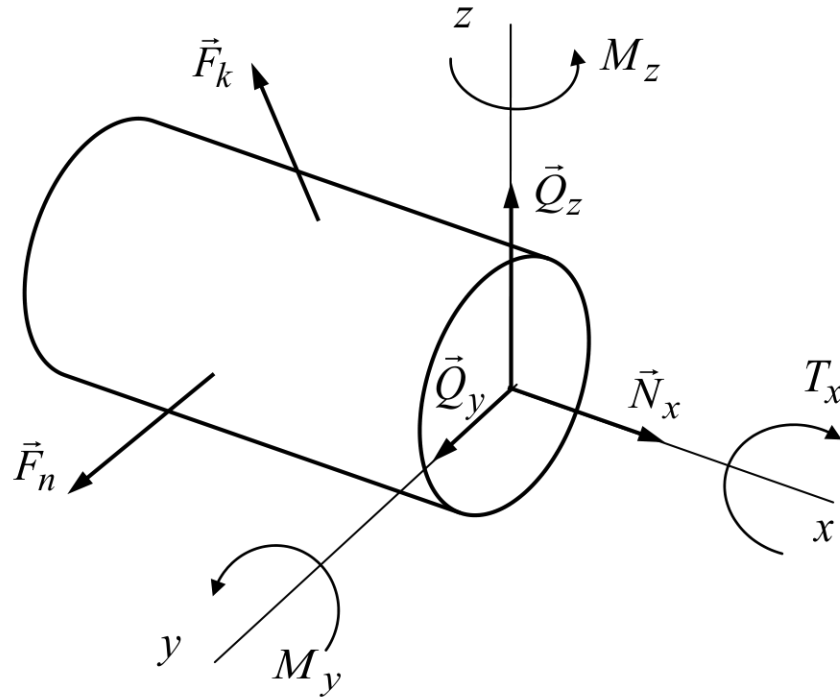


Figure 2.7

In order to determine the unknown internal power factors six static equilibrium equations are used:

$$\begin{cases} \sum_{i=1}^n F_{ix} = 0 ; & \sum_{i=1}^n F_{iy} = 0 ; & \sum_{i=1}^n F_{iz} = 0 ; \\ \sum_{j=1}^k M_{jx} = 0 ; & \sum_{j=1}^k M_{jy} = 0 ; & \sum_{j=1}^k M_{jz} = 0. \end{cases} \quad (2.14)$$

Mechanical stresses and deformations.

Stress is the local measure of internal forces; it characterizes their intensity on a dimensionless area of the section.

The dimension of tension is Pascal ($1 \text{ Pa} = 1 \text{ N/m}^2$).

Combined stress in a point on area ΔA :

$$\vec{p} = \lim_{\Delta A \rightarrow 0} \frac{\Delta \vec{R}}{\Delta A}, \quad (2.15)$$

where $\Delta \vec{R}$ is the resultant of the internal forces on dimensionless area ΔA .

$$\Delta \vec{R} = \Delta \vec{N}_x + \Delta \vec{Q}_y + \Delta \vec{Q}_z, \quad (2.16)$$

where $\Delta \vec{N}_x$ is the normal component,

$\Delta \vec{Q}_y, \Delta \vec{Q}_z$ are the tangential components.

Mechanical stresses:

- normal:

$$\sigma_x = \lim_{\Delta A \rightarrow 0} \frac{\Delta \vec{N}_x}{\Delta A}, \quad (2.17)$$

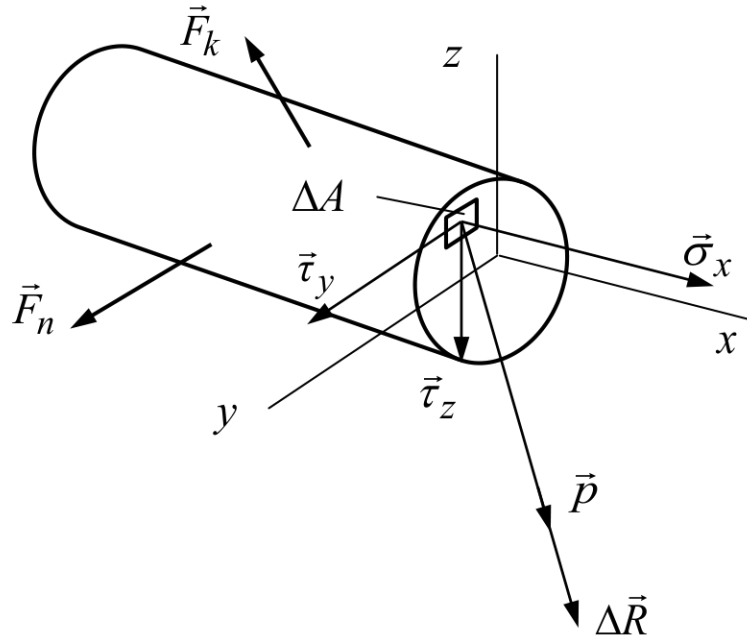


Figure 2.8

- tangential:

$$\tau_y = \lim_{\Delta A \rightarrow 0} \frac{\Delta \vec{Q}_y}{\Delta A}, \quad (2.18)$$

$$\tau_z = \lim_{\Delta A \rightarrow 0} \frac{\Delta \vec{Q}_z}{\Delta A} \quad (2.19)$$

The modulus of a combined stress on area

$$\Delta A: p = \sqrt{\sigma^2 + \tau^2}, \quad (2.20)$$

where:

$\sigma = \sigma_x$ is the normal stress in the plane perpendicular to the section and characterizes the intensity of the pryout or compressive forces to the particles of the structural element located on both sides from the section;

$\tau = \sqrt{\tau_y^2 + \tau_z^2}$ is the combined tangential stress in the plane of the section and characterizes intensity of forces which shift particles of the structural component in the plane of the section under study.

Deformation is the change in form and size of a detail or structure under the external forces or thermal effect.

Deformation is the quantitative characteristic of distortion.

Geometrical deformation is divided into:

- linear deformations (ε) characterize the specific extension or shortening of a dimensionless line which is conditionally put along a corresponding direction from a specified point.
- angular deformations (γ) characterize the change in the initial right angles.

Elastic deformation is the deformation disappearing after termination of the forces causing this deformation (the detail returns to its initial form and size).

Residual deformation is the deformation which does not disappear after termination of the forces causing this deformation (the detail does not return to its initial form and size). And the residual deformation without deterioration is called the plastic deformation.

Basic types of deformations:

- Extension or compression is characterized by lengthening or shortening of a bar.
- Shift (cut) is characterized by a relative parallel shift of two adjacent transversal sections.

- Torsion is characterized by the angle of mutual twisting of sections relative to the bar axis.

- Flexure is accompanied by curving the bar axis and characterized by the deflection value and rotation angle in each section.

A combination of several basic types of deformations is called a complex deformation.

Basic hypotheses and assumptions.

1. Hypothesis on material continuity. The material is supposed to completely (without hollows) fill the body shape.

2. Hypothesis on homogeneity and isotropy. The material properties in any volume and in any direction are supposed to be similar. (If physical and mechanical characteristics of the body material are equal along all directions, the body is called isotropic; and if they are not equal it is called anisotropic).

3. Hypothesis on infinitesimality of deformations. The deformations of a body are supposed to be so small in comparison with the size of a deformed body that they do not influence the mutual location of stresses.

4. Principle of independent effect of stresses (principle of superposition). The result of a system of stresses on the structure is supposed to be equal to the sum of all stresses separately.

5. Saint-Venant's principle. It is supposed that if within some area of an elastic body a system of forces is applied, at distances which considerably excess the specific dimensions of this area, stresses and deformations are virtually equal for all static equivalent systems of forces.

6. Hypothesis of plane sections (Bernoulli's hypothesis). It is supposed that lateral sections of a bar, plane and perpendicular to its axis before deformation, remain plane and perpendicular to its axis after deformation.

2.2 Strangth calculations for deformations “tension-compression”

Axial tension or compression of a bar is the simple loading at which only one internal power factor, internal longitudinal force N , emerges in its lateral sections, but all other forces are equal to zero.

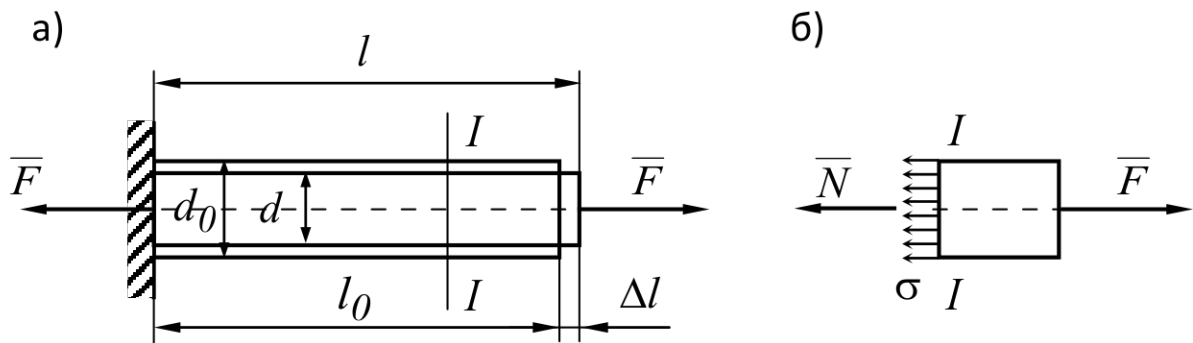


Figure 2.9

By applying the section method: $|N| = |F|$, $\bar{N} = -\bar{F}$.

Longitudinal force N in the cross section of a bar is numerically equal to the algebraic sum of projections of external forces to its axis, located at one side from the section.

Law of signs:

- $N > 0$, if it extends (directed from the section);
- $N < 0$, if it compresses (directs to the section).

In cross sections only evenly distributed normal stresses σ act:

$$\sigma = \frac{N}{A}, \quad (3.21)$$

where A is the area of a section.

The bar under extension is being deformed by changing its longitudinal and lateral dimensions at corresponding values:

- for tension: $\Delta l = l - l_0 > 0$, $\Delta d = d - d_0 < 0$;
- for compression: $\Delta l = l - l_0 < 0$, $\Delta d = d - d_0 > 0$.

Relative deformations:

$$\text{longitudinal: } \varepsilon = \frac{\Delta l}{l_0}; \quad (2.22)$$

$$\text{lateral: } \varepsilon' = \frac{\Delta d}{d_0}. \quad (2.23)$$

Coefficient of lateral deformation (Poisson's ratio): demonstrates the dependency between longitudinal and lateral deformations of an element, and characterizes the elastic properties of materials.

$$\mu = \left| \frac{\varepsilon'}{\varepsilon} \right|. \quad (2.24)$$

- $0 \leq \mu \leq 0,5$ for isotropic materials;
- $\mu \approx 0,3$ for structural materials;
- $\mu = 0$ for cork;
- $\mu \approx 0,5$ for rubber and liquid.

Hooke's law: the normal stresses are directly proportional to the relative longitudinal deformation:

$$\sigma = E \cdot \varepsilon, \quad (2.25)$$

where E is the modulus of elongation, the modulus of type I elasticity, Young's modulus (dimension is Pascal).

Modulus E characterizes the properties of material to resist elastic deformation, i.e. the higher is the modulus, the less the material becomes deformed.

Absolute tension of a bar:

$$\Delta l = \frac{N \cdot l_0}{E \cdot A}, \quad (2.26)$$

where $E \cdot A$ is the rigidity at tension.

The formula can be used for the section of a bar, within which N and A remain constant.

Strength condition at tension (compression):

$$\sigma_{max} = \frac{N_{max}}{A} \leq [\sigma], \quad (2.27)$$

where $[\sigma]$ is the permissible stress (the safest),

$$[\sigma] = \frac{\sigma_{on}}{[n]}, \quad (2.28)$$

where σ_{on} is the unsafe stress (at which there appears a possibility to break the detail or disturb its functionality);

$[n]$ is the normative safety factor $[n]=1.5 \div 5$. It depends on working conditions, accuracy of calculation methods, material properties and purpose of the structure);

N_{max} is the maximum value of a normal force.

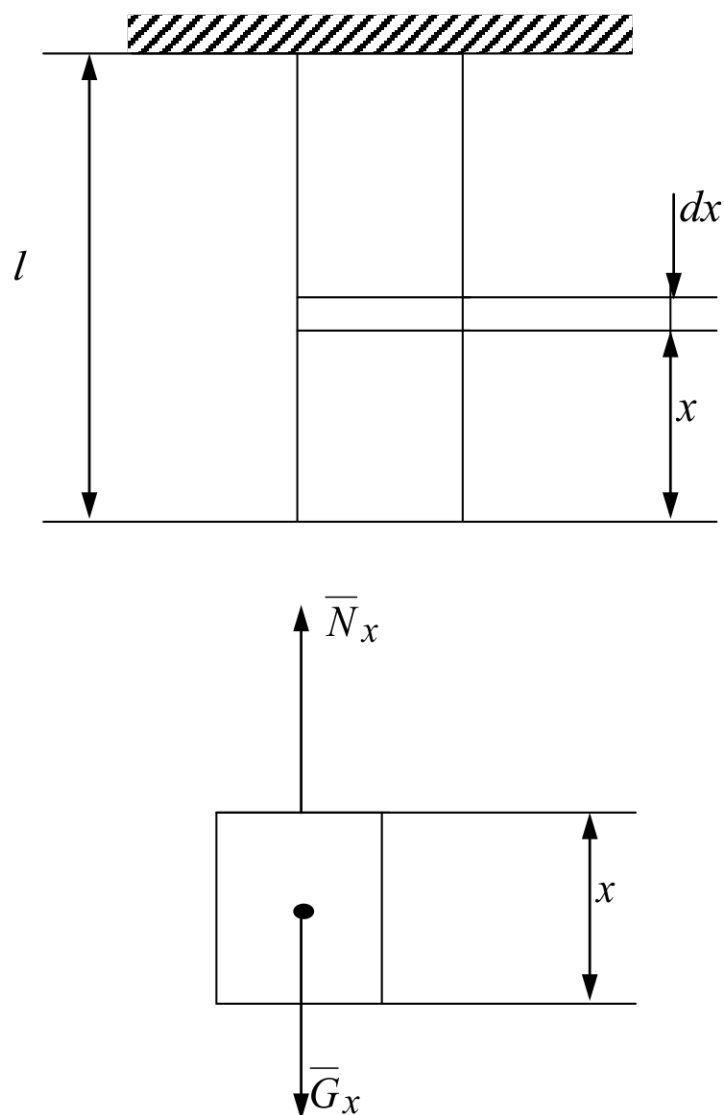


Figure 2.10

On taking into account the dead weight in tension let us consider a uniform section bar of weight G and length l clamped with its top side and loaded with its dead weight.

According to the method of sections

$$\sum x = 0, \quad N_x - G_x = 0, \quad N_x = G_x, \quad (2.29)$$

where G_x is the dead weight of the cross-section of length x ,

$$G_x = \gamma \cdot A \cdot x, \quad (2.30)$$

where γ is the specific weight of the material of a bar,

A is the cross section area.

Stress in the longitudinal section:

$$\sigma = \frac{N_x}{A} = \frac{\gamma \cdot A \cdot x}{A} = \gamma \cdot x \quad (2.31)$$

$$\sigma_{max} = \gamma \cdot l \quad (2.32)$$

Absolute extension of the element of the bar of length dx

$$\Delta x = \varepsilon \cdot dx = \frac{\gamma \cdot x}{E} dx \quad (2.33)$$

Complete extension of the bar:

$$\Delta l = \frac{\gamma}{E} \int_0^l x dx = \frac{\gamma \cdot l^2}{2E} \quad (2.34)$$

By multiplying the denominator and numerator in the formula by cross sectional area A , we obtain:

$$\Delta l = \frac{\gamma \cdot l \cdot A \cdot l}{2 \cdot E \cdot A} = \frac{G \cdot l}{2 \cdot E \cdot A} \quad (2.35)$$

2.3 Mechanical characteristics of materials

In order to determine mechanical characteristics of materials (modulus of elasticity, Poisson's coefficient, plasticity, solidity, etc.) special tests are made, the simplest of them is the elongation test.

Special cylindrical or prismatic (plane) test-pieces are made of the material under study:

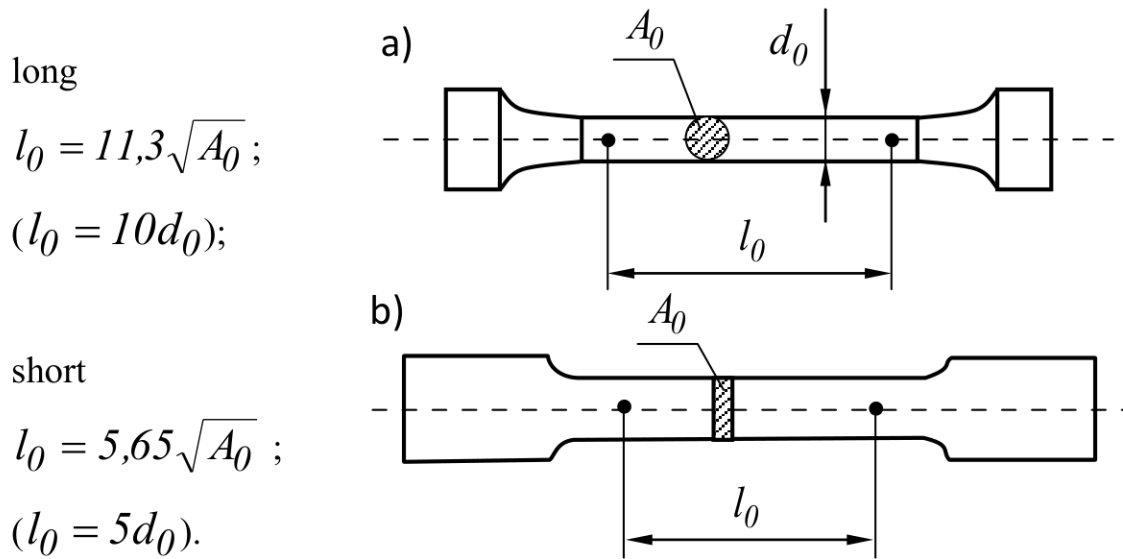


Figure 2.11

The test piece is mounted in clamps and extended with a special machine, which automatically measures load F , absolute tension Δl and write stress-strain curve $F = f(\Delta l)$, with subsequent reconstructing it into the coordinate system

$$\sigma = f(\varepsilon) \left(\sigma = \frac{F}{A_0}, \varepsilon = \frac{\Delta l}{l_0} \right) \quad (2.36)$$

Strain-stress curve for low-carbon steel

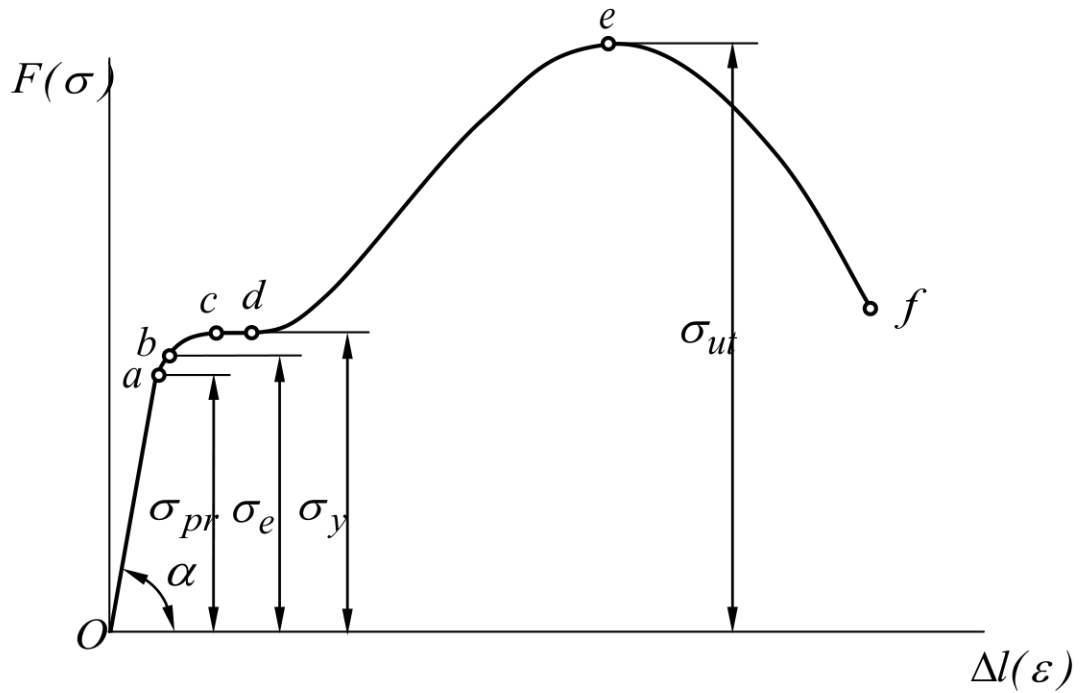


Figure 2.12

Section Oa is the zone of proportionality $\Delta l(\varepsilon)$

Proportional limit $\sigma_{pr} = \frac{F_a}{A_0}$ is the boundary stress, to which the material follows Hooke's law ($\operatorname{tg} \alpha = \sigma / \varepsilon = E$).

Section ab is the zone of elasticity.

Elastic limit $\sigma_e = \frac{F_b}{A_0}$ is the boundary stress to which the material gets deformed elastically. Points a and b on the curve practically coincide. (Hooke's law is not followed with adequate accuracy).

A further increase in the load after point b produces residual deformations.

Horizontal section cd is the zones of yield.

Yield limit $\sigma_y = \frac{F_d}{A_0}$ is the stress at which deformation of the test-piece

goes at a constantly extending load.

Yield is an increase in deformation without an increase in loading. Here, the crystal lattices reconstruct and the material hardens. Besides, slant lines (the Chernov-Lüders bands) at an angle of 45° to the axis of the test-piece emerge on the surface.

Cold hardening is the process of increasing elastic properties of material through plastic pre-deformation (used for hardening details).

Section de is the zone of hardening.

Ultimate stress or ultimate resistance.

$$\sigma_{ut} = \frac{F_{max}}{A_0} \quad (2.37)$$

After running through yield, the material gets harder; it again acquires the capacity to resist tension.

Section ef is the zone of local yield.

When the test-piece reaches point e on the curve, a neck emerges. And deformations are concentrated only at the neck, which rapidly becomes thin, and, consequently, the stress and conventional stress fall. In point f the test-piece breaks.

The tension tests also define the characteristics of plasticity:

- Relative residual elongation in breakage

$$\delta = \frac{l_p - l_0}{l_0} \cdot 100 \%, \quad (2.38)$$

where l_p is the effective length of the test-piece after breakage.

Value δ depends on the ratio of length to cross sectional dimensions of the test-piece.

- Relative residual constriction in breakage

$$\psi = \frac{A_0 - A_{uu}}{A_0} \cdot 100 \%, \quad (2.39)$$

where A_{uu} is the area of the smallest cross section of a neck after breakage.

Value ψ characterizes the plasticity of material more precisely than δ , because it depends less on the shape of the test-piece.

In accordance with a relative residual elongation in breakage all materials are divided into plastic and brittle.

Plasticity is the property of material to acquire more residual deformations without damages.

Brittleness is the property of material to break without visible residual deformations.

- $\delta > 5 \%$ for plastic materials (copper, aluminum, brass, low-carbon steel, lead);
- $\delta < 5 \%$ for brittle materials (hardened steel, cast iron, glass, stone, concrete).

Unsafe stress for plastic materials is taken as limit of fluidity σ_y , and for brittle materials – ultimate tensile strength σ_{ut}^+ (for tension) and σ_{ut}^- (for compression).

Ultimate tensile stress of a brittle material at compression several times higher than that for tension, and a brittle material compresses well and extends poorly.

At high temperatures the creep is of considerable importance, it implies a growth of plastic deformation in time at a constant stress which does not cause plastic deformations at short loads.

A decrease in stresses in time due to creep in a loaded detail at its complete steady deformation is called relaxation.

Solidity test is used to access the value of ultimate tensile strength.

Solidity is the property of material to resist intrusion of a more solid body – indenter – into its surface. In order to determine solidity the following methods are used: the Brinell scale, the Rockwell scale and the Vickers hardness test.

Brinell Hardness Number is the ratio of the load with which a steel hardened sphere presses on the surface of a test-piece to the spherical indentation area obtained (m^2):

$$HB = \frac{2F}{\pi \cdot D \cdot \left(D - \sqrt{D^2 - d^2} \right)}, \quad (2.40)$$

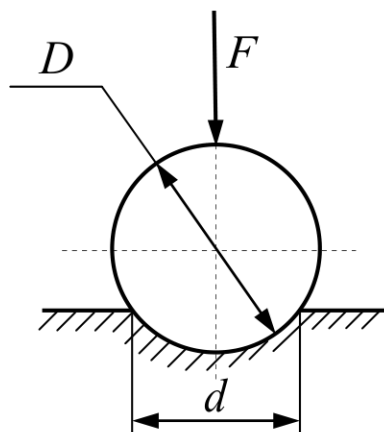


Figure 2.13

where F is the applied load, N;

D is the diameter of the sphere, m ;

d the diameter of the indentation, m .

When using the Rockwell scale, a sharp diamond cone (HRC) indents in the surface of a test-piece, and for the Vickers hardness test a diamond pyramidion (HV) is used.

2.4 Strangth calculations for deformation “shear”

Shear is the simple deformation of a bar at which only internal lateral force ($Q \neq 0$) acts in the cross section.

It is the type of resistance at which a bar is loaded with two equal oppositely-directed and infinitely closely spaced forces which cause shear of the area between them.

Pure shear is the plane stressed state at which only tangential stresses act on the edges of a rectangular element.

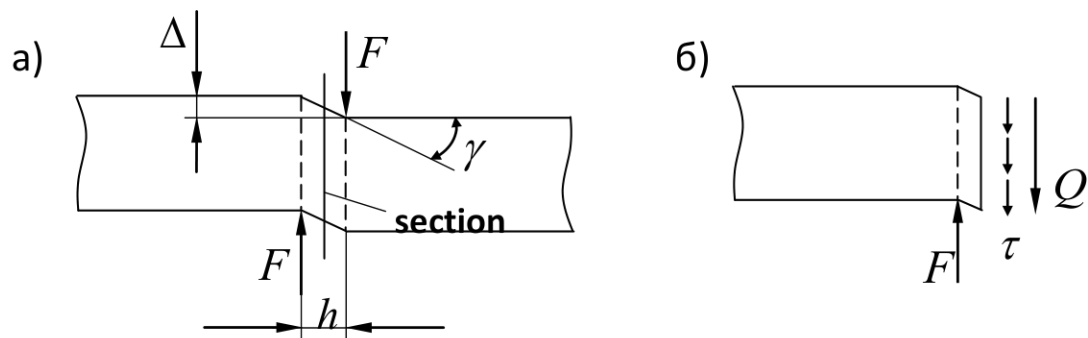


Figure 2.14

According to the equilibrium state in the left side of a bar (applying the method of sections) the lateral force:

$$Q = \int \tau dA = F. \quad (2.41)$$

Considering that the shearing stresses are evenly distributed on the cross section, we can obtain:

$$\tau = \frac{F}{A} \quad (2.42)$$

The following values characterize the shear:

- Δ absolute shear; and
- Δ/h relative shear (measure of the direct angle shift of on element).

Angle of shear:

$$\Delta/h = \operatorname{tg} \gamma \approx \gamma.$$

Hooke's law at shear (shearing stresses are directly proportional to angular deformations):

$$\tau = G \cdot \gamma, \quad (2.43)$$

where G is the type II modulus of elasticity or the modulus of shear (Па).

The ratio between modulus of shear G , Young's modulus E and Poisson's coefficient μ is expressed by the formula:

$$G = \frac{E}{2(1 + \mu)} \quad (2.44)$$

Taking that $\tau = \text{const}$: $\tau = Q/A$.

By substituting τ and γ in Hooke's law we obtain the formula for determination of the absolute shear:

$$\Delta = \frac{Q \cdot h}{G \cdot A}, \quad (2.45)$$

where $G \cdot A$ is the rigidity at shear.

Strength condition at shear:

$$\tau_{max} = Q_{max} / A \leq [\tau_{cp}]. \quad (2.46)$$

where $[\tau_{cp}]$ is the safe load for shear.

2.5 Geometric characteristics of plane sections

In strength and rigidity calculations under tension and shear one characteristic of a plane section, the area, is used. For torsion and flexure the following geometric characteristics of plane sections are used.

Statistic moments of the section relative to axes x and y are the integrals:

$$S_x = \int_A y dA, \quad S_y = \int_A x dA \quad (2.47)$$

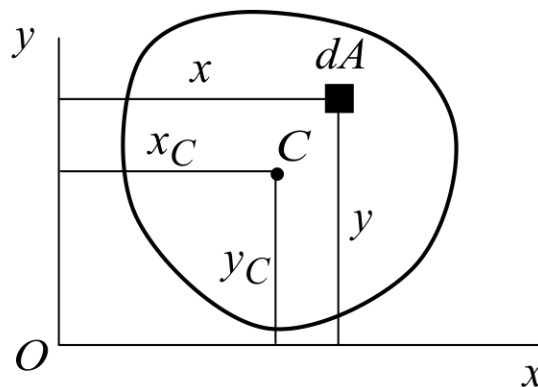


Figure 2.15

On the basis of the theorem on the moment of a resultant force:

$$S_x = A \cdot y_C, \quad S_y = A \cdot x_C, \quad (2.48)$$

where x_C, y_C are the coordinates of the center of gravity of the section.

The static moments of sections relative to the central axes (axes going through the center of gravity of the section) equal to zero.

The dimension of static moments of a section is cm^3 or m^3 .

Axial (equatorial) moments of inertia of the section relative to axes x and y are integrals of the type:

$$I_x = \int_A y^2 dA, \quad I_y = \int_A x^2 dA \quad (2.49)$$

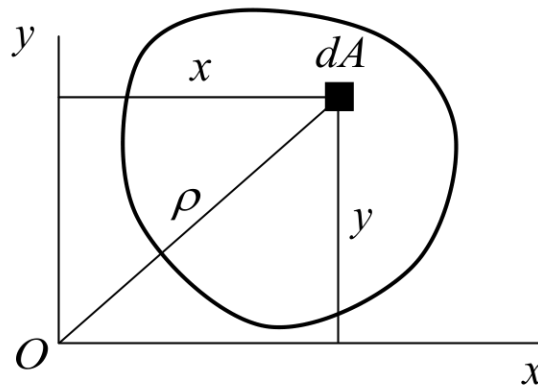


Figure 2.16

The dimension of axial moments of inertia of the section are cm^4 or m^4 .

Polar moment of inertia of the section relative to a given point (pole O) is an integral of the type:

$$I_\rho = \int_A \rho^2 dA, \quad (2.50)$$

where ρ is the distance from an element area to the coordinate origin.

$$\text{As } \rho^2 = x^2 + y^2, \quad I_\rho = I_x + I_y \quad (2.51)$$

The dimension of the polar moment of inertia of the section is cm^4 or m^4 .

Centrifugal moment of inertia of the section is an integral of the form

$$I_{xy} = \int_A xy dA \quad (2.52)$$

The dimension of the centrifugal moment of inertia of the section is cm^4 or m^4 .

According to the position of the axes the centrifugal moment of inertia can be positive or negative, and also equal to zero.

The axes, relative to which the centrifugal moment is zero, are called the principal axes of inertia.

All mutually perpendicular axes, at least, one of which is the axis of symmetry of a figure, are its principal axes.

The principal axes, running through the center of gravity of the section, are called the centroidal principal axes.

2.6 Strangth calculations in deformation “torsion”

Torsion is the simple load at which only internal torque moment ($T_x \neq 0$) acts in the cross section of a bar.

The bar (rod) acting for torsion, regardless the form of its section, is called the shaft.

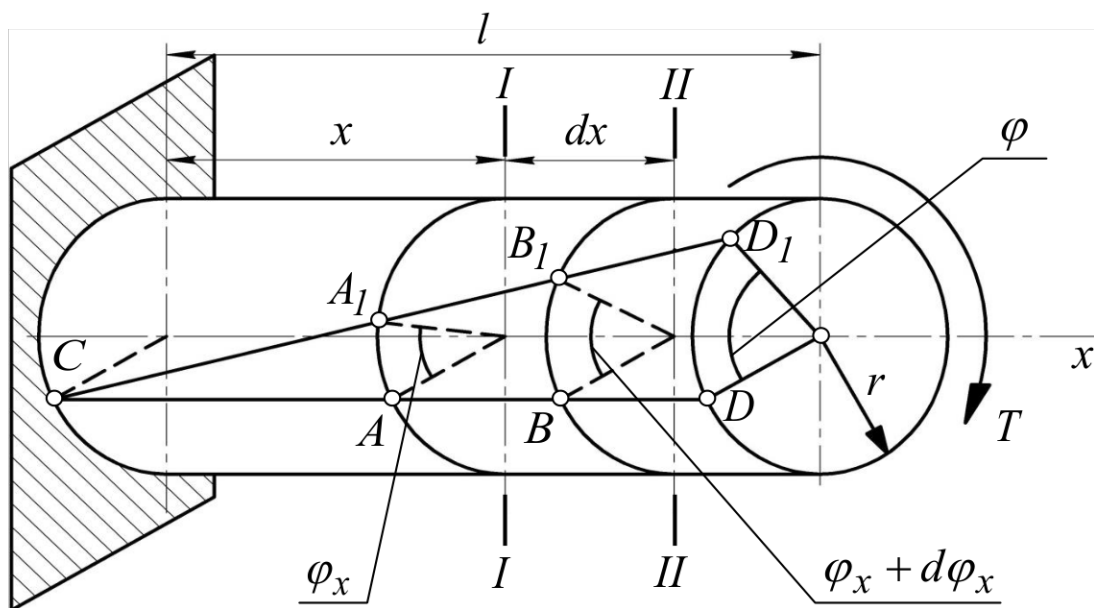


Figure 2.17

It is taken that in torsional deformation:

- shaft axis remains rectilinear;
- cross sections of the shaft remain plane and rotate around its axis relative to each other at an angle called the torsion angle (φ);
- distances between cross sections of the shaft do not change;

- rectilinear generatrices turn into helical lines, (e.g. generatrix CD into helical line CD_1);

- radii of the sections remain rectilinear.

Considering the all above-mentioned, torsion of a cylindrical bar can be taken as the result of shears due to mutual turn of the cross sections. Therefore in cross sections of the shaft only shearing stresses occur, but normal stresses are equal to zero.

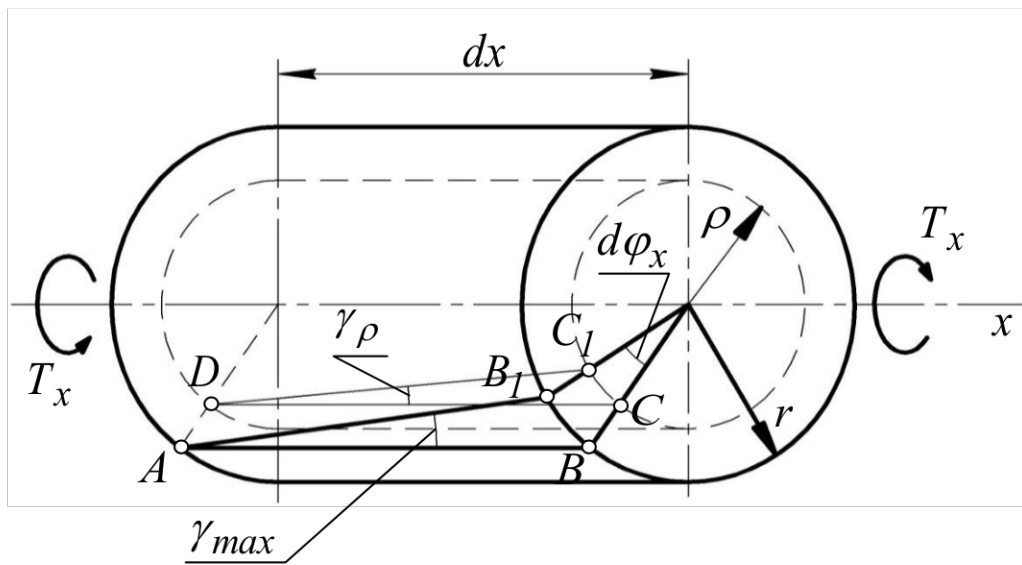


Figure 2.18

Relative torsion angle:

$$\theta = \frac{\varphi}{l} = \frac{d\varphi_x}{dx} = const, \quad (2.53)$$

where l is the shaft length,

$d\varphi_x$ is the torsion angle on a section of the shaft of length dx .

Angle of relative shear:

$$\gamma_{max} = \frac{BB_1}{AB} = \frac{r \cdot d\varphi_x}{dx} = r \cdot \theta$$

$$(\gamma_\rho = \frac{CC_1}{DC} = \frac{\rho \cdot d\varphi_x}{dx} = \rho \cdot \theta)$$
(2.54)

On the basis of Hooke's law at shear shearing stresses in a section of the shaft are:

$$\tau_{max} = G \cdot \gamma_{max} = G \cdot \frac{d\varphi_x}{dx} \cdot r \quad (\tau_\rho = G \cdot \gamma_\rho = G \cdot \frac{d\varphi_x}{dx} \cdot \rho) \quad (2.55)$$

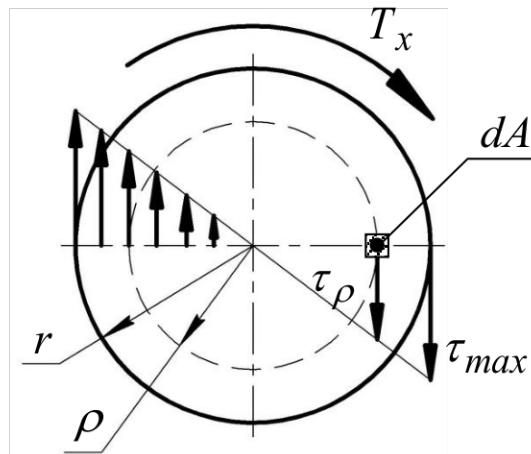


Figure 2.19

Shearing stresses change by the linear law. And they are maximal on the shaft surface.

Complete moment of internal forces (torsion moment):

$$\begin{aligned}
 T_x &= \int_A \tau_\rho \cdot \rho \cdot dA = \int_A G \cdot \frac{d\varphi_x}{dx} \cdot \rho \cdot \rho \cdot dA = \\
 &= \int_A G \cdot \theta \cdot \rho^2 \cdot dA = G \cdot \theta \cdot \int_A \rho^2 \cdot dA = G \cdot \theta \cdot I_\rho,
 \end{aligned} \tag{2.56}$$

where I_ρ is the polar moment of inertia of the cross section of a bar (for a round solid bar):

$$I_\rho = \int_A \rho^2 dA = \int_0^{d/2} 2\pi\rho^3 d\rho = 2\pi \frac{(d/2)^4}{4} = \frac{\pi \cdot d^4}{32}, \tag{2.57}$$

where $dA = 2\pi\rho d\rho$

Relative torsion angle:

$$\theta = \frac{T_x}{G \cdot I_\rho}, \tag{2.58}$$

where $G \cdot I_\rho$ is the rigidity of the cross section at torsion.

Complete torsion angle (measured in radians):

$$\varphi = \int_0^l \frac{T_x}{G \cdot I_\rho} dx \tag{2.59}$$

If $T_x = \text{const}$ and $I_\rho = \text{const}$, the complete torsion angle is presented as Hooke's law at torsion:

$$\varphi = \frac{T_x \cdot l}{G \cdot I_\rho} \quad (2.60)$$

If the shaft has several sections distinguishing by the size of sections and values of torsion moments, the complete torsion angle equals the algebraic sum of torsion angles of these sections.

Shearing stresses in an arbitrary point of the section of the shaft are:

$$\tau = \frac{T_x \cdot \rho}{I_\rho} \quad (2.61)$$

Maximum shearing stresses take place on the surface of the shaft at $\rho = r$:

$$\tau_{max} = \frac{T_x \cdot r}{I_\rho} = \frac{T_x}{W_\rho}, \quad (2.62)$$

where $W_\rho = \frac{I_\rho}{r}$ is the polar moment of resistance at torsion (m^3).

For a solid round section:

$$W_\rho = \frac{\pi \cdot d^3}{16} \quad (2.63)$$

Strength condition at torsion:

$$\tau_{max} = \frac{T_{xmax}}{W_{\rho}} \leq [\tau], \quad (2.64)$$

where $[\tau]$ is the permissible shearing stress at torsion.

The minimal diameter of a shaft (by strength condition)

$$d_{min} = \sqrt[3]{\frac{16 \cdot T_{kp max}}{\pi \cdot [\tau]}} \quad (2.65)$$

Rigidity condition at torsion:

$$\theta_{max} = \frac{T_{xmax}}{G \cdot I_{\rho}} \leq [\theta], \quad (2.66)$$

where $[\theta]$ is the permissible relative torsion angle.

Internal torsion moment T_x in an arbitrary section is equal to the algebraic sum of external torsion moments located at one side from the section.

2.7 Strength calculations under deformations “flexure”

Flexure is the deformation at which bending moments M_z appear in the cross sections of a beam (due to which the beam axis curves).

Pure flexure is the deformation at which only the bending moment appears in the section of a beam.

Lateral flexure is the deformation at which the bending moment along with lateral force (Q_y) act in the section of a beam.

Beam is a straight-line bar working for flexure. A distance between the rests of a beam is called the span.

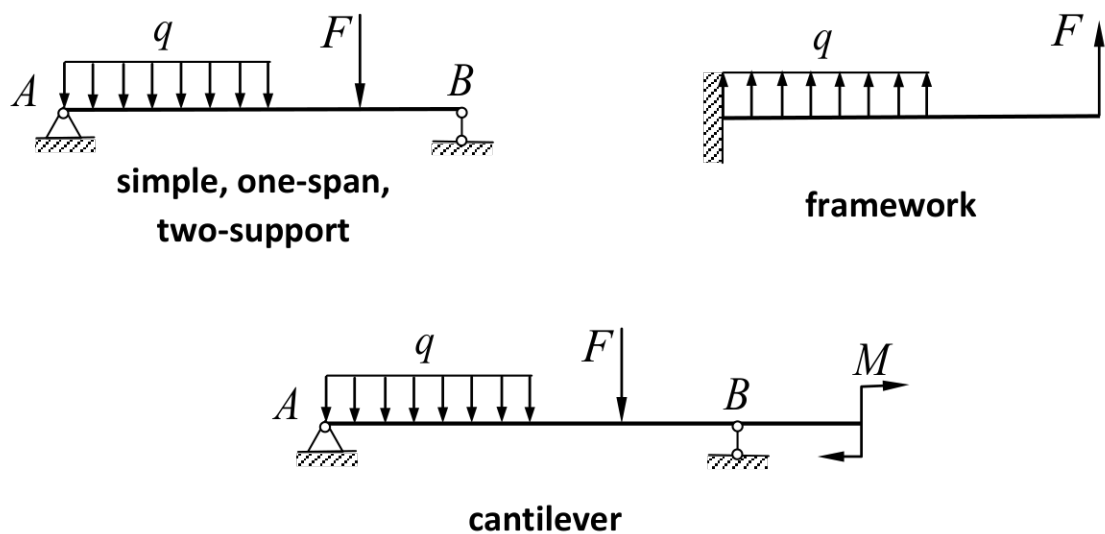


Figure 2.20

Lateral force and bending moment.

For a given design diagram the strength and rigidity calculations at flexure begin with determination of support reactions, and then, with the method of

sections, one should analyze dependencies by which the internal power factors change (lateral force Q_y and bending moment M_z) and build their diagrams.

Calculation rules for Q_y and M_z :

- lateral force Q_y is numerically equal to the algebraic sum of the external forces acting on the detached part of a beam;
- bending moment M_z is numerically equal to the algebraic sum of moments from the loads applied to the detached part of a beam relative to the centroidal principal axis of the section.

Rules of signs for Q_y and M_z :

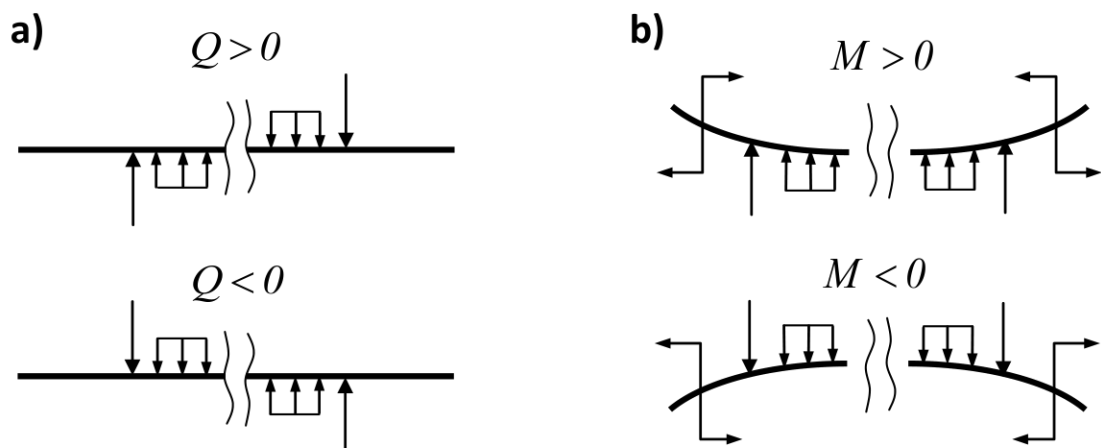


Figure 2.21

Lateral force is positive, if its vectors try to rotate parts of a dissected beam clock wise, and negative if vice versa.

Bending moment is positive, if it causes compression in upper fibers of a beam, and negative if vice versa.

When building diagrams of lateral forces and bending moments the following rules are followed:

- positive values of Q_y are put from the basis horizontal line upwards, and negative – downwards;
- moment diagram M_z is built from the side of stretched fibers, i.e. positive values of bending moments are put from the basis horizontal line downwards, and negative – upwards.

Construction of diagrams.

Support reactions (from the static equilibrium conditions):

$$R_A = q \cdot l, \quad M_A = \frac{q \cdot l^2}{2} \quad (2.67)$$

Analytical expressions for the lateral force and the bending moment:

$$Q_y = q \cdot l - q \cdot x \quad (2.68)$$

(the equation of line)

$$M_z = q \cdot l \cdot x - \frac{q \cdot x^2}{2} - \frac{q \cdot l^2}{2} \quad (2.69)$$

(the equation of square parabola)

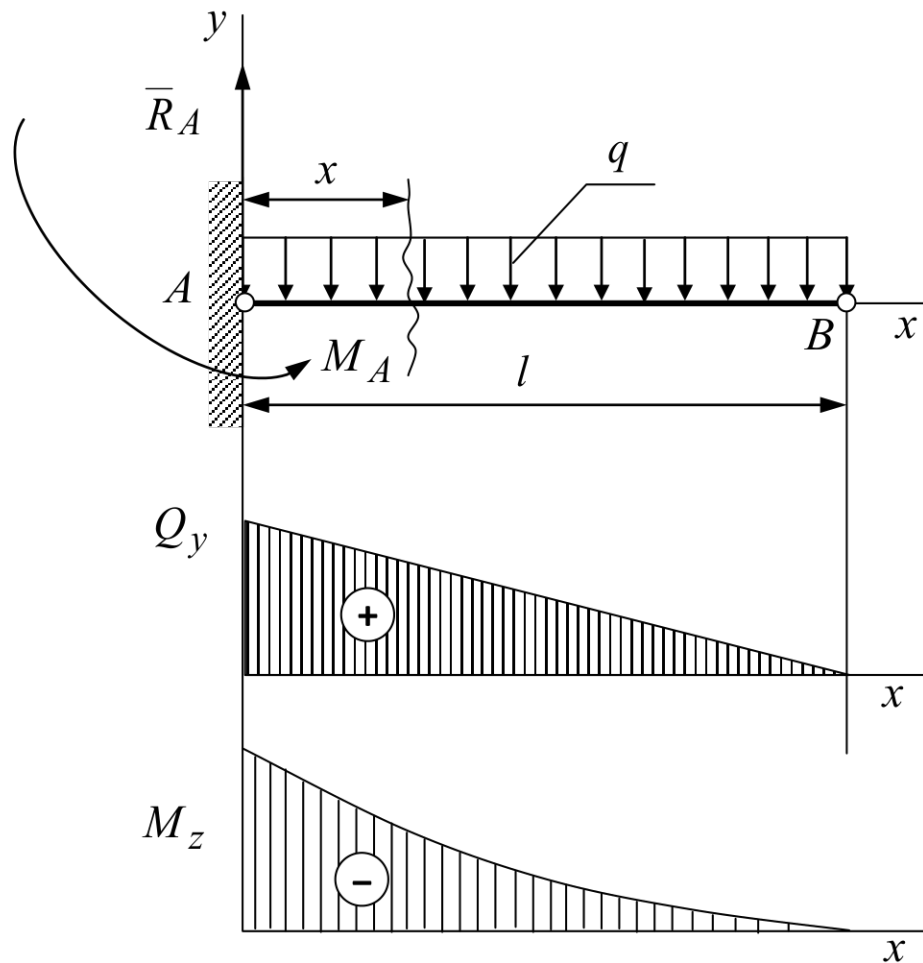


Figure 2.22

Differential dependencies at flexure

The differential dependencies between bending moment, lateral force and distributed load (by prof. Zhuravskii)

$$Q_y = \frac{dM_z}{dx}, \quad q = \frac{dQ_y}{dx}, \quad q = \frac{d^2 M_z}{dx^2} \quad (2.70)$$

The correctness of the diagrams of lateral forces and bending moments built is controlled with the following statements:

- if in a given section concentrated force F is applied perpendicularly to the beam axis, the value of lateral force Q_y in this section changes in discrete steps by the value of applied force F ;
- if in a given section the external moment of couple of forces M is applied, the value of bending moment M_z in this section changes in discrete steps by the value of applied moment M ;
- the larger is lateral force Q_y by absolute value, the steeper is the line limiting diagram M_z ;
- on a beam section with the constant value of a lateral force, the diagram of bending moments M_z is limited with a direct slanting line;
- if on a beam section lateral force Q_y is positive, bending moment M_z on this section increases, and if Q_y is negative, M_z decreases;
- on sections with uniformly distributed load q , lateral force Q_y changes by a linear dependency, and bending moment M_z changes by a quadratic dependency in which the convexity faces the side of action of distributed load q .

Normal and tangential stresses at flexure

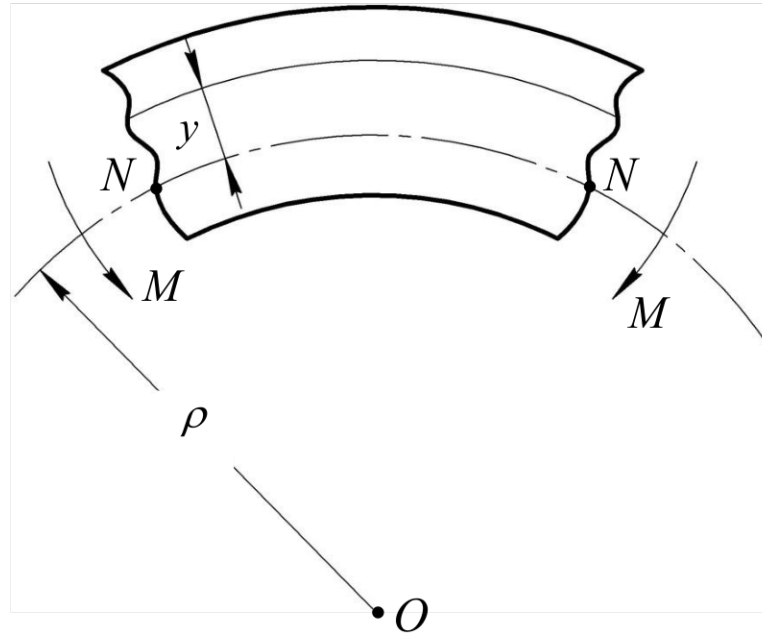


Figure 2.23

A neutral layer is the fiber layer which bears neither tension nor compression

In order to determine normal stresses at a pure flexure the following dependencies are used:

$$\sigma = E \cdot \frac{y}{\rho}, \quad (2.71)$$

where ρ is the radius of curvature of the neutral layer (line NN),

y is the distance from the neutral layer.

Stresses in the cross section of a flexed beam change proportionally to the distance from the neutral layer.

According to the equilibrium condition the sum of all elementary moments of internal elastic forces are equal to the external moment:

$$M_z = \frac{E}{\rho} \int_A y^2 \cdot dA = M, \quad (2.72)$$

where $\int_A y^2 \cdot dA = I_z$ is the inertia moment relative to the neutral axis.

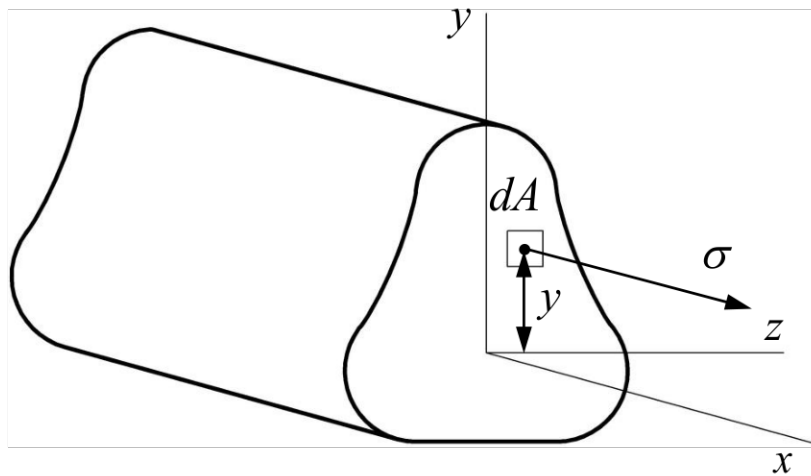


Figure 2.24

On the basis of the above-mentioned formula we can obtain:

$$\frac{l}{\rho} = \frac{M_z}{E \cdot I_z}, \quad (2.73)$$

where $\frac{l}{\rho}$ is the curvature of the flexed axis of the beam (characterizes the value of deformation at flexure);

$E \cdot I_z$ is the rigidity of the beam at flexure.

Normal stresses at flexure:

$$\sigma = \frac{M_z \cdot y}{I_z} \quad (2.74)$$

Maximum normal stresses (in the farthest points from the neutral layer):

$$\sigma_{max} = \frac{M_z \cdot y_{max}}{I_z} = \frac{M_z}{W_z}, \quad (2.75)$$

where $\frac{I_z}{y_{max}} = W_z$ is the axis moment of resistance of the section of a beam.

For example: for a round section at $y_{max} = d / 2$ the axis moment of resistance of the section of a beam is $W_z = \frac{\pi \cdot d^3}{32}$.

In the cross sections of a beam at lateral flexure the tangential stresses appear together with the normal stresses (determined by Zhuravski's formula):

$$\tau = \frac{Q_y \cdot S_z}{b \cdot I_z}, \quad (2.76)$$

where Q_y is the lateral force acting across the section,

S_z is the static moment of the section relative to the neutral axis,

I_z is the inertia moment of the section relative to the neutral axis,

b is the width of the section on the level of a point where stresses are determined.

The tangential stresses in the upper and lower layers equal 0 , and in fibers of the neutral layer they gain the maximum values.

As are as tangential stresses are not considerable in comparison with normal stresses, they can be neglected in the strength calculation. Then, the strength condition at flexure deformation looks like:

$$\sigma_{max} = \frac{M_{z max}}{W_z} \leq [\sigma] \quad (2.77)$$

Differential equation of the elastic line of a beam

The axis of a beam deformed under loads is a smooth curve called the elastic curve.

While calculating the normal stresses the following formula is obtained

$$\frac{l}{\rho} = \frac{M_z}{E \cdot I_z} \Rightarrow \rho = \frac{E \cdot I_z}{M_z} \quad (2.78)$$

Mathematics has it that the radius of curvature of a curve in point A with coordinates x, y is determined by the formula:

$$\rho = \frac{[1 + (y')^2]^{3/2}}{y''}, \quad (2.79)$$

where $y' = \frac{dy}{dx} = \operatorname{tg} \varphi$ (where φ is the angle formed with the tangent to the elastic line of a beam with the positive direction of axis x); $y'' = \frac{d^2 y}{dx^2}$.

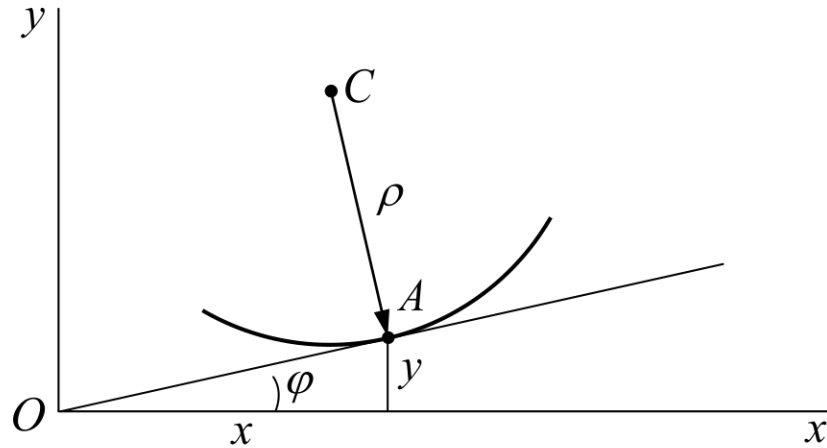


Figure 2.25

Due to infinitesimality of $\frac{dy}{dx}$ in the equation, expression $(y')^2$ can be neglected. Thus, the radius of curvature of the elastic line of a beam:

$$\rho = \frac{l}{y''} \quad (2.80)$$

Considering the above-mentioned formulae we can obtain the differential equation of the elastic line of a bar in general form:

$$y'' \cdot E \cdot I_z = M_z \quad (2.81)$$

As the figures below demonstrate, according to the coordinate axes and the sign of the bending moment we can define the sign of curvature.

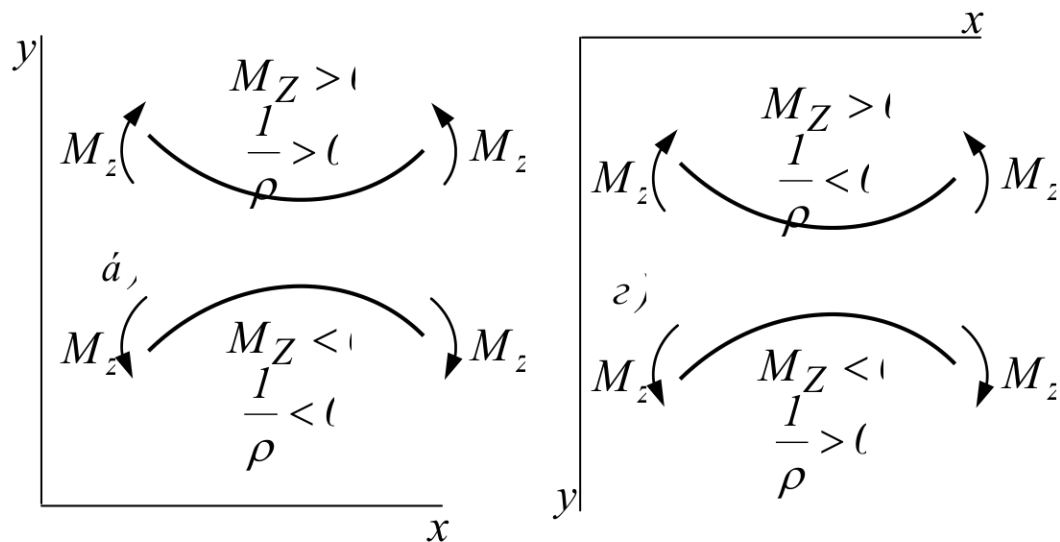


Figure 2.26

2.8 Basics of theory of stressed and deformed state

Stress state in a point. By studying the stress state in point A , let us allocate an element in the form of an infinitely small parallelepiped near it. It is considered that the stresses at each side are uniformly distributed.

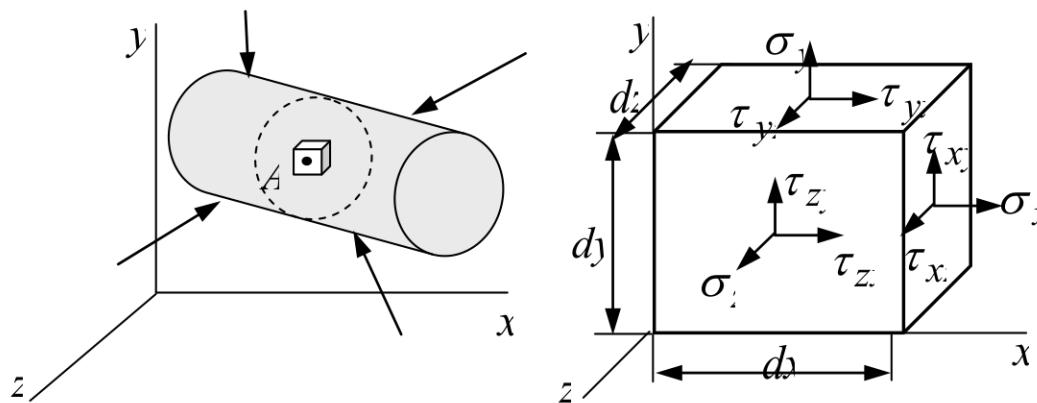


Figure 2.27

The complete stresses at the edges are normal σ and tangential τ components – the projections of complete stresses on the coordinate axes.

The index at σ corresponds to the direction of the normal to the area. The first index at τ corresponds to the direction of the normal to the area, and the second – to the direction of the stress.

$$\begin{Bmatrix} \sigma_x & \tau_{xy} & \tau_{xz} \\ \tau_{yx} & \sigma_y & \tau_{yz} \\ \tau_{zx} & \tau_{zy} & \sigma_z \end{Bmatrix}$$

The set of stresses applied to various areas across a point, is called the stress state in a point. This set of stresses, presented as a square matrix, is called the stress tensor.

The areas with no tangential stresses are called the principal cross-sections, and the normal stresses on these areas – the principle stresses.

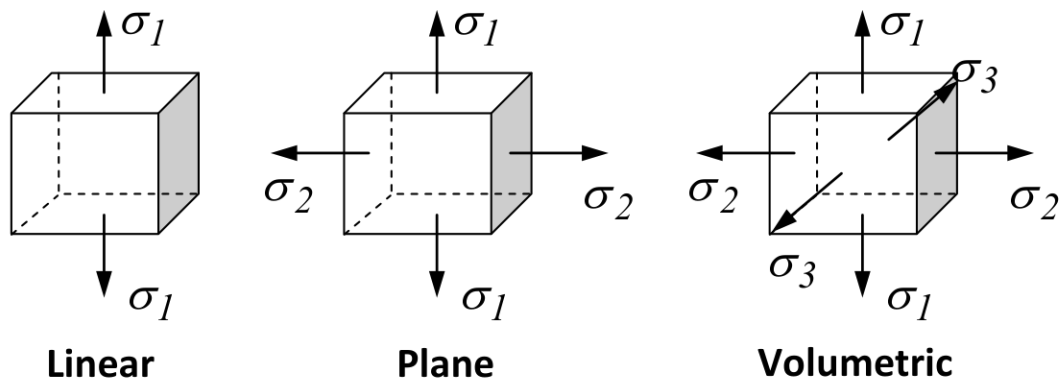


Figure 2.28

The principal stresses are indicates as σ_1 , σ_2 and σ_3 , and the inequality $\sigma_1 > \sigma_2 > \sigma_3$ is satisfied.

In the points of a stressed body we can distinguish elementary parallelepipeds, on the edges of which only normal stresses act, they are the principal stresses. And the following stress states are called: linear, plane and volumetric.

Reciprocity law for tangential stresses: the tangential stresses on two mutually perpendicular areas directed perpendicular to the cross line of these areas are equal by value:

$$\tau_{xy} = \tau_{yx}, \quad \tau_{xz} = \tau_{zx}, \quad \tau_{yz} = \tau_{zy} \quad (2.82)$$

For the volumetric stress state the dependency between linear deformations and principal stresses is expressed by the generalized Hooke's law:

$$\begin{cases} \varepsilon_1 = \frac{1}{E} \cdot [\sigma_1 - \mu \cdot (\sigma_2 + \sigma_3)]; \\ \varepsilon_2 = \frac{1}{E} \cdot [\sigma_2 - \mu \cdot (\sigma_3 + \sigma_1)]; \\ \varepsilon_3 = \frac{1}{E} \cdot [\sigma_3 - \mu \cdot (\sigma_1 + \sigma_2)]. \end{cases} \quad (2.83)$$

Strength theories. Theory of the largest normal stresses (the I strength theory) – unsafe condition of material when any principal stress reaches an unsafe value.

Strength condition:

$$\sigma_{\sigma K6} = \sigma_{max} = \sigma_1 \leq [\sigma] \quad (2.84)$$

where $\sigma_{\sigma K6}$ is the equivalent stress (the stress under which the material in a simple stress-strain condition is in an equally unsafe state as if for the given complex stress).

This strength theory is experimentally confirmed only for some very brittle materials (stone, brick, ceramics, etc.).

Theory of the largest linear deformations (the II strength theory): structural failure for a general stress state occurs when the greatest relative linear elongation reaches its unsafe value (at tension and compression).

Strength condition:

$$|\varepsilon_{max}| \leq [\varepsilon], \quad (2.85)$$

using the generalized Hooke's law:

$$\sigma_{\partial KB} = \sigma_I - \mu \cdot (\sigma_2 + \sigma_3) \leq [\sigma] \quad (2.86)$$

This theory is experimentally confirmed only for some brittle materials (alloy iron, high-strength steel).

Theory of the largest tangential stresses (the III strength theory): the material reaches its limiting state when the highest tangential stress reaches an unsafe value (the Tresca – St.-Venant theory).

Strength condition: $\tau_{max} \leq [\tau]$,

or with principle stresses: $\sigma_{\partial KB} = \sigma_I - \sigma_3 \leq [\sigma]$,

and, besides, for torsion with flexure: $\sigma_{\partial KB} = \sqrt{\sigma^2 + 4\tau^2}$.

This strength theory is well proved by tests for materials similarly working for tension and compression.

- Theory of the largest potential distortion energy (the IV strength theory) – an unsafe state (yield) for a general stress state occurs when the specific potential distortion energy reaches its limiting value (determined at a simple torsion in the moment of yield) (energy, theory of Huber-von-Mises-Hencky).

Strength condition:

$$u_\phi \leq [u_\phi], \quad (2.87)$$

or with principle stresses:

$$\sigma_{\text{экв}} = \sqrt{\sigma_1^2 + \sigma_2^2 + \sigma_3^2 - \sigma_1\sigma_2 - \sigma_1\sigma_3 - \sigma_2\sigma_3} \leq [\sigma], \quad (2.88)$$

and, besides, for torsion with flexure:

$$\sigma_{\text{экв}} = \sqrt{\sigma^2 + 3\tau^2} \quad (2.89)$$

The tests confirm the forth theory for plastic materials, equally working for torsion and compression. Moreover, the forth theory is describes appearance of small plastic deformations in the material more accurately than it does the third theory.

2.9 Stability calculations

Stable and unstable elastic equilibrium. The elastic equilibrium is stable, if, at small deviation from the equilibrium state, the system, after termination of the forces causing this deviation, returns to its initial state.

The elastic equilibrium is unstable, if the system, after termination of the forces causing the deviation, does not return to its initial state and deviates more.

Between these two equilibrium states there exists a transient state, called critical, at which a deformed body is in an indifferent equilibrium: it can keep its initial shape and it can even lose it because of a minor disturbance.

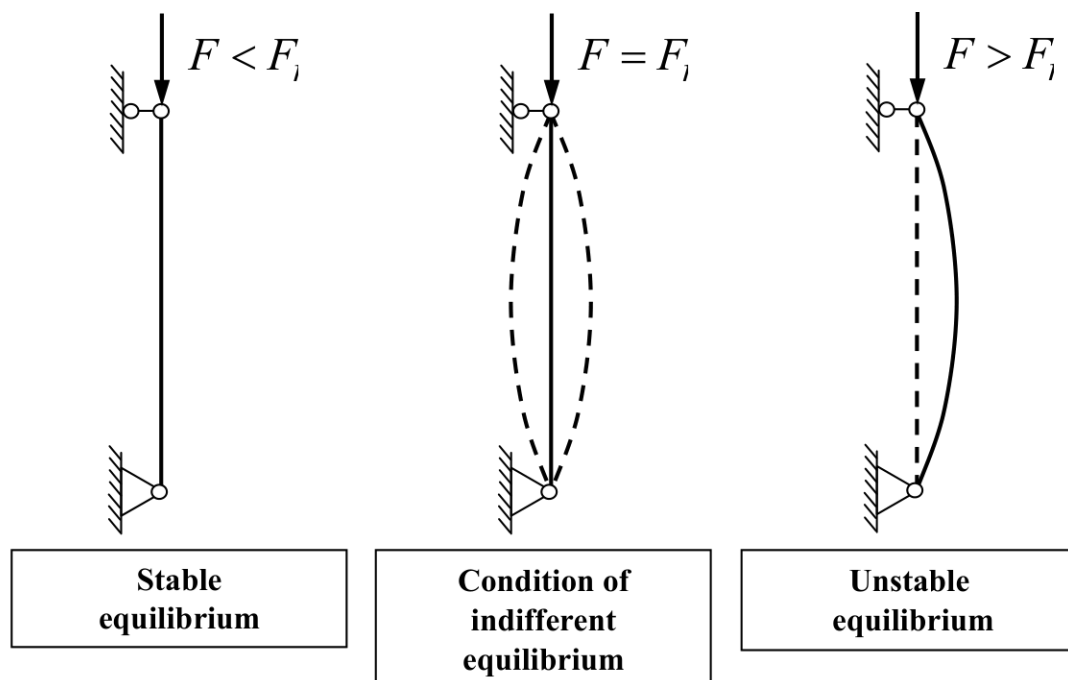


Figure 2.29

The load, an excess of which causes a loss of stability in the initial shape of a body, is called the critical force (F_{kp}).

Basic task of stability calculations: to determine the critical value of external forces at which the working elastic system may lose its stability.

Condition to provide a certain stability margin:

$$F \leq [F], \quad (2.90)$$

where F is the acting load,

$[F]$ is the permissible force providing strength and durability,

$$[F] = \frac{F_{kp}}{k}, \quad (2.91)$$

where F_{kp} is the critical force;

k is the safety factor.

Euler's formula for determination of the critical force.

The critical force is determined by Euler's formula and depends on a fixation method for bars.

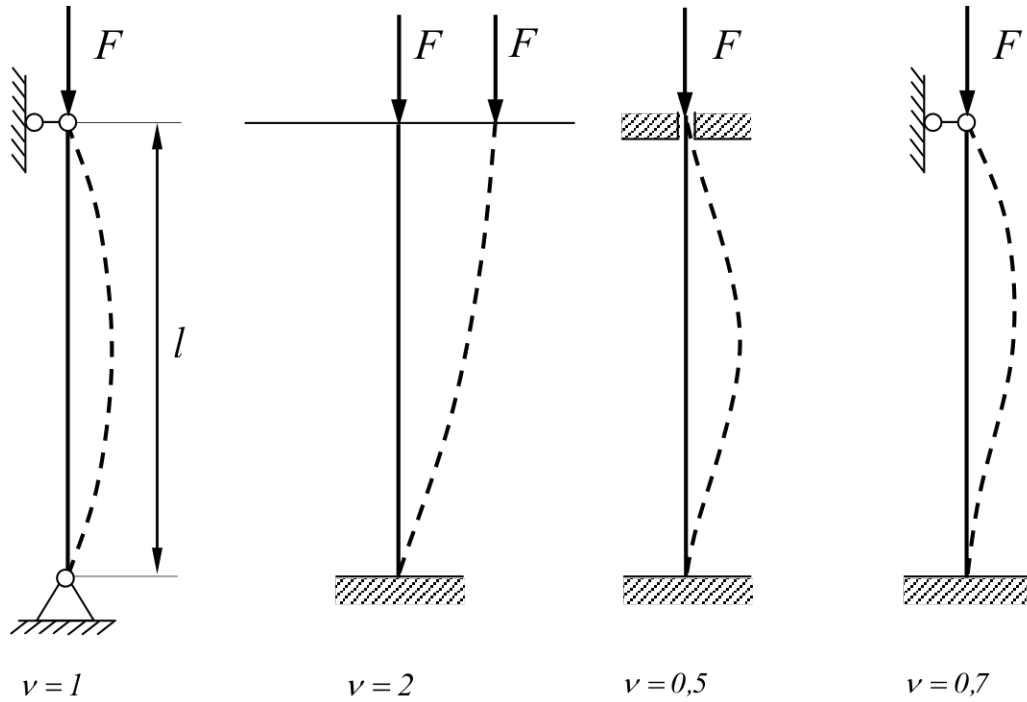


Figure 2.30

Euler's formula in a general view:

$$F_{kp} = \frac{\pi^2 EI_{min}}{(\nu \cdot l)^2} = \frac{\pi^2 EI_{min}}{l_{np}^2}, \quad (2.92)$$

where E is the modulus of elasticity of the material of a bar (Young's modulus);

I_{min} is the smallest axial moment of inertia of a section;

l is the length of a bar;

ν is the coefficient of a reduced length (depends on the method of bar fixation);

l_{np} is the reduced length of a bar ($l_{np} = \nu \cdot l$).

Application limits for Young's formula. Euler's formula is used when Hooke's law is true, i.e. when the critical strength (the compression stress corresponds to the critical force) does not exceed the limit of proportionality.

$$\sigma_{kp} = \frac{F_{kp}}{A} = \frac{\pi^2 \cdot E \cdot I_{min}}{(\nu \cdot l)^2 \cdot A} = \frac{\pi^2 \cdot E}{\lambda^2} \leq \sigma_{pr}, \quad (2.93)$$

where $\lambda = \frac{\nu \cdot l}{i_{min}}$ is the elasticity of a bar (dimensionless quantity which characterizes the sizes and methods of bar fixation);

$i_{min} = \sqrt{\frac{I_{min}}{A}}$ is the minimal radius of inertia of the cross sections of a bar.

Limiting value of elasticity:

$$\lambda_{np} \geq \pi \sqrt{\frac{E}{\sigma_{pr}}} \quad (2.94)$$

When elasticity of a bar is less than limiting ($\lambda < \lambda_{np}$), the critical stress is determined by Jasinski's empirical dependency:

$$\sigma_{kp} = a - b\lambda \quad (2.95)$$

where a and b are the coefficients depending on the properties of the material (determined experimentally).

Jasinski's formula is used for bars of low-carbon steel at an elasticity of $\lambda = 40.....100$. At an elasticity of $\lambda = 0.....40$ the critical stresses are considered approximately constant and equal to the yield strength.

Stability condition

$$\sigma_{max} = \frac{F}{A} \leq [\sigma_{ycm}], \quad (2.96)$$

where $[\sigma_{ycm}]$ is the permissible stress at stability calculations,

$$[\sigma_{ycm}] = \frac{\sigma_{kp}}{n_{ycm}}, \quad (2.97)$$

where n_{ycm} is the safety factor (depends on the material and elasticity of a bar). For steel $n_{ycm} = 1,8.....3,0$; for iron cast $n_{ycm} = 5,0.....5,5$.

2.10 Strength of materials at cyclic stresses

Concept of fatigue failure of the material. Cyclic loads are the loads which cause periodically changing stresses in cross sections.

At stress fluctuations microcracks appear in the material of a detail which gradually penetrate deep in the detail and considerably weaken the section, thus leading to failures of a detail.

Fatigue failure is the failure of material due to stress fluctuations.

Fatigue of material is the process of gradual accumulation of failures in the material due to stress fluctuations which lead to crack development in the material and its damage.

Durability is the capacity of material to resist fatigue failure. Cycles of stresses.

Stress cycle is a set of all values of stress fluctuations per cycle.

Period (T) is the time of a single stress measurement.

A cycle of stress fluctuations is characterized by the following parameters:

- maximum stress (σ_{max} or τ_{max});
- minimum stress (σ_{min} or τ_{min});
- mean stress (σ_m or τ_m) can be both positive and negative

$$\sigma_m = \frac{\sigma_{max} + \sigma_{min}}{2}, \quad (2.98)$$

$$\left(\tau_m = \frac{\tau_{max} + \tau_{min}}{2} \right), \quad (2.99)$$

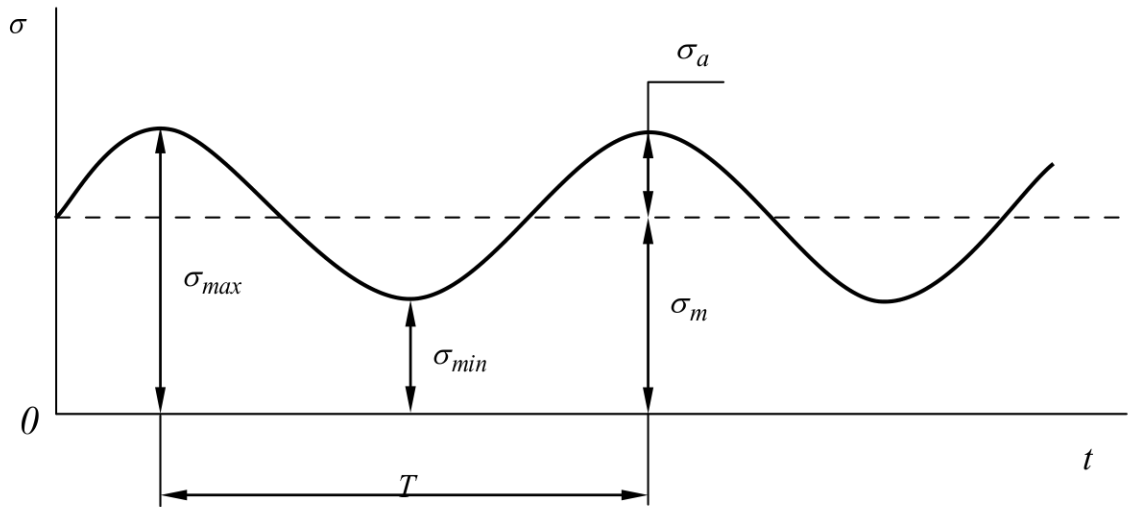


Figure 2.31

- cycle amplitude (σ_a or τ_a) is always positive

$$\sigma_a = \frac{\sigma_{max} - \sigma_{min}}{2}, \quad (2.100)$$

$$\left(\tau_a = \frac{\tau_{max} - \tau_{min}}{2} \right) \quad (2.101)$$

Coefficient of cycle asymmetry:

$$R_\sigma = \frac{\sigma_{min}}{\sigma_{max}}, \quad (2.102)$$

$$\left(R_\tau = \frac{\tau_{min}}{\tau_{max}} \right) \quad (2.103)$$

The most unsafe cycle in terms of strength is a symmetric cycle, because its fatigue limit is of the minimal value. The maximum and minimum stresses are equal to the absolute value and opposite by sign:

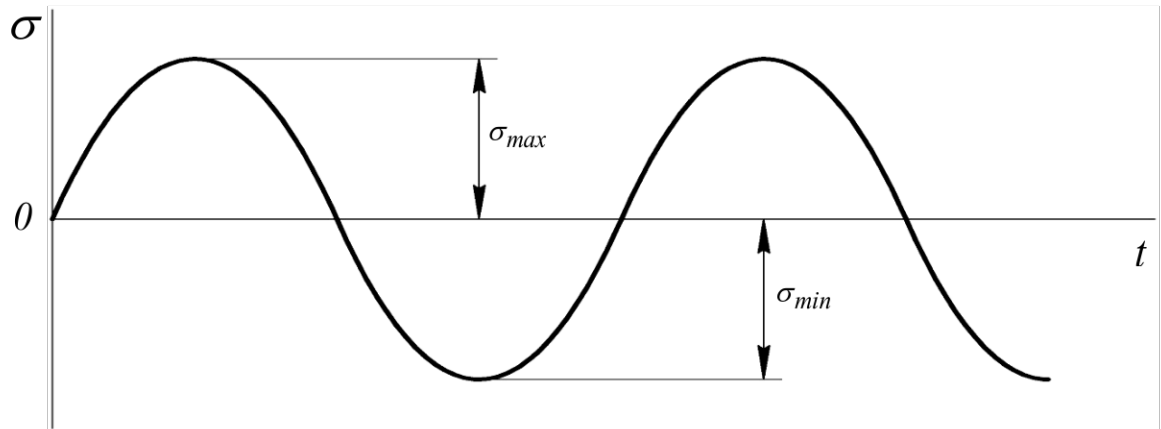


Figure 2.32

$$\sigma_{max} = -\sigma_{min}, \quad R = -1.$$

Asymmetric cycle: the maximum and minimum stresses are not equal by absolute value ($\sigma_{max} \neq -\sigma_{min}$).

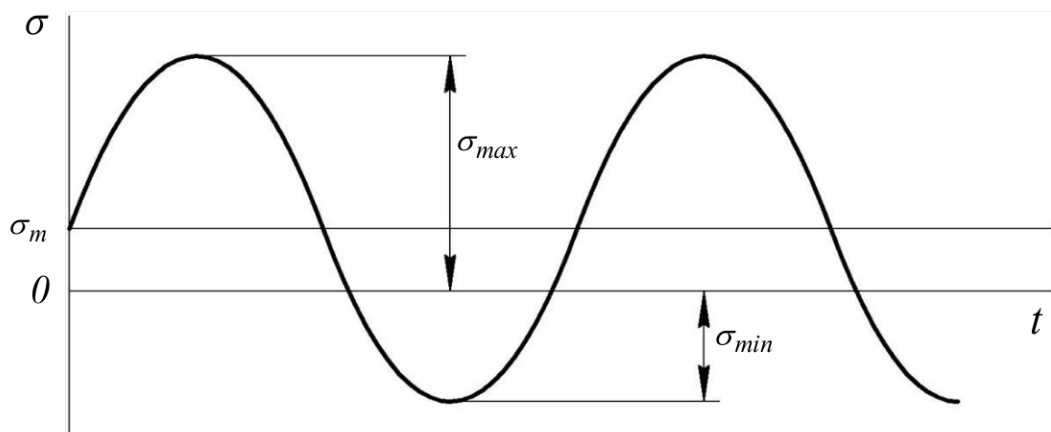


Figure 2.33

Asymmetric cycles can be:

- sign-changing ($\sigma_{max} \neq -\sigma_{min}$, $R < 0$, $R \neq -1$)
- constant-sign ($\sigma_{max} \neq -\sigma_{min}$, $R > 0$, $R \neq +1$).

Pulsating (zero-to-tension) cycle: the maximum or minimum stresses are equal to zero:

$$\sigma_{min} = 0 \text{ or } \sigma_{max} = 0; R = 0 \text{ or } R = \infty$$

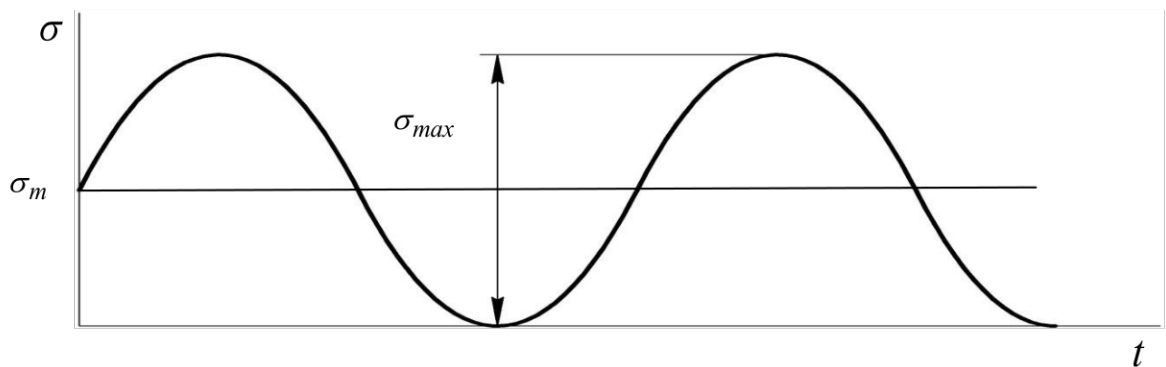


Figure 2.34

At a constant stress, when $\sigma_{max} = \sigma_{min} > 0$, $R = +1$. Such a cycle is called the cycle of constant static loading.

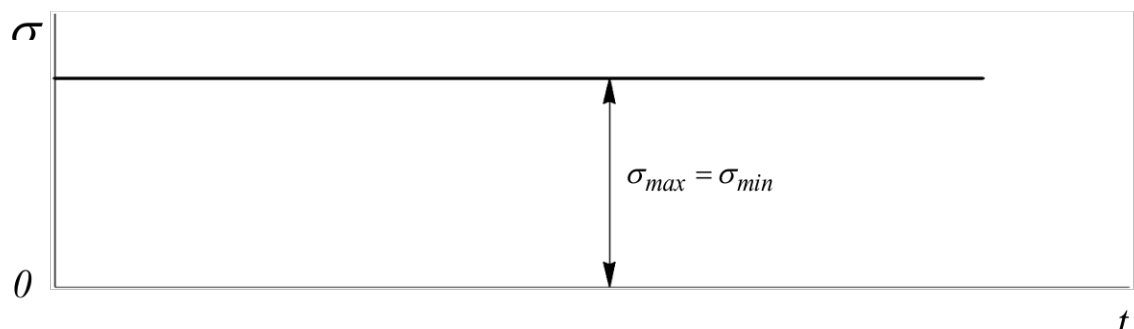


Figure 2.35

Cycles of equal asymmetry coefficients R are called similar.

Endurance limit (fatigue) is the largest (limiting) stress of a cycle, at which a test-piece does not suffer from the fatigue failure after a random number of cycles.

Generally, in endurance calculations the limit of endurance is indicated σ_R (τ_R). And for a symmetry cycle it is σ_{-1} (τ_{-1}), for pulsing it is σ_0 (τ_0), for a constant static loading cycle it is σ_{+1} (τ_{+1}).

In order to determine the limit of endurance, test-pieces are tested for endurance, and the most popular of which is the test for pure flexure at a symmetric cycle.

By the results of the tests the stress-number of cycle diagram (S-N diagram) is built (the endurance curve, August Wöhler's curve) which is the dependency of maximum stress σ_{max} on the number of cycles N .

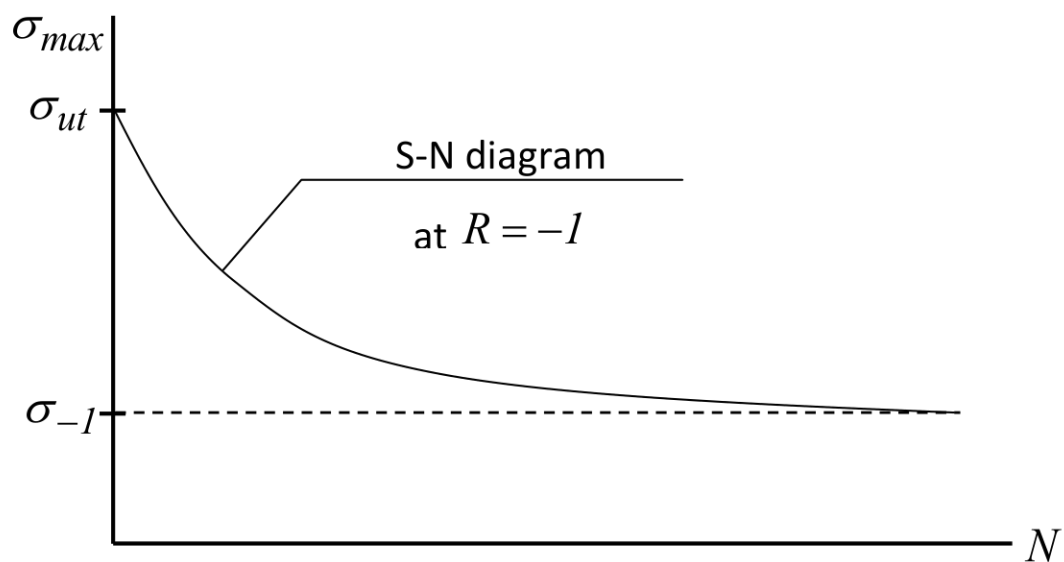


Figure 2.36

The maximum number of cycles at which a test is made, is called the base cycle number (for steel and iron cast the base number is taken equal to 10^7).

If a test-piece bears the base cycle number, it is considered that the stress in it does not exceed the limit endurance and it can bear any more number of cycles without failure.

For non-ferrous metals and their alloys the base of tests increases to $N = 10^8$.

The endurance limit, at any cycle ratio, can be determined with the diagram of limiting stresses built in the coordinate system $\sigma_a = f(\sigma_m)$ for which a fatigue test is made at different values of R .

Point A corresponds to the endurance limit at an asymmetry cycle: $\sigma_a = \sigma_{-1}$, $\sigma_m = 0$.

Point B corresponds to the endurance limit of a constant static loading cycle: $\sigma_a = 0$, $\sigma_m = \sigma_{ut}$.

Point C corresponds to the endurance limit at a pulsing cycle: $\sigma_a = \sigma_m = \frac{\sigma_0}{2}$.

The area of a diagram limited by curve ACB and coordinate axes determines the zone of safe stress cycles (in terms of fatigue failures).

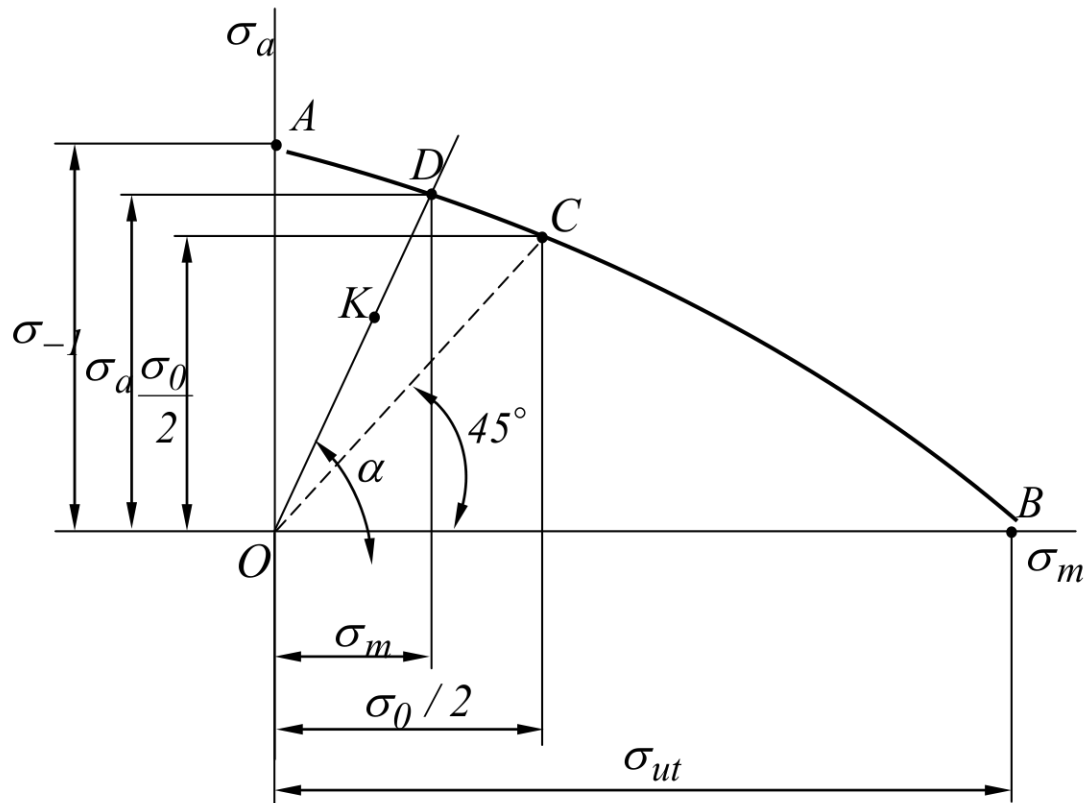


Figure 2.37

OC characterizes a pulsing cycle and is the border of the zones of sign-changing and sign-constant cycles:

- for sign-changing cycles $\sigma_a > \sigma_m$ (the zone of these cycles is located higher than ray OC);
- for constant-sign cycles $\sigma_a < \sigma_m$ (the zone of these cycles is located lower than ray OC).

Random ray OD is a geometric place of points characterizing similar cycles for which $\operatorname{tg} \alpha = \frac{\sigma_a}{\sigma_m} = \frac{1-R}{1+R} = \operatorname{const}.$

If point K , characterizing a specified cycle, is located inside area $OACB$, the cycling strength of the material is guaranteed.

Influence of structural and technological factors on the endurance limit

Influence of stress concentration. The stress concentration is the phenomenon of a rapid increase in stresses in the zone of a rapid change of shape and cross section of some area of a detail (holes, groove, key grooves, dents, carvings, etc.):

The stress concentration is evaluated: by the theoretic concentration coefficient, and also by the efficient concentration coefficient.

Theoretical coefficient of stress concentration:

$$\alpha_{k\sigma} = \frac{\sigma_{max}}{\sigma_n}, \quad (2.104)$$

$$\left(\alpha_{k\tau} = \frac{\tau_{max}}{\tau_n} \right) \quad (2.105)$$

where σ_{max} , τ_{max} are the maximum local stresses near a concentrator;

σ_n , τ_n are the nominal stresses.

Efficient coefficient of stress concentrations:

$$K_\sigma = \frac{\sigma_{-1}}{\sigma_{-1k}}, \quad (2.106)$$

$$\left(K_{\tau} = \frac{\tau_{-I}}{\tau_{-Ik}} \right) \quad (2.107)$$

where σ_{-I} , τ_{-I} are the endurance limits for a symmetric cycle of the test-piece without a stress concentrator;

σ_{-Ik} , τ_{-Ik} are the endurance limits for a symmetric cycle of the test-piece with a stress concentrator;

Stress concentrations considerably decrease the endurance limit of a detail.

Influence of the sizes of a detail on the value of the endurance limit is considered by the scale parameter (coefficient of influence of the absolute sizes of a cross section):

$$\varepsilon_{\sigma} = \frac{\sigma_{-Id}}{\sigma_{-Id_0}}, \quad (2.108)$$

$$\left(\varepsilon_{\tau} = \frac{\tau_{-Id}}{\tau_{-Id_0}} \right) \quad (2.109)$$

where σ_{-Id} , τ_{-Id} are the endurance limits of specified diameter d ;

σ_{-Id_0} , τ_{-Id_0} are the endurance limits of a laboratory test-piece of the similar configuration ($d_0 = 7.....10 \text{ mm}$).

When the sizes of a test-piece increase the endurance limit decreases.

Influence of the surface state is evaluated by the coefficient of surface quality:

$$\beta_{n\sigma} = \frac{\sigma'_{-1}}{\sigma_{-1}}, \quad (2.110)$$

$$\left(\beta_{n\tau} = \frac{\tau'_{-1}}{\tau_{-1}} \right) \quad (2.111)$$

where σ'_{-1} , τ'_{-1} are the endurance limits for a set of test-pieces with a specified surface treatment;

σ_{-1} , τ_{-1} are the endurance limits of a polished test-piece.

The endurance limit can be increased by several times through a decrease in the roughness of the surface of a detail.

Influence of the temperature. Generally, when the temperature increases the endurance limit decreases, and when the temperature decreases, the endurance limit increases.

Strength calculation at variable stresses.

Safety factor at a symmetrical cycle:

$$n_{\sigma} = \frac{(\sigma_{-1k})_d}{\sigma_a}, \quad (2.112)$$

where $(\sigma_{-1k})_d$ is the actual endurance limit of a detail,

$$(\sigma_{-1k})_d = \frac{\sigma_{-1}}{K_{-1}}, \quad (2.113)$$

where K_{-1} is the overall coefficient of change in the endurance limit at a symmetric cycle,

$$K_{-I} = \frac{K_{\sigma}}{\varepsilon_{m\sigma} \cdot \beta_{n\sigma}}, \quad (2.114)$$

where K_{σ} is the effective coefficient of stress concentrations,

$\varepsilon_{m\sigma}$ is the scale parameter,

$\beta_{n\sigma}$ is the coefficient of surface quality,

σ_{-I} is the endurance limit for a symmetric cycle.

σ_a is the amplitude of a symmetric cycle.

Safety coefficient under torsion is determined similarly:

$$n_{\tau} = \frac{(\tau_{-Ik})_d}{\tau_a} \quad (2.115)$$

Under the commutative action of normal and tangential stresses the safety factor is determined with the empirical dependency:

$$\frac{1}{n^2} = \frac{1}{n_{\sigma}^2} + \frac{1}{n_{\tau}^2} \quad \text{whence} \quad n = \frac{n_{\sigma} \cdot n_{\tau}}{\sqrt{n_{\sigma}^2 + n_{\tau}^2}} \quad (2.116)$$

In order to determine the safety factor for non-symmetrical cycles for any type of loading (flexure, torsion, compression, bending) the following dependencies can be used:

$$n_{\sigma} = \frac{\sigma_{-I}}{\sigma_a \frac{K_{\sigma}}{\beta_{n\sigma} \cdot \varepsilon_{m\sigma}} + \psi_{\sigma} \sigma_m}, \quad (2.117)$$

$$\left(n_{\tau} = \frac{\tau_{-1}}{\tau_a \frac{K_{\tau}}{\beta_{n\tau} \cdot \varepsilon_{M\tau}} + \psi_{\tau} \tau_m} \right), \quad (2.118)$$

where ψ_{σ} and ψ_{τ} are the coefficients which characterize the material sensitivity to asymmetry of a cycle under tension, compression, flexure and torsion, respectively.

On determining the safety factor by fatigue resistance, it should be compared with the safety factor by resistance to plastic deformations. The latter ones are determined by the formulae below:

$$n_{\sigma} = \frac{\sigma_y}{\sigma_{max}} = \frac{\sigma_y}{\sigma_a + \sigma_m}, \quad (2.119)$$

$$\left(n_{\tau} = \frac{\tau_y}{\tau_{max}} = \frac{\tau_y}{\tau_a + \tau_m} \right) \quad (2.120)$$

where σ_y , τ_y are the limits of yield.

The stability of a detail in calculations is evaluated by the least safety factor, obtained by corresponding formulae in both cases.

Ways to increase the endurance limit:

- grinding or polishing the surface;
- surface treatment with high-frequency currents;
- thermo-chemical treatment of the surface with azotizing or cement stabilization; and

- rolling the surface or blowing with steel or iron shot.

Vibration damping systems are divided into static and dynamic.

Static vibration damping systems provide for:

- ❖ introduction of elements increasing viscous resistance of vibration processes in the structure of a facility (use of hydraulic and pneumatic dampers [shock absorbers], dry friction dampers [springs], etc.).

- ❖ design and use of special multilayer details, which increase viscous resistance to vibration processes due to friction between adjacent layers, in vibroactive mechanisms.

- ❖ design of a facility by the condition of a low initial level of vibroactivity (the use of self-balancing or structural balancing with counterweights, balance-beams, rotors, etc.).

Dynamic (active) vibration damping systems provide for the use of special devices, vibration dampers, which create dynamic counterinfluences to acting vibrations and decrease their effect. The simplest example of such systems is a mechanical gear linkage system of Lanchester used for balancing the inertia forces of the reciprocating masses in an internal combustion engine.

In order to protect facilities and biological objects (humans, first of all) from vibrations of the low-frequency range, where static systems are of low-inefficiency (especially from time-variant vibration spectra), automated dynamic vibro-protection systems are used.

Structural diagram of a vibro-protection dynamic system controlled by the excitation compensation method.

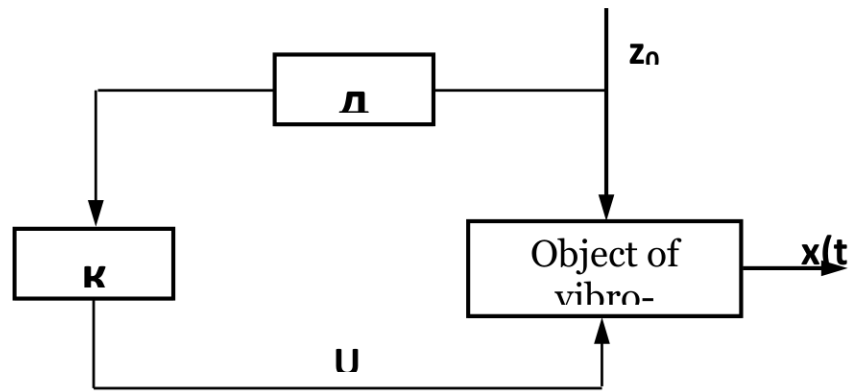


Figure 2.38

Such systems are controlled on the basis of excitation compensation methods, compensation of the deviations of a regulated variable, or their combination.

Control of such a system requires a possibility to register (modeled in design) vibration excitations and have appropriate execution modules of the structure for their compensation.

The diagram demonstrates that exaltation z_0 (e.g. vertical vibration displacements of an internal combustion engine) is perceived by sensitive element Π (sensor), the signal from which is transmitted to bucking-out system K which fulfils regulated counteraction U , which compensates excitation z_0 and supports the specified law of motion of object $x(t)$, while satisfying the requirements for the vibration level (degrees of compensations z_0).

Wear resistance is the capacity of material to resist wear.

The wear resistance of details considerably decreases under corrosion. Corrosion is the process of constant damage of surface layers of metal due to oxidation.

Heat resistance is the capacity of details of a facility to maintain operating capacity within the prescribed limits of a temperature change conditioned by the working process and friction in its mechanisms and units.

Excessive heating of details can cause:

- lower material strength,
- additional deformations and stresses,
- breakage of normal lubrication conditions (increased wear), and
- change in gaps of mating parts.

Calculations aimed at support and control of operation capacity are divided into two groups: design and test.

The objective of design (preliminary) calculations is determination of the basic sizes of details which satisfy most important criteria for the operation capacity.

Complete mechanical stress:

$$\overline{p_n} = \overline{\sigma} + \overline{\tau}, \quad (2.121)$$

where $\overline{\sigma}$ is the normal stresses;

$\overline{\tau}$ are the tangential stresses.

For example: the strength condition for a detail which bears tensile deformation:

$$\sigma_{max} \leq [\sigma], \quad [\sigma] = \sigma_{on} / n, \quad (2.122)$$

where σ_{on} is the unsafe stresses;

n is the safety factor.

Under complex deformation (e.g., calculation of shafts):

$$\sigma_{\text{экв}} \leq [\sigma], \quad (2.123)$$

where $\sigma_{\text{экв}}$ is the equivalent stresses.

The objective of revised calculations is determination of the safety factors in unsafe sections of details of facilities.

Condition of a safety factor:

$$S \geq [S], \quad (2.124)$$

where S is the safety factor in an unsafe section of a detail,

$[S]$ is the permissible values of a safety factor.

Reliability is the capacity of a facility to fulfill the prescribed functions (to maintain the operation capacity) during a needed time or running hours.

Criteria of reliability:

- refusal,
- durability,
- maintainability, and
- safety.

Refusal is a loss of operational capacity of a facility.

Durability is maintenance of operational capacity of a facility to the boundary state at which its further operation is impossible or inefficient.

Maintainability is the capacity of a facility regarding regeneration of operational capacity to prevent failures, reveal and remedy faults in maintenance and repair.

Safety is assurance of operation capacity during and after the prescribed terms of storage and transportation.

The probability of no-failure operation is widely used as a factor to assess operational reliability of a device in solving technical and engineering tasks; it demonstrates that within a given interval (running hours) no failures of the facility are registered.

Probability of no-failure operation:

$$P(t) = 1 - \frac{N(t)}{N}, \quad (2.125)$$

where $N(t)$ is the number of test facilities in which failures are registered,

N is the general number of test facilities.

Probability of no-failure operation of an engineering system:

If structural modules are connected in series:

$$P_{\Sigma nocn} = P_1(t) \cdot P_2(t) \cdot \dots \cdot P_n(t) = \prod_{i=1}^n P_i(t) \quad (2.126)$$

If structural modules are connected in parallel:

$$P_{\Sigma nap} = 1 - \prod_{i=1}^n [1 - P_i(t)] \quad (2.127)$$

Manufacturability of details and assembly units is characterized by the minimal expenditures of materials, time and labor in production, operation and maintenance.

Major ways to provide manufacturability of details:

- simple outline surfaces of details (cylindrical, conical, etc.) which are easy in the mechanical and physical treatment;

- use of building materials which require low-waste and resource-saving treatment technologies for manufacture of details (pressing, precision casting, laser, explosive, welding etc.); and
- effective use of a single system of tolerances and fits (grounded technical specification for manufacturing).

Efficiency is characterized by achieving a high cost-effectiveness of a facility in design, production and maintenance.

The basic quantitative factor of economic efficiency is the annual saving rate

$$E_z = (E_n + E_g) \cdot A_n, \quad (2.128)$$

where E_n , E_g are the savings at production and maintenance of a new facility, in comparison with the values of the facility replaced, respectively;

A_n is the annual output of a new facility.

Aesthety is the level of perfection and attractiveness of forms, exterior view of details, assembly units and the whole facility. Ecological compatibility is the no adverse effect level for humans and environment.

2.11 Basic types and characteristics of modern materials

A choice of materials for details and units of mechanisms is a very significant stage for a designer engineer. Therefore, some special requirements should be satisfied so that to provide operational capacity and reliability. For example, for mechanisms of aviation and space engineering the basic requirements are provision of the minimal mass and overall dimensions; for details working at sliding friction – wear resistance, at high temperatures – heat resistance etc. The technological characteristics of materials should conform to production methods (casting, press forming, cutting) and production types (series or mass). Besides, cost of the material chosen is of considerable importance.

Machine engineering uses the following materials for machine elements:

- ferrous metals:
 - ⇒ steels, and
 - ⇒ iron casts.
- non-ferrous metals:
 - ⇒ copper-based alloys (brass, bronze),
 - ⇒ tin-based alloys (babbits),
 - ⇒ aluminum alloys, and
 - ⇒ titanium alloys.
- combined materials:
 - ⇒ composite,
 - ⇒ reinforced, and
 - ⇒ metal-ceramic.
- non-metal materials:
 - ⇒ plastics, and

⇒ rubber.

The choice of a material is determined by:

- functionality of a detail,
- conditions of its operation,
- structural requirements,
- technological requirements, and
- efficiency requirements.

Steels are iron-carbon alloys in which the carbon content does not exceed 2%.

Steels are divided into carbon and alloy. Carbon steels are divided into:

- low-carbon ($C < 0,25 \%$),
- medium-carbon ($C = 0,25.....0,6 \%$), and
- high-carbon ($C > 0,6 \%$).

Carbon steels are divided into:

- steels of regular quality (Steel 0, Steel 1, ... , Steel 6)

They are used for production of basic and fastening details, and also additional, non-responsible details, which operate at low stresses.

Quality structural steels:

- grades 7.....10: used for details operating at constant stresses;
- grades 15.....20: used for details bearing insufficient dynamic loads;
- grades 30.....55: used for loaded details.

Marking of carbon steels uses figures indicating the carbon content in hundredth of percent (e.g. steel grade 40 means the carbon content is 0.40%).

The steel with low amount of carbon is characterized by high plasticity and weldability. When the carbon content increases the strength increases, the plasticity decreases and weldability worsens.

Alloy steels are produced from carbon steels by adding alloying elements (Cr - chromium, Ni – nickel, W – wolfram, Al – aluminum, Mn – manganese, Mo – molybdenum, Ti – titanium, etc.) in order to increase the indices of strength, yield, impact elasticity etc. The element factor in percent is indicated with figure after letter. If the figure is not included in the marking, the content of alloyed element is less than 1%.

According to the amount of alloying elements (AE) the steels are divided:

- low-alloy ($AE < 3\%$),
- medium-alloy ($AE = 3.0.....5.5\%$),
- high-alloy ($AE > 5.5\%$).

For example, steel 38Cr2Al

0.38% - carbon, 2% - chromium, 1% - aluminum).

Alloy steels are divided into:

- quality, and
- high-quality (letter *A* is added in marking):

(e.g., steel 12Cr2N4A – 0.12% carbon, 2% chromium, 4% nickel, A – high-quality steel).

Carbon and alloy steels are tempered, the process includes three stages: heating to a required temperature, soaking at this temperature and cooling with a prescribed speed. The basic types of the steel thermal treatment are:

- anneal: mainly used to decrease the hardness in order to facilitate mechanical treatment and relieve the internal stresses in steel. The annealing temperature depends on the carbon content in steel.

- normalization: used to improve the steel structure, relieve the internal stresses and provide better conditions for cutting. It differs from anneal by cooling in open air and not in a furnace.

- hardening: heating steel to a certain temperature, annealing at this temperature with a further rapid cooling in water, oil, melted salts or in air.

Annealing is used together with tempering to increase hardness, strength and wear resistance of steel.

At rapid cooling during anneal there appear internal stresses in metal, which can cause cracks, distortion and brittleness. These defects are eliminated with further tempering.

- tempering: heating steel to the temperature much lower than that during annealing, soaking at this temperature and cooling in air.

Details bearing the maximum stresses on the surface (flexure, torsion, contact stresses), are exposed to the surface hardening to increase the fatigue resistance. There exist the following methods of surface hardening: mechanical, thermal, surface, laser hardening, ion implantation.

Mechanical method. Better resistance of a detail to damages can be achieved by generating tension stresses on the surface. It is obtained with cold hardening by bead blasting with rolls or bullets. Bead blasting is the plastic deformation of the surface layer of a detail at a depth of 0.15 ... 0.30 mm with steel or iron shot which forcefully beats the surface. Cold hardening increases the surface hardness and the fatigue strength. With the same purpose cylinder-surface details are exposed to pressure rolling (axles of transport facilities, crankshafts).

Thermal method. Hardening is the basic method, at which a thin surface layer is heated and hardened with high-frequency currents, and the detail core remains viscous. The depth of a hardened layer is 0.5-1.0 mm, surface hardening is HRC 50-55, and the fatigue resistance increases 1.5 times on average.

Surface methods.

Cementation is saturation of the surface layer with carbon at heating to a temperature of 880-950°C with further hardening. Its objective is to gain a better hardness and wear resistance of the surface layer of a detail. Cementation is used for carbon and alloy steels with the carbon content to 0.25 %.

Carbonization of steel gives the cemented layer of a depth of 0.8-2.5 mm and surface hardness HRC 56-62.

Nitriding (surface saturation of steel nitrogen at heating to a temperature of 500-700°C in ammonia) increases the corrosion resistance in the atmospheric conditions, and the surface hardness. The depth of the nitriding layer is 0.3-0.5 mm. Nitriding is used for a better hardness, wear resistance of a surface layer and the corrosion stability mainly for a detail made of steels containing aluminum, chromium and molybdenum.

Cyanidation is surface saturation of steel with carbon and nitrogen simultaneously at a temperature of 530-550°C. It can be conducted in liquid, solid and gas media. Cyanidation is used to increase strength of twist drills and other high-speed steel tools and details of irregular shapes.

Laser hardening. It is used for hardening surface layers. The process implies melting a very thin layer under emission with rapid hardening and, thus, obtaining new properties. Advantages of laser hardening in comparison with traditional methods are a possibility to treat limited areas of a detail at a specified depth, including nooks of irregularly-configured details.

Ion implantation. It implies bombardment of the surface of a detail with ions of various chemical elements (carbon, nitrogen, boron, titanium), causing changes in the structure and chemical composition of the surface layer, and also increasing micro hardness and durability by several times. It is used to increase the strength of cutting tools.

Iron casts are ferricarbonic alloys, with the carbon content $C > 2\%$.

According to the structure, iron casts are divided into:

- white (characterized by a high hardness and brittleness),
- annealed (characterized by a high strength and low plasticity), and
- grey (characterized by a relatively high strength, wear resistance and damping capacity – vibration damping).

They are characterized by high antifriction, casting and anticorrosion capacities, besides, they have sufficient strength.

Brasses (basic alloying element is zinc) are divided into:

- double (copper and zinc alloys). For example, grades Л59, Л62, Л90 with the content of copper – 59, 62, 90 %, respectively,
- multicomponent (alloys with such elements as lead, silicon, manganese, aluminum, iron, nickel, brass, apart from copper and zinc). For example: grades CuSiPb 80-3-3 – 80% - copper, 3% - silicon, 3% - lead; CuMnPb 58-2-2 – 58% - copper, 2% - manganese, 2% - lead).

Brasses have good corrosion resistance, antifriction properties, electric conductivity, and good technological properties. And their cost is higher, than that, for example, of steels 45 by five times on average.

Bronzes (all copper alloys with the exception of brass) are divided by content of the basic alloying element into:

- tin, and
- tinless.

For example, bronze grades: tin-phosphorous БрОФ 10-1-1 (basic – copper, 10% - tin, 1% - nickel, 1% - phosphorus); aluminum-iron БрАЖ 9-4 (9% - aluminum, 4% - iron).

Bronzes have high antifriction and anticorrosion properties. And the cost of bronze is higher than that of steel 45 by ten times on average.

Babbits are fusible alloys based on tin, lead, zinc and aluminum with high antifriction properties; they are used as an antifriction material of liners for friction bearings.

The babbits are divided into:

- high-tin (alloy of tin with stibium and copper) the tin content is > 70%,

- tin-lead – the content of tin is 5.....20%, of stibium is 15% , of lead is 65.....75%,

- lead – the lead content is > 80%.

For example, babbitt grade B83 has 83% of tin. The cost of babbitts is several times higher than that of bronze.

Among aluminum-based alloys are:

- silumins (alloys of aluminum with silicon),
- duraluminium (alloys of aluminum, copper and magnesium).

Aluminum alloys are used as a casting material for making details of irregular shape, and also various bodies, shells, containers, pipes etc., of sufficient strength, and the specific weight of more than three times less in comparison with that of steel.

They are mostly used in aviation, rocket engineering and chemical machine building for manufacture of critical parts of high strength, heat resistance, corrosion resistance, but with low antifriction properties and low heat conductivity.

By specific weight they are 1.7 times lighter in comparison with steel, and by stability they are of the highest strength level among alloy steels.

Plastics by their strength characteristics are similar to some metals, and by corrosion resistance can be even better.

Among medium-strength materials are laminated plastics, such as getinax (paper-based laminate), textolite (cloth-based laminate), lignofol (lignin-based laminate).

Among high-strength materials are glass-fiber plastics.

Rubber is characterized by high elasticity, weather resistance, and shock absorbing properties.

2.12 Production specifications for machine tools

At present the machines and equipment production as well as their operation and maintenance is based on the principle of interchangeability of parts, assembly units and aggregates.

Interchangeability is the principle to design and manufacture details, which provides a possibility to assemble or change units, manufactured separately and with prescribed quality, without additional treatment and adjustment by maintaining the corresponding quality during repairs.

Interchangeability can be:

- complete (implies connection of all adjacent details in the process of assembly operations without additional treatment); and
- incomplete (implies connection of part of details produced with lower precision without additional treatment).

Size (quantitative value of parameters of a detail) is a numerical value (diameter, length, height, etc.) in chosen measuring units.

Sizes are divided into:

- actual is the dimension set by measuring with a permissible error;
- limiting is two permissible dimension (largest and smallest) between which an actual dimension should be; and
- nominal is the dimension relative to which the boundary dimensions are determined and which is used to read errors (set in designs).

There are upper and lower limiting deviations.

In standards:

- upper deviation in size is indicates as ES -holes, es -shaft,
- lower deviation – as EI -holes, ei -shaft.

Limiting deviations:

$$\begin{aligned} ES &= D_{max} - D, & EI &= D_{min} - D, \\ es &= d_{max} - d, & ei &= d_{min} - d, \end{aligned} \quad (2.129)$$

where D, d are the nominal size of a hole and a shaft,

D_{max}, d_{max} are the largest limiting size of a hole and a shaft,

D_{min}, d_{min} are the smallest limiting size of a hole and a shaft.

Limit sizes and tolerance zone for holes

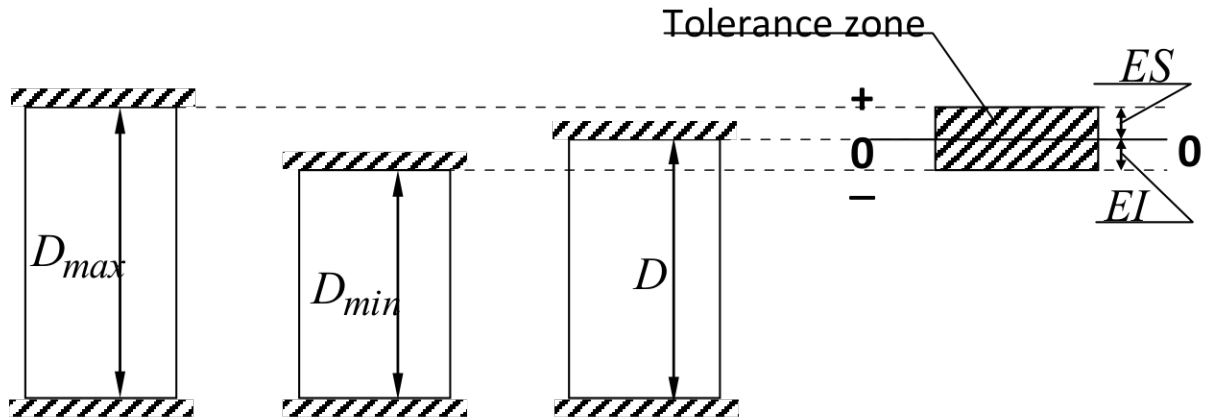


Figure 2.39

Table 2.1 The Techniques to Process the Grade Estimation in Order to Determine the Value of the System

Type of the generalized estimator	Formula	Geometry	Remarks
1	2	3	4
1. Absolute arithmetic mean	$\bar{p}_1 = \frac{\sum p_i}{n}$		Simple calculation
2. Relative arithmetic mean	$\bar{p}_2 = \frac{\sum p_i}{np_{\max}} = \frac{\bar{p}_1}{p_{\max}}$	Average value	Compare with the perfect version $p_2 \leq 1$
3. Weighed absolute arithmetic average	$\bar{p}_3 = \frac{\sum p_i g_i}{\sum g_i}$		Take into account the importance of the properties
4. Weighed relative arithmetic average	$\bar{p}_4 = \frac{\sum p_i g_i}{\sum p_{\max} g_i} = \frac{\bar{p}_3}{p_{\max}}$		$\bar{p}_4 \leq 1$
5. Absolute geometrical average	$\bar{p}_5 = \sqrt[n]{p_1 \dots p_i \dots p_n}$	Side of n -dimensional cube equivalent to the plate with sides $p_1 \dots p_n$	$p_5 = 0$ at $p_i = 0$
6. Relative geometrical average	$\bar{p}_6 = \bar{p}_5 / p_{\max}$		$\bar{p}_6 \leq 1$
7. Weighted absolute geometric mean	$\bar{p}_7 = \frac{\sqrt[n]{p_1 g_1 \dots p_n g_n}}{\sqrt[n]{g_1 \dots g_i \dots g_n}}$		Insignificant since g is like para. 4
8. Weighted relative geometric mean	$\bar{p}_8 = \bar{p}_7 / p_{\max}$		
9. Absolute vector	$\bar{p}_9 = \sqrt{p_1^2 + p_2^2 + \dots p_n^2}$		
10. Revative vector	$\bar{p}_{10} = \bar{p}_9 / p_{\max}$		$\bar{p}_{10} \leq 1$
11. Weighted absolute vector	$\bar{p}_{11} = \sqrt{(p_1 g_1)^2 + \dots + (p_n g_n)^2}$	Diagonal line n -gauge block with sides of $p_1 \dots p_n$	
12. Weighted revative vector	$\bar{p}_{12} = \bar{p}_{11} / p_{\max}$		$\bar{p}_{12} \leq 1$

Notes:

$p_1 - p_n$ - criteria estimation in grade system;

$1, \dots, n$ - index of grade estimations of the perfect version;

$g_1 - g_n$ - value of the estimation criterion;

p - generalized estimator;

n - number of estimation criteria;

p - the sum of estimation grades from to.

2.13 Analysis of the forces acting on the supporting structure of the flat car in operation

The main forces acting on the flat car in operation include [15-17]:

- the own weight of the flat wagon (tare) and the weight of the cargo;
- inertial forces appearing during oscillation;
- forces of an oscillatory or shock nature, as well as those that appear in the horizontal longitudinal plane during different modes of train movement and shunting work.

The forces listed above in the calculation and design of wagons lead to the following schemes of their application:

- vertical load: static and dynamic;
- lateral load;
- longitudinal;
- a combination of self-balanced forces;
- the load acting on the flat car through the fitting stops.

The vertical load consists of the sum of the tare, payload, and vertical dynamic load.

Vertical loads.

The main vertical load consists of tare weight, useful, and vertical dynamic loads.

The vertical force due to the tare weight and payload is called vertical static and is determined by the formula:

$$P_B^{cm} = \frac{P_{\sigma p} - P_q}{m}, \quad (2.130)$$

where P_{br} – the gross weight of the wagon;

R_h – the weight of the parts of the wagon from which the load is transferred to the rail track from those parts that are calculated;

m is the number of parts of the same name loaded in parallel.

The gross vehicle weight is determined by the formula:

$$P_{\text{gp}} = (P + T) \cdot g, \quad (2.131)$$

where P is the carrying capacity of the wagon;

T – wagon container;

g - acceleration of free fall.

The vertical dynamic load is calculated according to the formula:

$$P_{\text{с}}^{\text{d}} = P_{\text{с}}^{\text{cm}} \cdot k_{\text{дс}}, \quad (2.132)$$

where k_{dv} is the coefficient of vertical dynamics, which is calculated

$$k_{\text{дс}} = \frac{\bar{k}_{\text{дс}}}{\beta} \cdot \sqrt{\frac{4}{\pi} \cdot \ln\left(\frac{1}{1 - P(k_{\text{дс}})}\right)}, \quad (2.133)$$

where $\bar{k}_{\text{дс}}$ – mathematical expectation ;

β – distribution coefficient, for freight wagons $\beta = 1.15$;

$P(k_{\text{dv}})$ – and the coefficient of vertical dynamics, $P(k_{\text{dv}}) = 0.97$.

$$\bar{k}_{\text{дс}} = a + 3,6 \cdot 10^{-4} \cdot b \cdot \frac{V - 15}{f_{\text{сr}}} \quad (2.134)$$

where a is a dimensionless coefficient depending on the type of node, $a = 0.05$;

b is the coefficient of basicity and is calculated according to the formula:

$$b = \frac{n' + 2}{2 \cdot n'} \quad (2.135)$$

where n' – the number of axles in a wagon or in groups of wagons at one end of the wagon, $n = 2$.

V – design speed, $V = 33$ m/s;

f_{cr} – static deflection of the spring strut, $f_{cr} = 0.45$ m

The centrifugal force is calculated by the formula:

$$H_u = P_{\sigma p}^{\kappa} \cdot \eta, \quad (2.136)$$

where η – coefficient for freight wagons, $\eta = 0.075$.

Lateral loads.

Wagon load is determined

$$H_{\sigma} = \omega_{\sigma} \cdot F_{\sigma}, \quad (2.137)$$

where ω_{σ} – specific wind pressure, $\omega_{\sigma} = 0.5$ kN/m²;

F_{σ} – the area of the side projection of the body with cargo.

Lateral forces of dynamic interaction between the wagon and the track (frame force)

$$H_p = \bar{H}_p \cdot \sqrt{\frac{4}{\pi} \cdot \ln\left(\frac{1}{1 - P(H_p)}\right)} \quad (2.138)$$

where $\bar{H}_p$ – mathematical expectation of frame effort;

$P(H_p)$ is the probability of frame force, $P(H_p) = 0.97$.

Then the mathematical expectation of the frame force is equal to

$$\bar{H}_p = q_0 \cdot b \cdot \sigma \cdot (5 + V), \quad (2.139)$$

where σ – coefficient depending on the type of running parts, $\sigma = 0.003$;

q_0 – axial load.

Inertial load is calculated

$$N_i^{ky3} = N \cdot \frac{m}{M_{6p}}, \quad (2.140)$$

where N is the normalized value of the longitudinal load applied to the auto coupling;

M_{6p} – gross weight of the wagon;

m is the mass of the body.

Vertical force caused by the action of lateral forces

$$P_{\epsilon}^{\sigma} = \frac{H_u \cdot h_u + H_{\epsilon} \cdot h_B}{m' \cdot b'}, \quad (2.141)$$

where H_u, H_B – centrifugal and wind loads, respectively ;

h_{ts}, h_{in} – vertical distances from the point of application of efforts to the point of additional loading or unloading;

m' – the number of nodes of the same name loaded in parallel;

b' – the horizontal distance between the points of additional loading and unloading.

The vertical force applied to the stops of the auto coupling is determined

$$P_{\text{B}}^{\text{y.a.}} = \pm N \cdot \frac{l}{2a}, \quad (2.142)$$

where N – normalized longitudinal force;

l – the difference in the level of the coupling axles;

and is the calculated length of the body of the auto coupling (when compressed $a = 1$ m, when stretching $a = 0.9$ m).

Lateral forces acting on the wagon through the auto coupling device:

– when braking

$$P_N = N \cdot \left(\frac{\delta \cdot L}{l_6^2} \cdot \left(1 + \frac{L}{a} \right) \cdot \frac{L_c}{R} \right) \cdot \frac{l_6}{L}, \quad (2.143)$$

where N – normalized longitudinal force;

δ – a one-sided displacement of the bolt section of the body is possible due to the gaps between the elements of the wagon;

L - half the distance between the rear abutment surfaces of the abutments of the auto-coupling device;

L_c – half the length of the wagon along the axles of couplings;

l_b – half of the wagon base;

R – calculated curve radius.

Longitudinal loads.

Longitudinal loads are tensile and compressive forces (quasi-static and dynamic) arising from the interaction of wagon wagons and locomotives during various modes of train movement and shunting operations, as well as inertial forces that arise at the nodes of wagons.

Tensile and compressive forces are applied respectively to the front and rear stops of the auto-coupling device. Their values are accepted as normative for calculation modes and are listed in Table 2.2.

Table 2.2 – Values of longitudinal forces acting on the flat wagon in operation

<i>The magnitude of the longitudinal force, MN</i>			
<i>Calculation modes</i>			
<i>AND</i>		<i>III</i>	
<i>Quasi-static power</i>	<i>A blow, a jerk</i>	<i>Quasi-static power</i>	<i>A blow, a jerk</i>
- 2.5	- 3.5	- 1.0	- 1.0
+2.0	+2.5	+1.0	+1.0

“ + ” sign indicates stretching, jerking forces, and “ – ” – compression force, impact force. The time of action of impulse forces (impact, jerk) is taken as 0.3 s.

The following patterns of action of longitudinal forces are established:

– quasi-static stretching or compression applied to the stops of the auto coupling at both ends of the wagon;

- impact or jerk forces applied to the stops of the autocoupling of one end wagon and are balanced by the forces of inertia of the wagon masses.

2.14 Classification of rolling stock dimensions

More than 120 years ago (March 18, 1860) in our country, for the first time in the world, the uniform dimensions of the approach of buildings and rolling stock were established, mandatory for all railways.

Introduced in 1934. OST 6435 provided for broad-gauge wagons (1524 mm) three dimensions:

O – for wagons allowed to travel on the railways of the Soviet Union and its neighboring states;

1-B – for wagons traveling on all railways of the USSR;

2-B – for wagons intended for rotation in separate closed directions.

There were also three dimensions for locomotives: 1-P, 1-Pb and 2-P.

GOST 9238-59 and GOST 9238–73 were introduced instead of the former standard, six uniform rolling stock dimensions were established for wagons and locomotives: T, 1-T, 0-T, 01-T, 02-T and 03-T.

Gauge T (Figure 2.1 a), which has the largest dimensions of width and height, is intended for wagons rotating along separate closed directions of the reconstructed railways of the USSR and Mongolia People's Republic (MNR). On the main contour outlined by solid lines 1, electric train wagons are being built, and in recent years, some freight wagons. Here, as in other dimensions, the limit for placement of signal devices on wagons is line 2, and for non-relevant parts (handrails, visors for water flow, shields, etc.) - a dash-dotted line. On the contours shown by dashed lines and marked with the letters аа1б1в1вр, аа1бвр and д1е1, wagons can be built with the permission of Ukrzaliznytsia after the rearrangement of buildings, tunnels and other artificial structures, and for rolling stock rotating only on the territory of industrial enterprises - with the permission of the relevant ministry or department in agreement with Ukrzaliznytsia.

Gauge 1-T (Figure 2.1 b) is intended for wagons that are allowed to turn around on all railways of the former USSR and the MNR. Wagons can be built according to the aalbvq contour after rearranging or removing rafter braces and overhangs of building roofs and platform canopies at railway stations.

The 0-T gauge (Figure 2.1c) is provided for wagons running on the railways of the former USSR and the MNR, as well as on individual reconstructed trunk lines of other countries participating in the Organization of Railway Cooperation (ORC).

In order to ensure the unhindered turning of wagons, work is being done to unify the dimensions and bring the railways into compliance with the uniform dimensions being introduced in the countries participating in the OZ. The size 0-T according to the OSZ classification is designated 1-VM

Size 01-T (Figure 2.1 g), which is indicated by classification OSZ 0-VM, designed for wagons traveling on all roads (except for some minor sections) of countries participating in the OSZ.

The 02-T gauge (Figure 2.1d) is provided for wagons that run on all railway lines of the countries participating in the OZ, as well as the railways of Germany, Austria, Yugoslavia, Greece and the European part of Turkey, without exception.

Gauge 03-T (Figure 2.1 e) is intended for wagons that are allowed to turn on the roads of all European and Asian countries.

2.15 Determination of the vertical dimensions of the construction outline of the wagon

This calculation of fitting into the dimensions of 1-BM is carried out in connection with the development of a wagon for the transportation of alumina.

The calculation is performed in accordance with GOST 9238-83 and the Instructions for the application of dimensions of rolling stock (GOST 9238-83).

A wagon for the transportation of alumina fits into the dimensions of 1-BM, based on the condition of providing it with the possibility of passing mechanized sorting slides at any position of the wagon retarder and tracks equipped with devices for pushing wagons.

The vertical dimensions of the dimensions of the rolling stock from above are at the same time the maximum building dimensions that the rolling stock designed for it can have in height in an unloaded state.

The smallest permissible vertical dimensions of the designed rolling stock at the bottom are obtained by increasing the corresponding vertical dimensions of the overall dimensions of the rolling stock by the amount of the static parallel lowering of the rolling stock possible in operation due to the maximum normalized wear of the running parts, and for sprung parts due to the uniform settling of the springs.

The maximum horizontal building dimensions of rolling stock that are allowed are obtained by reducing the transverse dimensions of the corresponding overall size of rolling stock on each side by the values of the necessary restrictions E_o , E_v , E_n .

The maximum permissible width of rolling stock, $2V$, mm, at a certain height H above the level of the top of the rail head, is determined by the formula:

$$2B = 2(B_o - E) \quad (2.144)$$

where B is the half-width of the corresponding dimensions of the rolling stock at the given height;

E is one of the above restrictions E_o , E_v , E_n .

The limitation of E_o , mm, of the guide cross-sections of the rolling stock, i.e. the cross-sections having the smallest transverse displacements relative to the track axis, is determined by the formula:

$$E_o = 0,5(S - d) + q + w + (\kappa_1 - \kappa_2) - \kappa \quad (2.145)$$

Internal limitation E_v , mm of cross-sections of rolling stock located between its guide sections:

$$E_o = 0,5(S - d) + q + w + [\kappa_2(l - n) \cdot n + \kappa_1 - \kappa_3] - \kappa + \alpha \quad (2.146)$$

External limitation E_n , mm of cross-sections of the rolling stock, located outside its guide sections:

$$E_n = [0,5(S - d) + q + w] \cdot \frac{2n + l}{l} + [\kappa_2(l + n) \cdot n - \kappa_1 - \kappa_3] - \kappa + \beta \quad (2.147)$$

For the designation of values given in the formulas, see GOST 9238-83 and "Instructions for the use of dimensions of rolling stock GOST 9238-83".

We find the following values of the coefficients:

- for points with coordinates 1675,430 mm and all points above:

$K = 0$;

$K_1 = 0.625 \cdot (2lt)^2$;

$2lt$ - cart base, m;

$$K_2 = 2.5;$$

$$K_3 = 180.$$

- for points with coordinates 1520,430 mm and all points below:

$$K = 25;$$

$$K_1 = 0.625 \cdot (2lt)^2;$$

$$K_2 = 2;$$

$$K_3 = 0.$$

Numerical values of α and β are accepted for the upper part of the dimension 1-BM:

$$\alpha = 0 \text{ if } l \cdot n - n^2 + 0,25 \cdot (2l_m)^2 \leq 72;$$

$$9 \cdot 1,5 - 1,5^2 + 0,25 \cdot 1,85^2 \leq 72;$$

$$12.1 < 72;$$

$$\beta = 0 \text{ if } l \cdot n + n^2 - 0,25 \cdot (2l_m)^2 \leq 120;$$

$$9 \cdot 1,5 + 1,5^2 - 0,25 \cdot 1,85^2 \leq 120;$$

$$14.9 < 120.$$

For rolling stock of railways, the value of $0.5(Sd)$ is determined in the upper part of the 1-BM dimension under the condition of passage along a track with a width of 1520 mm and is taken as:

- in the curve of the calculated radius $0.5(Sd) = 28.5$ mm;
- in a straight line $0.5(Sd) = 20.5$ mm.

In the lower part of the 1-VM gauge, under the condition of passing along a track with a width of 1435 mm $0.5(Sd) = 27.5$ mm.

$$f_2 = P_p \cdot \lambda_2, (2.5)$$

where P_p is the calculated load for one cart;

λ_2 is the flexibility of the trolley's spring suspension

Total possible decreases in transverse displacements $(q + w)$, mm

Cart frame and parts attached to it 3

The spring beam and the parts attached to it 27

The frame of the wagon and the parts attached to it 31

Design limitations for the wagon body.

For points 1...11:

$$E_0 = 0.5 \cdot (s - d) + q + w + \Delta q_{4i} + \Delta k_0 - k \quad (2.148)$$

$$E_g = 0.5 \cdot (s - d) + q + w + \Delta q_{4i} + \Delta k_g - k + \alpha \quad (2.149)$$

$$E_u = [0.5(s - d) + q + w] \cdot \varphi + \Delta q_{4i} + \Delta k_u - k + \beta \quad (2.150)$$

$$0.5(s - d) = 0.5[1530 - (1437 + 2 \cdot 26)] = 20.5 \text{ mm}$$

$$q + w = 31 \text{ mm.}$$

$$\Delta q_{4i} - \text{for rigidly fixed parts, } \Delta q_{4i} = 0.$$

$$\Delta k_0 = (k_1 - k_3) = (0.625 \cdot 1.85^2 - 180) > -10.$$

So it is equal to zero.

$$\Delta k_g = k_2(l - n_{gi}) + k_1 \cdot k_3 = 2.5 \cdot (9 - 4.5) + 0.625 \cdot 1.85^2 - 180 = 13.38 - 180 > -10,$$

$$E_0 = E_g = q' + q'' + 0.5 \cdot (w' + w'') + \Delta qji \quad (2.151)$$

$$E_u = [q' + q'' + 0.5 \cdot (w' + w'')] \cdot \varphi + \Delta qji, \Delta qji = 0 \quad (2.152)$$

2.16 Determination of the horizontal dimensions of the construction outlines of the wagon

For upper outlines of all dimensions and lower outlines up to 13 points inclusive

$$B_i = B_i^w - E \quad (2.153)$$

where B_i^w – half-width of the dimension at the height of the i-th point;

E is the limitation found for the part of the rolling stock under consideration;

The half-width of the construction outline obtained by this formula should not be more 1625 mm within points 10...11 of dimension 1–VM.

For the lower outline of the chairs. 15d number.

Points 14 or more.

Points 14, 17 $V_i = 720 + E$,

Points 18, 19 (only for brake rods):

$$B_i = B_i^w - E \quad (2.154)$$

When calculating all wagons, the following main forces must be taken into account:

- own gravity (weight) of the structure (tare) and gravity (weight) of the cargo;
- inertial forces caused by oscillating accelerations of masses when the wagon moves along road irregularities;
- forces that arise when the wagon moves along curves and turns;

- aerodynamic forces (wind pressure forces, etc.);
- forces of interaction between wagons, between the wagon and the locomotive and between the wagon body and the load in different modes of train movement and shunting, as well as the resulting longitudinal forces of inertia.

Depending on the purpose and features of the design [122-139] of the wagons, along with the above, the tension forces (pressure) of loose and bulk cargoes should also be taken into account.

The listed forces are reduced to the following main calculation schemes of their application:

- vertical load;
- lateral load;
- longitudinal load;
- separate groups of self-equilibrated forces: horizontal from the strut of bulk loads.

Wagon bodies and carriages are calculated first of all for the most unfavorable possible combination of simultaneously acting main and additional forces in accordance with the established calculation regimes.

Calculation forces, as a rule, are conditionally accepted as acting independently of each other.

The main calculated vertical forces include:

- own gravity of the wagon $Q_{\text{por.v}} = 201.105 \text{ kN (20.5t)}$ (taken into account automatically in the program when calculating own weight calculations schemes);
- force of gravity of cargo $Q_{\text{vant.}} = 779.895 \text{ kN (79.5t)}$;
- vertical dynamic load, which occurs during the oscillations of the wagon on the springs and the interaction of the wagons during the movement of the train and shunting work.

The approximate vertical dynamic load is determined by multiplying the gross force of gravity (weight) by the coefficient of vertical dynamics K_{dv} .

The gross gravity is understood as the gravity of the load Q_{quantity} and own gravity (weight) of the elements of the wagon $Q_{\text{vant.}}$ body, located above the degree of spring suspension under consideration, including 1/3 of the gravity of the spring suspension itself.

The weight of the loaded body $Q_{\text{vant.}}$ body:

$$Q_{\text{vant.}} = Q_v - Q_{\text{tei}} - Q_{\text{tel}} \quad (2.155)$$

Gross gravitational force Q_{brutto} :

$$Q_{\text{brutto}} = Q + 2Q_b + \frac{1}{3} \times 4Q_{\text{res}}, \quad (2.156)$$

where $Q_b = 5.071$ kN is the weight above the spring beam;

$Q_{\text{res}} = 1.5$ kN - weight of one spring set.

We apply the forces from the listed components of the static vertical load, as well as the weight of the braking and auto-coupling equipment, to the nodes of the calculation scheme.

In the first design load mode, the additional dynamic force is not taken into account when calculating the strength of the body.

In the case of the third load design mode, the additional dynamic force is determined by multiplying the active static vertical load by the coefficient of vertical dynamics $K_{dv} = 0.353$

Vertical dynamic load Q_{dyn}

$$Q_{\text{dyn}} = K_{dv} \times Q_{\text{brutto}} \quad (2.157)$$

The vertical dynamic force (additive) on the cart due to the action of the longitudinal force of inertia of the body is determined by the formula:

$$P_z = N_{in} \times \frac{h_k}{2l} \quad (2.158)$$

where $2l = 10.5$ m - the base of the wagon;

N_{in} is the longitudinal force of inertia of the gross body, determined by the formula:

$$N_{in} = N \times \frac{m_{kuz}}{m_{wag}}, \quad (2.159)$$

where $N = 3500$ kN is the external longitudinal impact force applied to the auto coupling;

$t_{kuzova} = 90.494$ t - weight of the loaded wagon body;

$t_{wagon} = 100.00$ t - total weight of the wagon;

h_k - the distance from the center of gravity of the loaded body to the axle of the auto coupling:

$$h_k = h_{navant.} - h_a, \quad (2.160)$$

where $h_{navant.body} = 2,392$ m – the height of the center of gravity of the loaded body from the level of the rail head;

$h_a = 1,060$ m – distance from the axis of the auto-coupling to the head of the rail;

When summing up with the rest of the loads in Mode 1, the vertical supplement from the longitudinal inertia force of the body is taken into account

in the amount of 50%; when summing up only with the force of gravity, the gross is taken into account in the amount of 100%.

Longitudinal forces are compressive and tensile forces of interaction between wagons and between a wagon and a locomotive, arising in different modes of train movement (when touching from a place, changing the speed of movement, braking) and shunting operations, as well as the resulting inertial forces perceived at nodes and details of wagons.

1 mode – (+2500 kN) – longitudinal quasi-static compression force, applied to the rear persistent kerchiefs automatic clutch;

(+2500 kN) - longitudinal quasi-static tensile force, applied to the rear persistent kerchiefs automatic clutch;

1 mode – (-3000 kN) – longitudinal compressive force (impact) applied to the rear persistent clutches;

3 mode – (-1000 kN) – longitudinal compressive force applied to rear persistent auto clutch clutches;

(+1000 kN)-longitudinal tensile force applied to rear persistent auto clutch clutches.

In accordance the lateral force, equal to the difference between the centrifugal force and the horizontal component of the force of gravity, which arises as a result of the elevation of the outer rail, taking into account the dynamism coefficients for freight wagons, is taken into account when calculating the wagon according to the 3rd calculation mode and is taken as equal to 7.5% of the force of gravity gross. The equivalent force of the specified force is considered to be applied at the center of mass of the body with the load. During the preliminary calculation of the side walls and pivot beams of the wagon body frames on the vertical forces, the influence of the lateral forces can be taken into account by increasing the gross force of gravity by 10%.

Centrifugal lateral force:

$$P_s = Q_{\text{brutto}} \times 0,1 \quad (2.161)$$

Transverse forces of interaction between wagons in curves when the train is moving at low speed and shunting are determined by the following formulas:

- for the case of tensile longitudinal forces:

$$P_N = H = N \times \frac{L_C}{R} \quad (2.162)$$

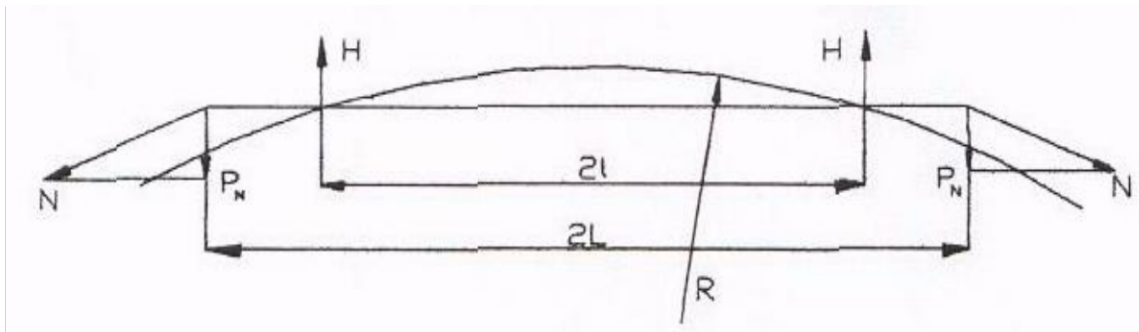


Figure 2.41

- for the case of compressive longitudinal forces:

$$P_N = H \times \frac{l}{L} = N \times \left(\frac{\delta \times L}{l^2} \times \left(1 + \frac{L}{a} \right) + \frac{L_C}{R} \right) \times \frac{l}{L}, \quad (2.163)$$

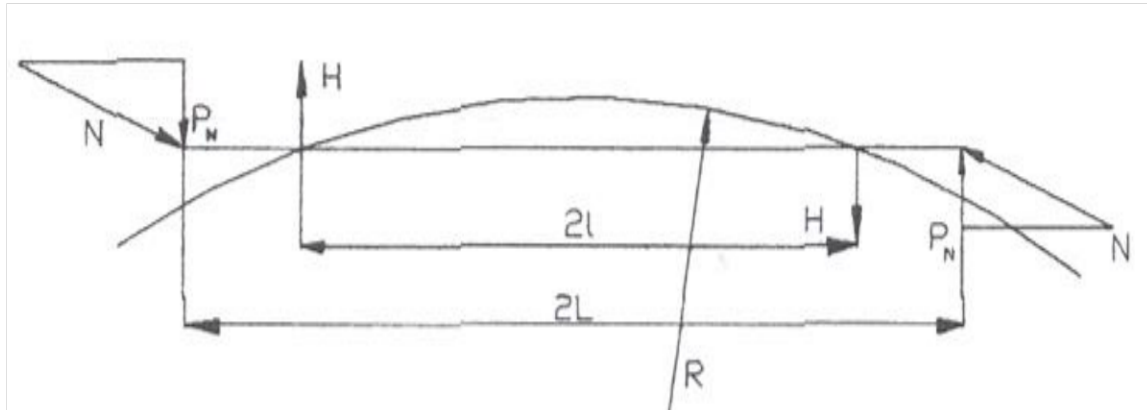


Figure 2.42

where N is the quasi-static force applied along the body axis self-clutch, the value of which is assumed to be equal to:

- for the case of action of tensile longitudinal forces $+2.5$ MN;
- for the case of compressive forces -2.5 MN;

N - horizontal transverse forces acting on the hinges;

$R = 250$ m - radius of the curve;

$2l = 9,000$ m - base of the wagon;

$2L = 11,200$ m - the distance between the thrust plates of auto couplings;

$2LS = 13,220$ m - the length of the wagon along the coupling axes of the couplings;

and– calculated length of the auto clutch housing (for CA-3 with compression $a = 1$ m);

δ - the possible lateral movement of the bolt section of the wagon body due to the clearances of the wheel pair in the rail track, the clearances in those of the axle guides, hinges and elastic deformations of the springs, is accepted when calculating freight wagons -40 mm.

The PN force is applied to the body frame in the plane of the front persistent struts of the auto-coupling device in the case of tensile forces and in the plane of the rear thrust struts in the case of compressive forces.

For calculation modes I and III, the strength assessment of the metal structure of the body of a four-axle semi-wagon was carried out taking into account the following operational loads.

a) longitudinal impact load, along the axis of the autocoupling, which is minus 3.5 MN, I mode;

b) longitudinal jerk load, along the axis of the autocoupling, which is equal to +2.5 MN, I mode;

c) longitudinal compressive load, along the axis of the autocoupling, which is minus 2.5 MN, I mode;

d) longitudinal tension load, along the axis of the autocoupling, which is equal to +2.0 MN, I mode;

e) longitudinal compressive load, along the axis of the autocoupling, which is minus 1.0 MN, III mode;

f) longitudinal tension load, along the axis of the autocoupling, which is equal to +1.0 MN, III mode;

g) vertical static load from the tare weight of the body, taking into account the payload, modes I and III;

i) vertical dynamic load from the tare weight of the body, taking into account the useful load, with the coefficient of vertical dynamics K_{dv} , III mode;

k) load due to the eccentricity of the longitudinal force during the non-central interaction of two adjacent wagons with a difference in the heights of the couplings.

l) loading by lateral forces of interaction between wagons in curves during train movement and shunting work;

m) repair loads;

Calculation of coefficients of vertical dynamics.

The calculation of the coefficient of vertical dynamics K_{dv} for the III mode was performed same time, the technical characteristics of the cart model 18-4129 were used.

The average value of the coefficient of vertical dynamics K :

$$k_{\partial g} = a + 3,6 \cdot 10^{-4} \cdot b \frac{V - 15}{f_{cm}^i}, \quad (2.164)$$

where a is a coefficient equal to 0.05 for body elements;

b - a coefficient that takes into account the effect of the number of axles n in a trolley or a group of trolleys under one end of the crew (for two-axle trolleys $b = 1$);

V - speed of movement in accordance with the accepted calculation mode, (III mode 33.3 m/s);

f_{cm} static deflection of spring suspension, (III mode 0.0453 m).

$$\overline{k_{\partial g}} = a + 3,6 \cdot 10^{-4} \cdot b \cdot \frac{V - 15}{f_{cm}^i} = 0,05 + 3,6 \cdot 10^{-4} \cdot 1 \cdot \frac{33,3 - 15}{0,0453} = 0,195$$

The coefficient of vertical dynamics of the k_{dv} :

$$k_{\partial g} = \frac{\overline{k_{\partial g}}}{\beta} \sqrt{\frac{4}{\pi} \cdot \ln \frac{1}{1 - P(k_{\partial g})}}, \quad (2.165)$$

where k_{dv} is the average value of the coefficient of vertical dynamics,

β - distribution parameter, specified according to experimental data, for of wagon parts under existing operating conditions $\beta = 1.13$;

$P(k_{dv})$ - confidence probability, when calculating strength based on allowable stresses, $P(k_{dv}) = 0.97$ is taken;

$$k_{\sigma\sigma} = \frac{\overline{k_{\sigma\sigma}}}{\beta} \sqrt{\frac{4}{\pi} \cdot \ln \frac{1}{1 - P(k_{\sigma\sigma})}} = \frac{0,195}{1,13} \sqrt{\frac{4}{\pi} \cdot \ln \frac{1}{1 - 0,97}} = 0,365.$$

The calculation of the cantilever part of the wagon was performed from the action of the vertical force P , MH , the value of which was determined according to the diagram in Figure 2.43

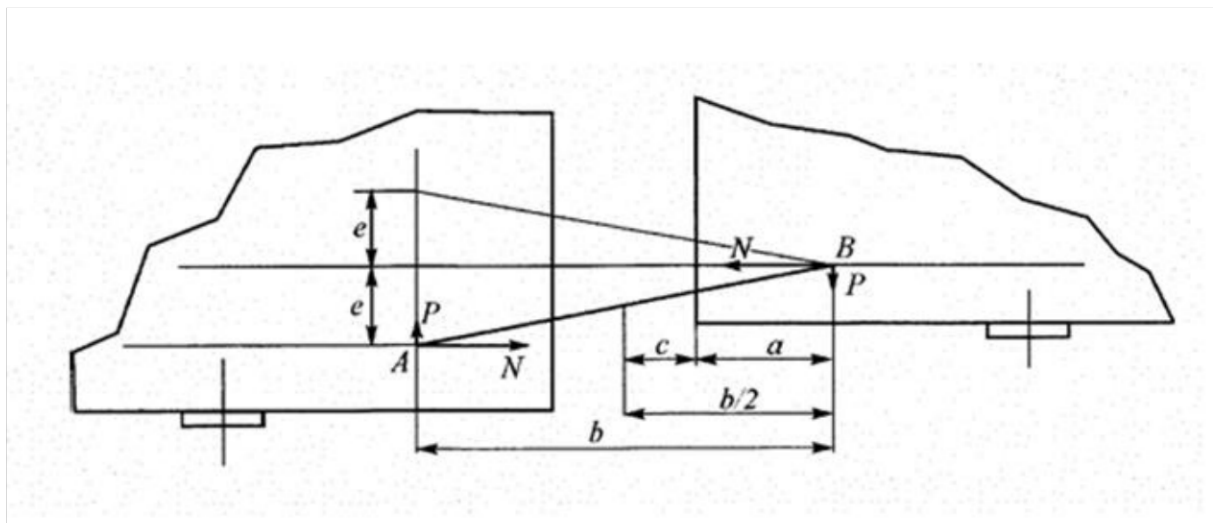


Figure 2.43

$$P = \pm N \cdot \frac{e}{b}, \quad (2.166)$$

where N - 3.5 MN - the value of the calculated longitudinal force;

e - 0.1 m - the difference in the levels of the axles of the coupled wagons;

b - the length of the rigid rod formed by two coupled autocouplings at conventional hinges at the points of support for wagons A and B. For typical wagons with CA-3 type autocoupling (installation according to GOST 3475-81) it is accepted in compression $b = 2$ m, in tension $b = 1.81$ m.

The additional vertical force P, MN, at values of the longitudinal force of 3.5 MN is:

$$P = \pm N \cdot \frac{e}{b} = -3,5 \cdot \frac{0,1}{2} = -0,175 \text{ MH.}$$

The additional vertical force P, MN, at values of the longitudinal force of 2.5 MN is:

$$P = \pm N \cdot \frac{e}{b} = -2,5 \cdot \frac{0,1}{1,81} = -0,14 \text{ MH.}$$

Calculation of lateral forces arising during the interaction of wagons in curves. Load diagrams for cases of compressive and tensile forces are shown in Figure 2.44 and 2.45 (respectively). Lateral forces were determined by the following formulas:

- for the case of compressive forces (I mode):

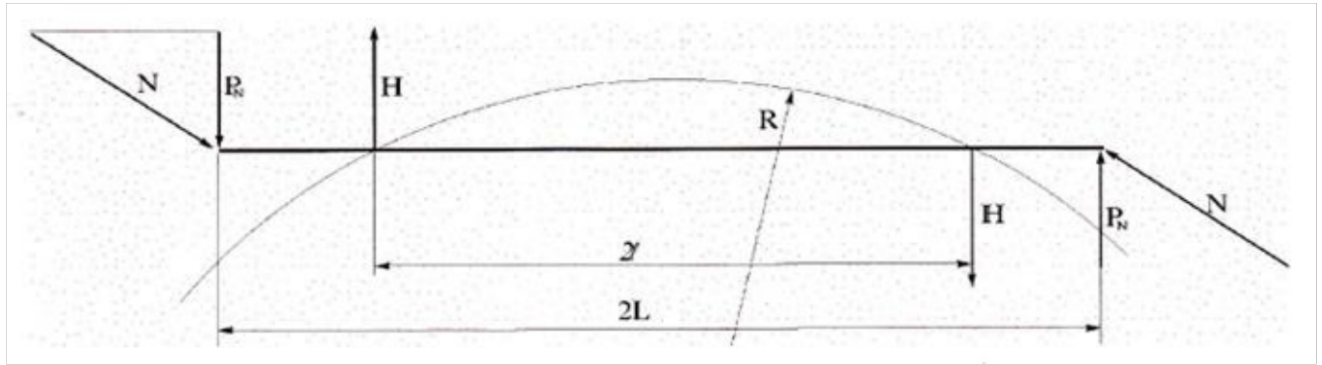


Figure 2.44

$$P_N = N \cdot \left(\frac{\delta \cdot L}{\ell^2} \left(1 + \frac{L}{a} \right) + \frac{L_c}{R} \right) \cdot \frac{\ell}{L}, \quad (2.167)$$

where $N = 2.5$ MN is the longitudinal force applied along the axis of the autocoupling during a collision according to the I load mode;

R - 250 m - radius of the curve;

l - 4.325 m - half of the wagon base;

L - 5.96 m - half the distance between the thrust plates of auto couplings;

L_c - 6.96 m - half the length of the wagon along the axles of the couplings;

P_N - horizontal transverse component of the longitudinal force;

a - 1 m - the length of the body of the auto coupling;

δ - 0.038 m - possible lateral movement of the pivot cross-section of the wagon body due to the clearances of the wheel pair in the rail track and the clearances in the axles and axles;

Lateral forces at compressive force values of 2.5 MN are:

$$P_N = N \cdot \left(\frac{\delta \cdot L}{\ell^2} \left(1 + \frac{L}{a} \right) + \frac{L_c}{R} \right) \cdot \frac{\ell}{L} = 2500 \cdot \left(\frac{0,038 \cdot 5,96}{4,325^2} \left(1 + \frac{5,96}{1} \right) + \frac{6,96}{250} \right) \cdot \frac{4,325}{5,96} = 203,524 \text{ кН}$$

- for the case of tensile forces, the lateral force P_N , кн.

$$P_N = N \cdot \frac{L_c}{R}, \quad (2.168)$$

where $N = 2.0 \text{ MN}$ is the longitudinal quasi-static force applied along the axis of the autocoupling for the I load mode;

$L_c = 6.96 \text{ m}$ - the length of the wagon along the coupling axes of the couplings;

$R = 250 \text{ m}$ - radius of the curve

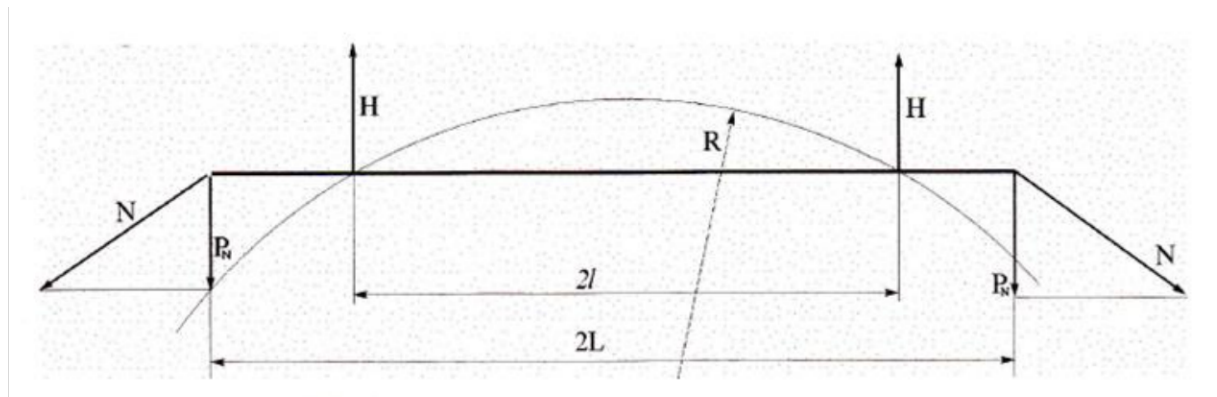


Figure 2.45

The lateral force, P , кН, according to the III calculation mode, was assumed to be equal to 12.5% of the gross weight of the body

$$P_N = 0.125 \times P_{\text{brutto}} \quad (2.169)$$

$$P_{\text{brutto}} = Q_{\text{br}} - Q_{\text{viz1}} - Q_{\text{viz2}} \quad (2.170)$$

where Q_{br} is the weight of the wagon (gross) 100,000 kg;

$Q_{\text{viz1}}, Q_{\text{viz2}}$ -the weight of the carts is 10,600 kg,

Vertical dynamic force (addition) of the longitudinal force of inertia.

The vertical dynamic force (additive) P_z , MH, from the longitudinal force of inertia was determined by the formula:

$$P_z = N_{\text{in}} \frac{h_k}{2l}, \quad (2.171)$$

where N_{in} is the longitudinal force of inertia of the body, node, cargo;

h_k - the distance from the center of gravity of the body, the node to the axis of the coupling (1.425 m - for the body);

$2l$ -wagon base - 8.65 m.

The longitudinal force of inertia N_{in} MH was determined by the formula:

$$N_{\text{in}} = N \frac{m}{m_{\text{bar}}} \quad (2.172)$$

where N is the longitudinal impact or jerk force applied to the auto coupling;

m - the mass of the body, assembly, cargo for which the longitudinal inertia force was determined (gross mass of the wagon (without carts) - 89.4 t), m_{bar} - mass of the wagon - 100 t.

The values of longitudinal forces of inertia and vertical additions of longitudinal forces of inertia determined according to formulas are given in table 2.3.

Table 2.3 - Longitudinal forces of inertia of individual wagon masses (MN)

<i>Longitudinal force</i>	<i>Longitudinal force of inertia (MN)</i>	<i>The value of the vertical dynamic additive (MN)</i>
<i>Impact (3.5 MN)</i>	<i>3.13</i>	<i>0.52</i>
<i>Jerk (2.5 MN)</i>	<i>2.24</i>	<i>0.37</i>

Self-balanced loads.

The main self-balanced load for the modernized semi-wagon is the strut forces from the bulk cargo.

Active (static) pressure of bulk cargo spacer per unit area of body walls, $R_a, \text{N/m}^2$,

where k_{dv} is the coefficient of vertical dynamics, taken during the calculation according to the I mode $k_{dv} = 0.1$, and according to the III mode $k_{dv} = 0.365$;

$\gamma = 1.03 \text{ t/m}^3$ - the bulk density of the cargo (the density of the transported cargo) was determined by the nominal carrying capacity (70.0 t) and the volume of the body (73.0 m^3), and was:

$$\gamma = \frac{m}{V} \text{ T/M}^3 \quad (2.173)$$

$g = 9.81 \text{ m/s}^2$ - acceleration of free fall;

in - the distance from the surface of the cargo to the point where the pressure was determined;

φ - the angle of the natural bevel of the load formed by the surface of the loosely packed load with a horizontal plane. The angle φ is taken during the calculation according to the I mode according to table 2.3 (0.62 rad for coal),

and according to the III mode equal to 0.2 from the value of table 2.3 ($0,62 \cdot 0.2 = 0.124$ rad);

$\alpha - 90^\circ$ - angle of inclination of the side wall of the body to the horizon;

$\delta = 0.45$ rad - the angle of friction of the cargo against the metal walls of the body, taken according to table 2.3 for coal;

$\beta = 0$ - the angle of inclination of the cargo surface to the horizon "without a cap".

The side walls are calculated according to modes I and III (in combination with other loads) for the pressure of the spacer R_a , N/m^2

- spacer with bulk cargo according to the 1st load mode. The active (static) pressure per unit area of the side wall is determined.

The load was modeled according to the height of the side wall according to the linear law by means of software;

- spacer with bulk cargo according to the III load mode. The active (static) pressure per unit area of the side wall is determined:

The load was modeled according to the height of the side wall according to the linear law by means of software.

Calculation of loads on the end wall.

The end walls of the body were calculated according to the I regime for the dynamic pressure of the bulk cargo evenly distributed over the entire area, which occurs when the wagons collide due to the action of the inertia force of the cargo mass, which is equal to 0.35 of the carrying capacity of the wagon under longitudinal acceleration for the 1st regime.

The force of inertia N_i , H acting on the end wall:

$$N_i = t \cdot a_h \quad (2.174)$$

where t is the weight of the load acting on the end wall, multiplied by a factor of 0.35, kg;

$a_h=3.5g$ - the standardized value of longitudinal acceleration (deceleration) for four-axle freight wagons.

$$t = 0.35 \cdot t_{gr} =$$

where $t_{gr} = 75.4 \text{ t}$ - the carrying capacity of the wagon.

Pressure R , N/m^2 acting on the end wall:

$$P = \frac{N_i}{S} \quad (2.175)$$

where S , m^2 is the area of the end wall.

SECTION 3

CONCEPTS FOR FREIGHT WAGONS MADE OF COMPOSITES

The section presents patented [93-120]. concepts for freight wagons made of composites.

3.1 Railway semi-wagon with a hollow body

The invention relates to railcar construction and can be used for rail transportation of bulk and bulk cargo that does not require protection from atmospheric precipitation.

A well-known specialized railway semi-wagon[model 12-1505, see: Freight wagons: Tutorial. allowance: In 2 h. Part 1: Half wagons and covered wagons/ M.I. Kharitonov, V.N. Pankin. - Khabarovsk: Publishing house - in DVGUPS, 2004. - p. 29], the structure of which consists of a crew part module containing two two-axle bogies, an auto coupling module, a braking equipment module, a frame module consisting of longitudinal and transverse beams and a body module containing two side walls having a skin and a frame, and two end walls, having sheathing and a frame, which includes longitudinal and transverse beams.

The disadvantages of this device are as follows: semi-wagons of this model are characterized by increased material capacity, insufficient load capacity, loading volume of the body, which leads to an increase in the cost of freight transportation and a decrease in the profitability and competitiveness of railway transport during their operation on railway networks.

The closest thing to the claimed object is a railway semi-wagon[model 12-1580, see: Грузовые вагоны: Textbook. allowance: In 2 h. Part 1: Half wagons and covered wagons/ M.I. Kharitonov, V.N. Pankin. - Khabarovsk: Publishing house - in DVGUPS, 2004. - p. 29], the structure of which consists of a crew part module containing two two-axle bogies, a self-coupling module, a braking equipment module, a frame module and a body module containing two side walls and two end walls.

The reasons preventing the achievement of the required technical result are as follows: the frame module is a welded steel structure made of longitudinal and transverse beams of different configurations, the side and end walls are made of steel sheathing and frames, while the frames are a structure of horizontal and vertical beams of different configurations, which causes the increased cost of manufacturing and operating a railway semi-wagon with a hollow body, due to: increased material capacity and correspondingly reduced load capacity and loading volume of the body, and increased corrosion wear of the frame and body modules in operation.

The invention is based on the task of improving the railway semi-wagon with a hollow body, namely: reducing the material capacity, increasing the carrying capacity and loading volume of the body, and reducing the corrosion wear of the frame and body modules, due to the improvement of the design of the frame and body modules, based on their execution as solid of composite material and cross-sectional configurations of equal resistance to the actions of the total relevant operating loads, while meeting the conditions of strength and operational reliability.

The task is solved by the fact that in a railway semi-wagon with a hollow body, the structure of which consists of a crew part module containing two two-axle bogies, an auto coupling device module, a brake equipment module, a frame module, a body module containing two side walls and two end walls , the

frame module is made of solid composite material with a trapezoidal cross-section and local protrusions corresponding to the sliders of the undercarriage module, the side walls are made of composite material with pyramid-shaped protrusions, the tops of which are shifted to the bottom of the wagon and lie in the corresponding vertical planes that pass through the pivot axes, the walls the end ones are made of composite material with pyramid-shaped protrusions, the tops of which are shifted to the bottom of the wagon and lie in the vertical longitudinal axis of symmetry of the semi-wagon.

The introduction of new features in interaction with the known ones ensure a reduction in material capacity, an increase in the carrying capacity and loading volume of the body, an increase in the corrosion resistance of the frame and body modules and, as a result of all the above, a reduction in the cost of manufacturing and operating a railway semi-wagon with a hollow body.

In fig. 3.1 shows the general view of the proposed railway semi-wagon with a hollow body; in fig. 3.2 – a demonstrative cross-section of the frame module of a railway semi-wagon with a hollow body; in fig. 3.3 – the bottom axonometric projection of the connected modules of the frame and body of the railway semi-wagon with a hollow body is shown; in fig. 3.4 shows the upper axonometric projection of the connected modules of the frame and body of the railway semi-wagon with a hollow body.

The proposed railway half-wagon with a hollow body (Fig. 3.1) consists of a crew part module 1 containing two two-axle bogies, an auto-coupling device module 2, a brake equipment module 3, a frame module 4 with a trapezoidal cross-section (Fig. 3.2) and local corresponding to the sliders chassis module with protrusions 5 (Fig. 3.3), and body module 6 (Fig. 3.1) which consists of two side walls 7 (Fig. 3.4) which are made with pyramid-shaped protrusions 8, the tops of which are shifted to the bottom of the wagon and lie in the corresponding vertical planes which pass through pivot axes 9 (Fig. 3.1), and

two end walls 10 (Fig. 3.4) which are made with pyramid-shaped protrusions 11, the tops of which are shifted to the bottom of the wagon and lie in the vertical longitudinal axis of symmetry of the semi-wagon.

The proposed railway semi-wagon with a hollow body works as follows. To form a railway freight train, a railway semi-wagon with a hollow body is connected to the rear wagon and the front wagon (or locomotive) through the coupling device module 2 (Fig. 3.1), and to the train brake line through the brake equipment module 3. As a result of loading the body 6 with bulk or bulk cargo, the corresponding loads will be received by the side walls 7 (Fig. 3.4) and end walls 10, as well as the frame module 4 (Fig. 3.1) and will be transmitted to the axles of the wheel pairs of two two-axle carts of the crew unit module 1. On horizontal sections of the railway track the body 6 through the corresponding pivot points of the frame module 4 will rest on the undercarriage module 1, and in the curved sections of the railway track to avoid overturning of the body 6, it will, along with the indicated type of support, be through the local protrusions 5 corresponding to the sliders of the undercarriage module (Fig. 3.3) additionally rely on the undercarriage module 1 (Fig. 3.1). During the movement of a freight train, the greatest loads on the structural elements of a railway semi-wagon with a hollow body act in extreme situations. For example, significant dynamic operating forces in the forward end wall and frame module during emergency braking. Unloading of a railway semi-wagon with a hollow body is carried out on a wagon dumper.

Making the frame and body modules of a railway semi-wagon with a hollow body solid from composite material and cross-sectional configurations of equal resistance to the actions of the total relevant operating loads will reduce the cost of its manufacture and operation due to a decrease in material capacity, and corresponding increases in the carrying capacity and loading volume of the

body and an increase in the corrosion resistance of the modules frame and body in operation, when the conditions of strength and operational reliability are met.

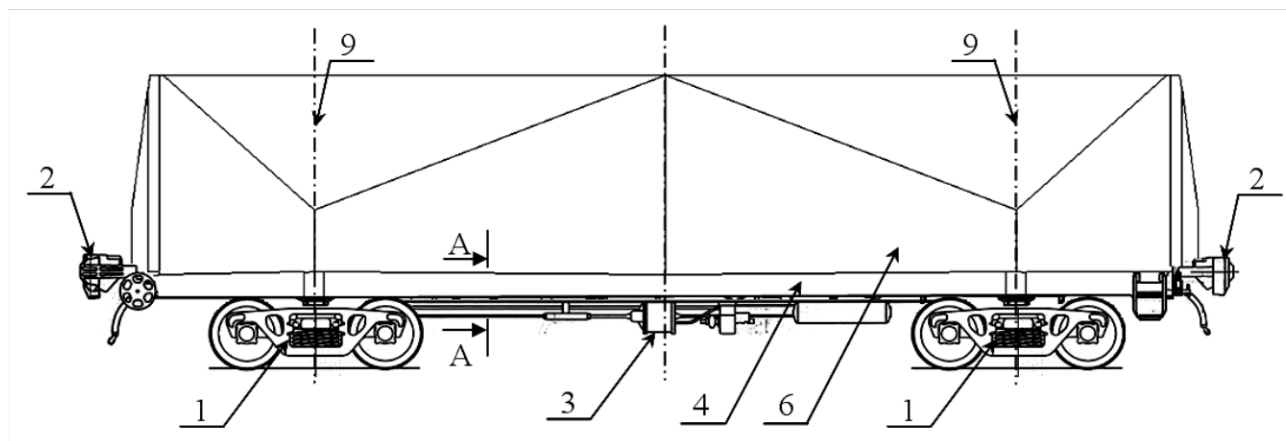


Fig. 3.1 Railway semi-wagon with a hollow body

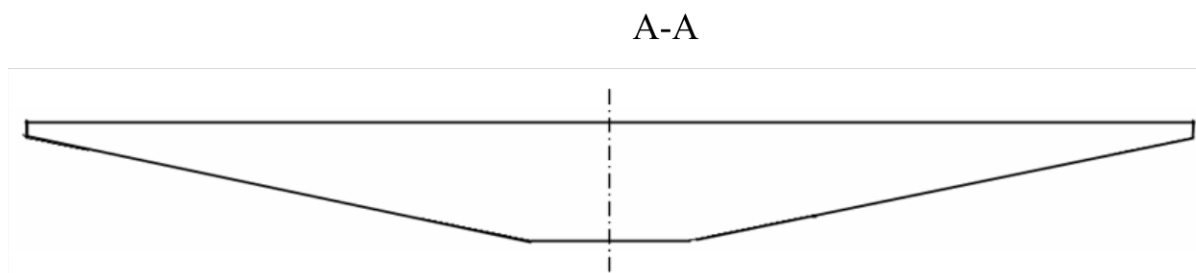


Fig. 3.2

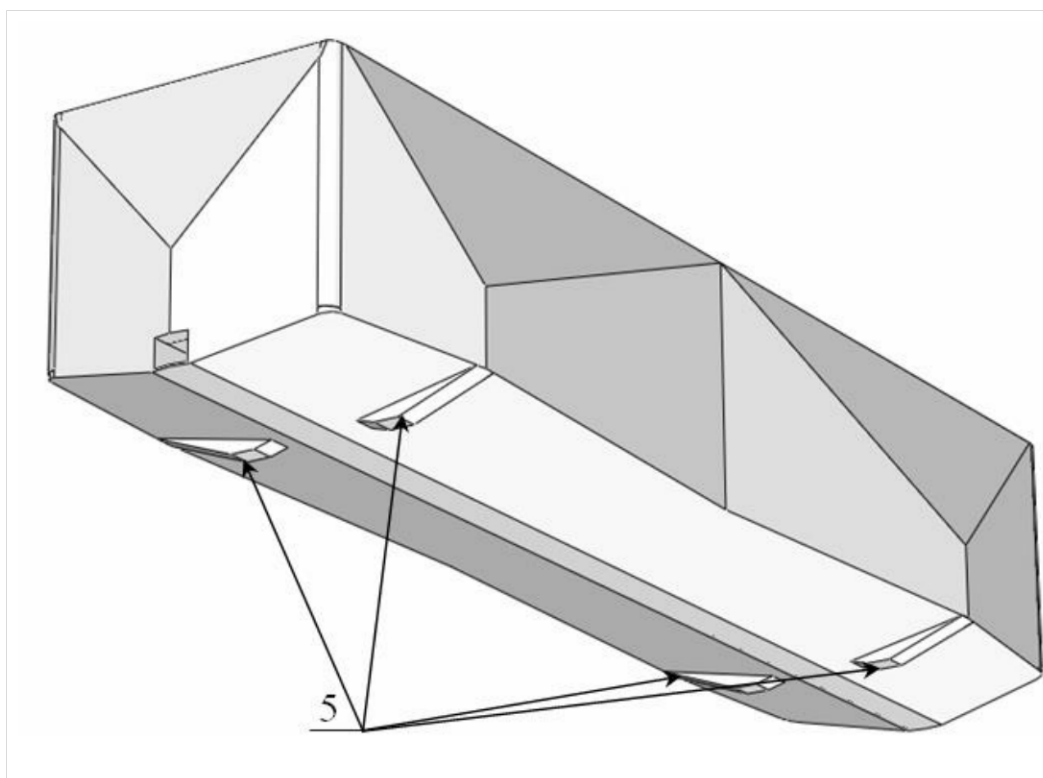


Fig. 3.3

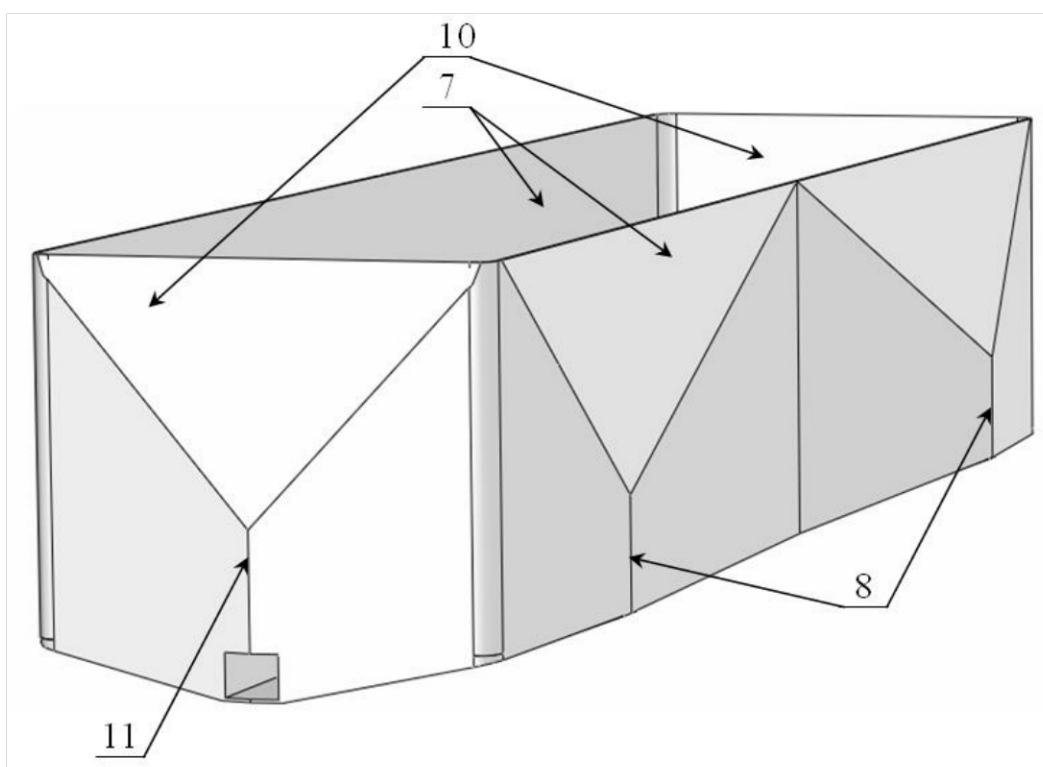


Fig. 3.4

3.2 Covered wagon

The useful model refers to wagon construction and can be used for railway transportation and is intended for the transportation of artificial, grain and other loads of a wide range that require protection from atmospheric influences.

A famous covered wagon[model 11-217, see: Freight wagons: Textbook. allowance: In 2 h. Part 1. / M.I. Kharitonov, V.N. Pankin. – Khabarovsk: Izd-vo DVGUPS, 2003. - p. 58-67], the structure of which consists of a crew part module containing two two-axle bogies, an auto coupling module, a braking equipment module, a frame module consisting of longitudinal and transverse beams and a body module containing two side walls having a skin and a frame, two end walls having a sheathing and a frame that includes longitudinal and transverse beams, and a roof having a sheathing and a frame that consists of arches.

The disadvantages of this device are as follows: covered wagons of this design are characterized by increased material capacity, insufficient load capacity, loading volume of the body, all of this determines, during their operation on railway networks, an increase in the cost of freight transportation and a decrease in the profitability of work and the competitiveness of railway transport

The closest to the claimed object is a covered wagon[universal covered wagon model 11-260 according to TU 24.05.498-86], the structure of which consists of a crew part module containing two two-axle bogies, a self-coupling device module, a brake equipment module, a body module containing a frame, two side walls, two end walls and a roof.

The reasons preventing the achievement of the required technical result are as follows: the body module is a welded steel structure, which includes a frame, two side walls, two end walls and a roof, made of beams of different configurations with steel cladding, which leads to increased production costs and operation of the covered wagon, due to: increased material capacity and correspondingly reduced load capacity and loading volume of the body, and increased corrosion wear of the frame and body modules in operation.

The basis of the invention is the task of improving the covered wagon to increase the efficiency of its use, namely: reducing the material capacity, increasing the carrying capacity and loading volume of the body, and reducing the corrosion wear of the body module, due to the improvement of its design, based on the execution of the body module solid from composite material and cross-sectional configurations of equal resistance to the actions of the total relevant operating loads, while meeting the conditions of strength and operational reliability.

The task is solved by the fact that in a covered wagon, the structure of which consists of a crew part module containing two two-axle trolleys, an auto coupling device module, a brake equipment module, a body module that contains a frame, two side walls, two end walls and a roof, the module the body is made of a solid composite material, and the side walls are made of a composite material with pyramid-shaped protrusions, the tops of which are shifted to the bottom of the wagon and lie in the corresponding vertical planes that pass through the pivot axes, the end walls are made of a composite material with pyramid-shaped protrusions, the tops of which shifted to the bottom of the wagon and lie in the vertical longitudinal axis of symmetry of the covered wagon, and also have horizontal corrugations.

The introduction of new features in interaction with the known ones provides a reduction in material capacity, an increase in the carrying 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 wagon.

In fig. 3.5 shows the general view of the proposed covered wagon; in fig. 3.6 shows the upper axonometric projection of the solid body module of the covered wagon.

The proposed covered wagon (Fig. 3.5) consists of a crew part module 1, which contains two two-axle trolleys, an autocoupling device module 2, a brake equipment module 3, and a body module 5 (Fig. 3.5) which consists of a frame 4, two side walls 9 (fig. 3.6) which are made with pyramid-shaped protrusions 10, the tops of which are shifted to the bottom of the wagon and lie in the corresponding vertical planes that pass through the pivot axes 6 (fig. 3.5), two end walls 11 (fig. 3.6), which are made with pyramid-shaped protrusions 11, the tops of which are shifted to the bottom of the wagon and lie in the vertical longitudinal axis of symmetry of the covered wagon, and also have horizontal corrugations 12, and a roof 8 (Fig. 3.6).

The proposed covered wagon works in this way depending on the transport tasks. To form a railway freight train, the covered wagon is connected to the rear wagon and the front wagon (or locomotive) through the coupling device module 2 (Fig. 3.5), and to the train brake line through the brake equipment module 3. As a result of loading the body 5 with artificial, grain and by other loads of a wide range, the corresponding loads will be perceived by the floor of the body and transferred to frame 4 and further to the axles of the wheel pairs of two two-axle trolleys of the crew unit module 1 (Fig. 3.5). During the movement of the freight train, the greatest loads on the structural elements of the covered wagon act in extreme situations. For example, significant dynamic operating forces act on the end wall and the backbone beam in front of the movement during emergency braking, which will be partially absorbed by the

cables stretched inside the corresponding supporting elements and thereby prevent their damage. When carrying out various types of repairs of the covered wagon, the worn cables will be replaced with new ones while preserving the structural properties of the load-bearing elements. The covered wagon is unloaded using specialized equipment, which was also used during loading.

Making the body module of the covered wagon solid from composite material and with cross-sectional configurations of equal resistance to the actions of the total corresponding operating loads will reduce the cost of its manufacture and operation due to the reduction of material capacity, and the corresponding increases in the carrying capacity and loading volume of the body and the increase of the corrosion resistance of the body module in operation, with meeting the conditions of strength and operational reliability.

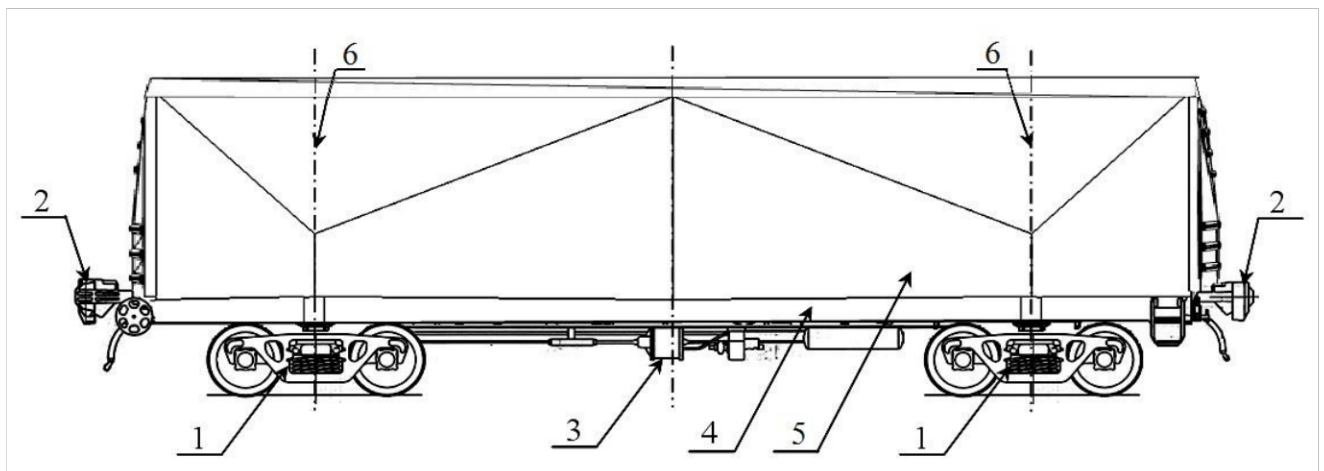


Fig. 3.5 Covered wagon

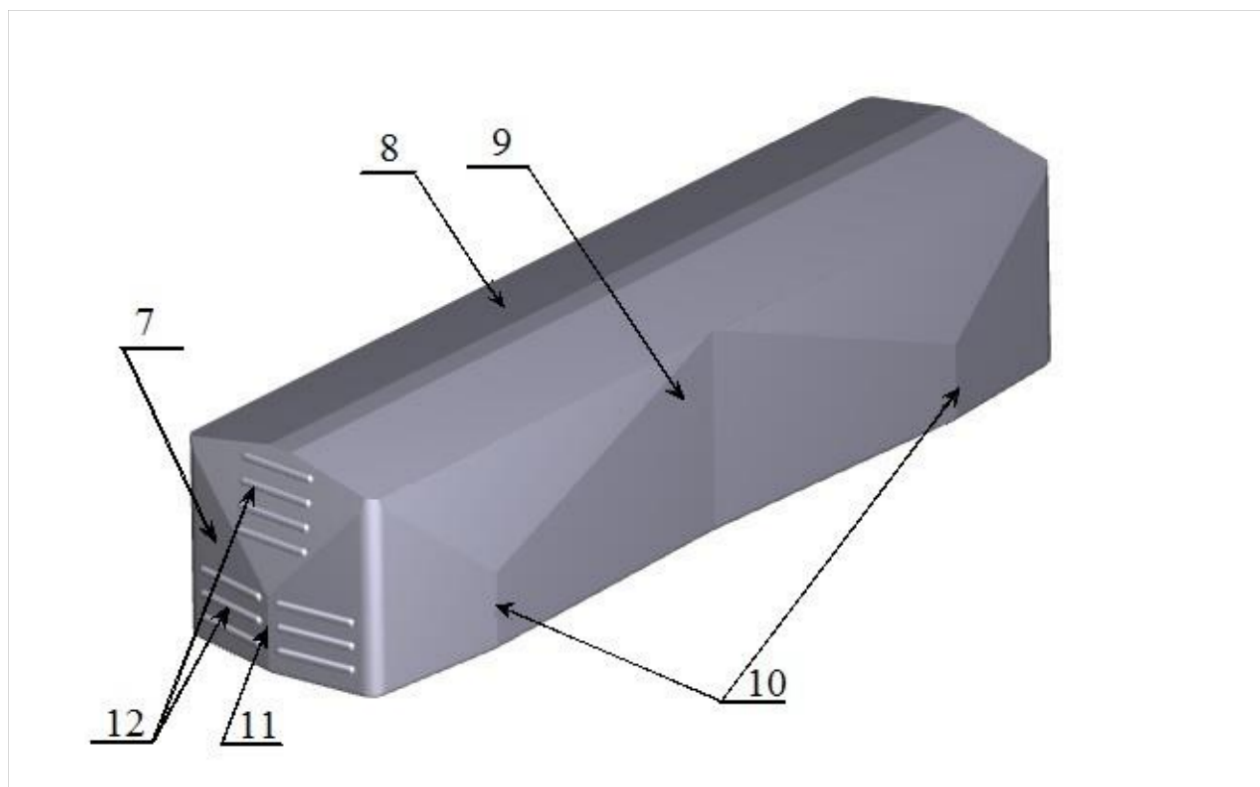


Fig. 3.6

3.3 Railway tank

The useful model belongs to railway transport, namely railway tanks and can be used for the transportation of liquid cargo.

A well-known railway tank, which contains trolleys, a frame, braking equipment, coupling devices, a boiler (see V.V. Lukyn, P.S. Anisimov, Y.P. Fedoseev. Wagons. General course: Textbook for railway universities. transp. / edited by V.V. Lukina. - M.: Route, 2004. - 424 pp. pp. 143-144 - prototype).

The disadvantages of such a design are as follows: a railway tank for liquid cargo is characterized by increased material capacity, insufficient load capacity, loading volume of the body, which leads to an increase in the cost of freight transportation and a decrease in the profitability and competitiveness of railway transport during their operation on railway networks, and imposes additional restrictions in terms of transportation of cargo volumes.

The basis of the useful model is the task of improving the railway tank for the transportation of liquid cargo, namely: reducing the material capacity, increasing the carrying capacity and loading volume of the body, and reducing the corrosion wear of the body module, due to the improvement of its design, based on the execution of the boiler as a solid composite material and cross-sectional configurations of equal resistance to the actions of the total relevant operating loads, while meeting the conditions of strength and operational reliability.

The task is achieved by the fact that in a railway tank for the transportation of liquid cargo, the construction of which consists of a module of the crew part containing two two-axle trolleys, a module of an auto-coupling device, a module of braking equipment, a body module that includes a boiler, according to a useful model, the boiler is made solid from composite material

and cross-sectional configurations of equal resistance to the actions of the total corresponding operating loads.

The introduction of new features in interaction with the known ones ensure a reduction in material capacity, an increase in the carrying 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 railway tank for the transportation of liquid cargo.

The essence of the useful model is explained by illustrative material, where in fig. 3.7 shows the general view of the proposed railway tank for the transportation of liquid cargoes, which contains carts 1, braking equipment 2, coupling devices 3, boiler 4, in fig. 3.8 shows the upper axonometric projection of a solid boiler of a railway tank.

The proposed rail tank for liquid cargo works as follows.

During movement, vertical and horizontal forces from the boiler 4 are transmitted to the frame through the fastening of the boiler to the frame and the supports of the boiler to the frame, vertical forces from the frame are transmitted to the trolleys. The movement of the railway tank for the transportation of liquid cargo is provided by trolleys 1 (Fig. 3.7). Braking of a railway tank for the transportation of liquid cargoes is provided by braking equipment 2. The connection of a railway tank wagon for the transportation of liquid cargoes with other wagons or locomotives is provided by auto-coupling devices 3.

The application of the proposed technical solution will allow to reduce the cost of manufacturing and operation of a railway tank for the transportation of liquid cargo due to the reduction of material capacity, and corresponding increases in the carrying capacity and loading volume of the body and increase of the corrosion resistance of the body module in operation, while meeting the conditions of strength and operational reliability.

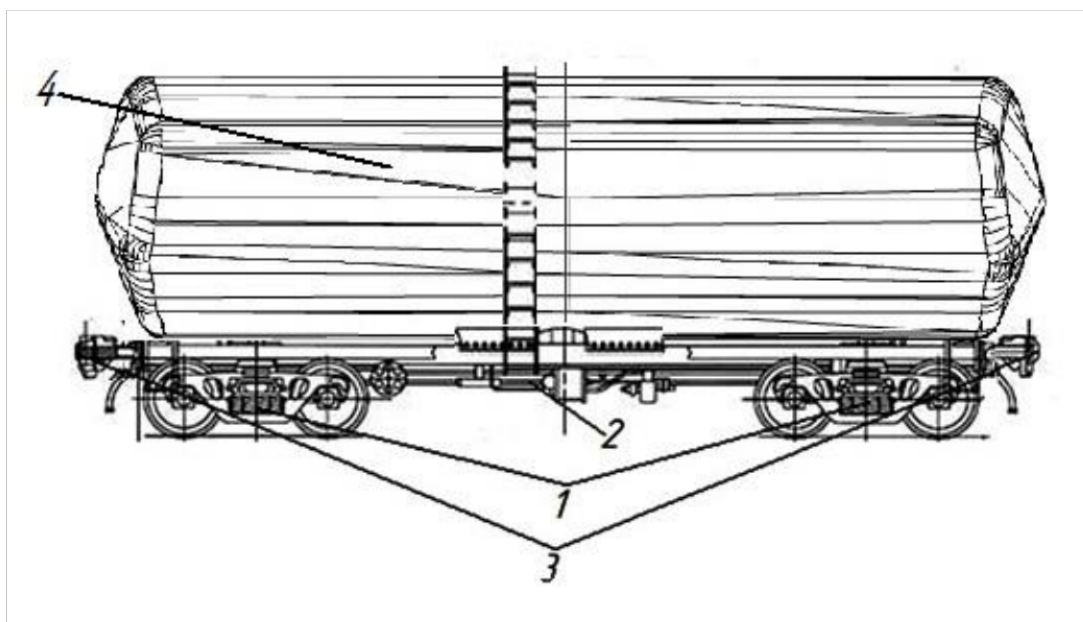


Fig. 3.7 Railway tank

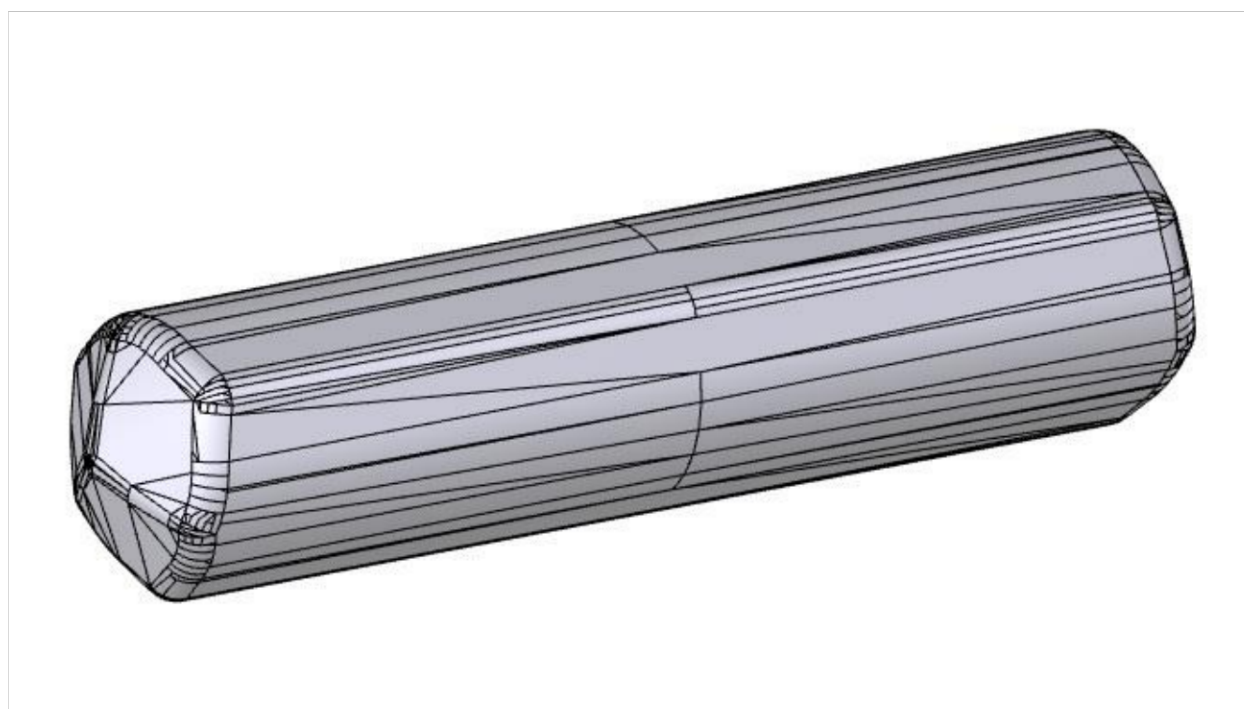


Fig. 3.8

3.4 Platform wagon for timber transportation

The useful model relates to wagon building and can be used for railway transportation of timber.

A platform wagon with racks is known, which includes undercarriages on which a frame is mounted, with a backbone beam, cross beams connected to the backbone beam and with longitudinal side beams. From above, the transverse beams are reinforced with overhead support beams, at the junctions of the transverse beams with the longitudinal side beams, vertical racks equipped with retractable telescopic tips are fixed. To increase the strength and rigidity of the supporting frame, the ends of the transverse beams, connected to the longitudinal side beams, are made with expansion. The lower ends of the vertical racks are fixed on extended brackets fixed on the longitudinal side beams. From the outer and inner sides - in relation to the longitudinal axis of the platform wagon - the lower ends of the vertical racks are provided with reinforcing outer and inner overlays. Reinforcing external linings are made with a lower extended support part connected to extended bearing brackets, which are reinforced from below by transverse stiffeners connected to longitudinal side beams. The middle part of the internal reinforcing pads is made with an extension and a bend, which forms a horizontal support part welded to the extended end of the transverse beams. The ends of the supporting overhead beams, also made with the extension of their ends, are fixed on the horizontal supporting parts of the internal reinforcing overlays. The lower ends of the vertical racks are equipped with lateral inclined stiffeners, placed and fixed between the reinforcing edges of the outer and inner overlays. With their lower parts, the lateral inclined ribs are connected to the brackets, and, like vertical racks, are additionally reinforced with shaped overlays, connected and rigidly

connected to the outer surface of the bend of the middle part with internal reinforcing overlays. Metal sheets forming a single floor of the platform wagon are fixed between the overhead support beams with support on the longitudinal side beams and the backbone beam [RU 166282 U1, 05/27/2016].

Also known is the design of a platform wagon for the transportation of timber, which contains a body mounted on the running gear, consisting of end walls, side vertical racks and a frame with fitting stops, which has longitudinal side and spine beams, as well as transverse end, pivot, intermediate , the central beam, while a transverse support is located between each pair of side vertical posts on the frame of the wagon, and each side vertical post is rigidly fixed to the longitudinal side beams of the frame, the side vertical posts have a variable section, the largest in the lower part of the frame, and that decreases to the upper part of the rack, while each wall of the vertical rack is made of sheets of different thickness, and in the lower part of the racks, sheets of greater thickness are installed, also the surface of the rack, facing the inside of the wagon, forms a right angle with the transverse support of the frame, and the increased section of the rack developed from the outside of the wagon, along with this, the supporting element of the rack protrudes above the level of the transverse support by no more than 10 mm, and the racks located on both sides of the central beam of the frame are additionally reinforced from the sides with inclined scarves [RU 2716603, 13.03.2020].

Disadvantages of these designs of platform wagons are the increased tare and insufficient carrying capacity, which leads to an increase in the cost of freight transportation and a decrease in the profitability and competitiveness of railway transport during their operation on railway networks.

The closest to the proposed object is a railway platform wagon with a tare of 20.9 tons and a carrying capacity of 70 tons[see: Freight wagons: Textbook. allowance: In 2 h. Part 2/ M.I. Kharitonov, V.N. Pankin. –

Khabarovsk: Publishing House of the DVGUPS, 2006. – p. 9, 10], the structure of which consists of a crew part module containing two two-axle bogies, an autocoupling device module, a braking equipment module, a frame module with a backbone beam with main and cantilever parts, main longitudinal beams with main and cantilever parts, intermediate longitudinal, intermediate transverse beams, braces and body module containing metal sides and floor covering.

The reasons preventing the achievement of the required technical result are the increased container and insufficient carrying capacity of the wagon, which leads to an increase in the cost of freight transportation and a decrease in the profitability and competitiveness of railway transport during its operation on railway networks.

The useful model is based on the task of reducing the tare of the platform wagon and increasing it accordingly carrying capacity, which contributes to increasing the efficiency of its functioning.

The task is solved by what is in the railway carriage-platform for the transportation of timber, the construction of which consists of a module of the crew part containing two two-axle trolleys, a module of an auto coupling device, a module of braking equipment, a frame module with a backbone beam from main and cantilever parts, main longitudinal beams from main and cantilever parts, intermediate longitudinal, intermediate transverse beams, braces and a body module containing metal sides, the backbone and main longitudinal beams of the frame have a closed cross-section, and on the main longitudinal beams, metal cups are installed on the rotary sectors, into which racks made of composite material are installed.

The introduction of new features in interaction with the known ones ensure a reduction in the tare of the platform wagon, and a corresponding increase in the carrying capacity, which contributes to increasing the efficiency of its operation.

The essence of the useful model is explained by the drawings, where:
in fig. 3.9 shows the general view of the proposed platform wagon;
in fig. 3.10 – platform wagon frame module;
in fig. 3.11 – section of the spinal and main longitudinal beams of the frame.

The proposed platform wagon for the transportation of timber (Fig. 3.9) consists of a crew part module 1, which contains two two-axle trolleys, a self-coupling module 2, a braking equipment module 3, a supporting structure module 4. The supporting structure module is represented by a frame (Fig. 3.10), which includes a spinal beam 5, which has a closed section (Fig. 3.11), end beams 6 (Fig. 3.10), braces 7, pivot beams 8, main longitudinal beams 9, which have a closed section (Fig. 3.11), beams intermediate longitudinal 10 and transverse 11 (Fig. 3.10). On the main longitudinal beams, metal cups 12 are installed on rotary sectors 13, in which racks 14 of composite material are installed.

The proposed platform wagon for the transportation of timber works as follows. To form a freight railway train, the platform wagon is connected to the rear wagon and the front wagon (or locomotive) through the coupling device module 2 (Fig. 3.9), and to the train brake line through the brake equipment module 3. Metal cups 12 with racks 14 rotate by 45° in order to be able to load a platform wagon. After it is loaded, the racks return to their original position, holding the transported cargo. Vertical loads from the transported cargo placed on the platform wagon are transmitted to the frame module (Fig. 3.10) and then to the axles of the wheel pairs of two two-axle trolleys (Fig. 3.9) of the crew unit module 1.

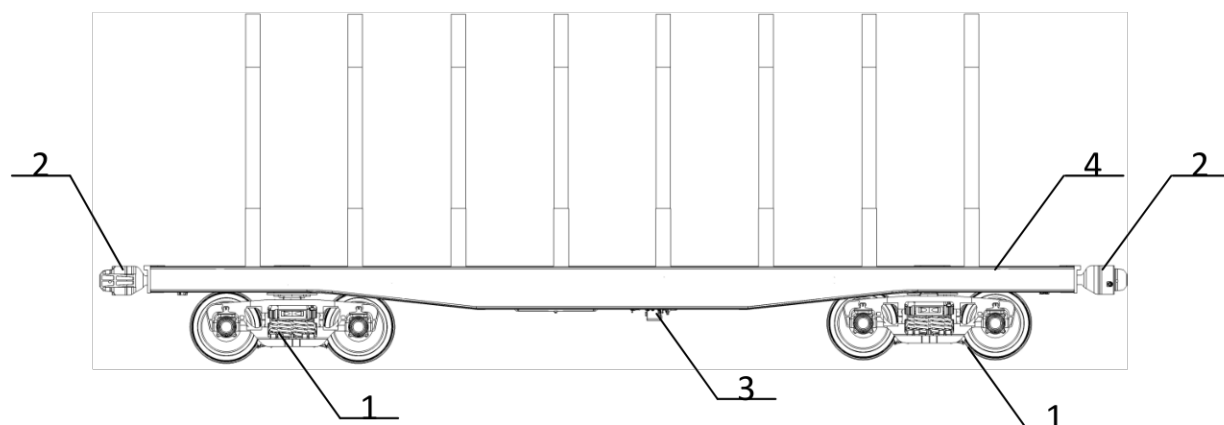


Fig. 3.9 Wagon-platform for transporting timber

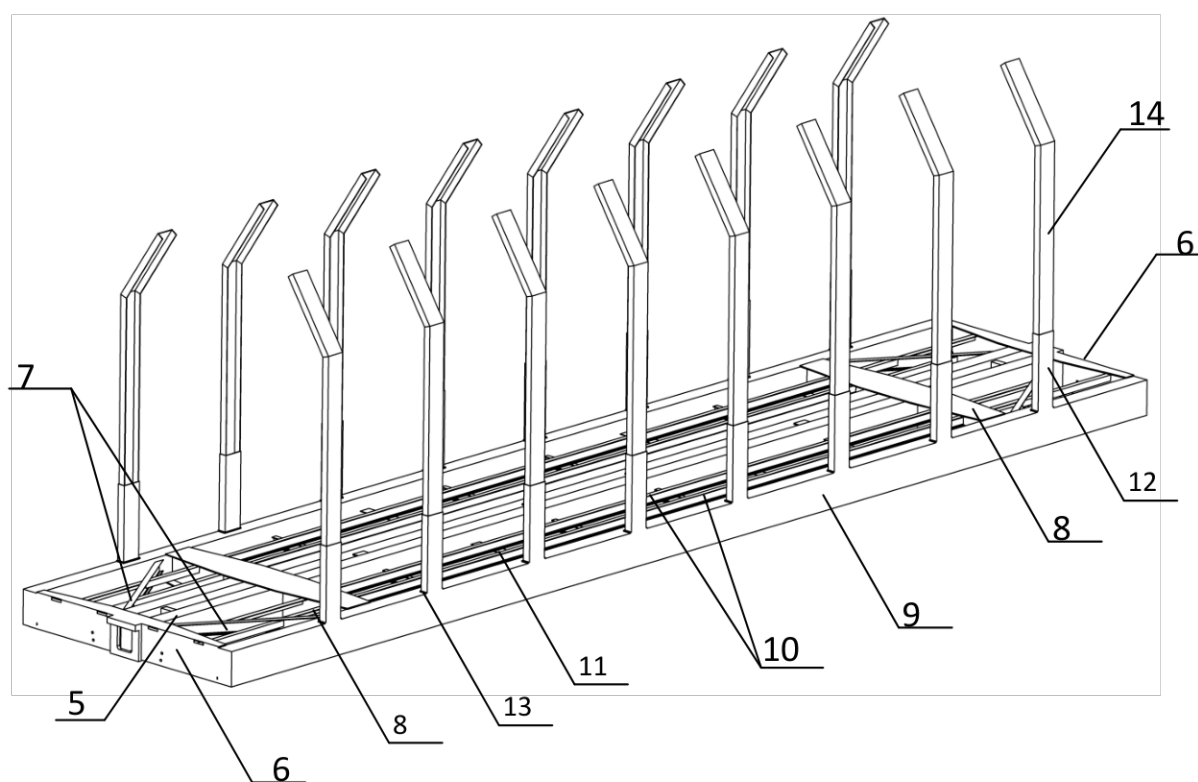


Fig. 3.10



Fig. 3.11

3.5 Hopper wagon

The useful model refers to wagon construction and can be used for rail transportation of bulk and bulk cargoes that do not require protection from atmospheric precipitation.

A well-known hopper wagon for the transportation of hot pellets and agglomerate, containing a body, which is a frame with a frame mounted on it, consisting of side and end walls, two unloading hoppers with lids, an unloading mechanism, a running part, the side walls of the frame consist of racks, cladding, upper and lower cladding, end walls of the frame consist of upper cladding, upper, middle and lower transverse beams, longitudinal beams, cladding (RU 179444 U1, 15.05.2018).

Also known is the design of a railway hopper wagon, which contains a frame installed on the running part, on which a body with internal and external unloading hatches is rigidly fixed, a mechanism for moving the lids of the internal and external hatches, which contains drive shafts connected to the corresponding power cylinders and connected connected to the hatch covers by lever systems, and a hinged dispenser with rigidly fixed stops for fixing the hatch covers in the transport position, while two-armed levers are rigidly fixed on the drive shafts, the ends of which are connected to the hatch covers by means of folded rods, parts of which are connected with the possibility of mutual rotation (UA 34188 C2, 15.02.2001).

The disadvantages of these designs of hopper wagons are the insufficient strength of the supporting structure under the action of operational loads, and as a result, the appearance of cracks in it.

The closest to the proposed object is an open-type railway hopper wagon (model 20-9749, TU U35.2-01124454-035:2005), the design of which consists

of a crew unit module containing two two-axle bogies, an auto-coupling module with typical harnesses, a brake equipment module, a frame module consisting of backbone, end, pivot and intermediate beams, an unloading equipment module and a body module consisting of two side vertical walls that include upper and lower strapping, vertical and inclined struts , two end inclined walls, which include upper and lower binding, and two bunkers with two unloading hatches.

The reasons that prevent obtaining the required technical result are the insufficient strength of the supporting structure of the hopper wagon under the action of operational loads.

The basis of the useful model is the task of increasing the strength of the load-bearing structure of the hopper wagon, and as a result, the operational resource.

The task is solved by that in hopper wagons, the construction of which consists of a crew unit module containing two two-axle bogies, a self-coupling module with typical harness devices, a brake equipment module, a frame module consisting of backbone, end, pivot and intermediate beams, an unloading equipment module and a body module, which consists of two side vertical walls that include top and bottom binding, vertical and inclined racks, two end inclined walls that include top and bottom binding, and two bunkers with two unloading hatches, the backbone beam consists of two W-shaped profiles covered from above with a horizontal sheet, in the areas of interaction between the backbone beam and the pivot beams, angles are placed to strengthen it, and the body cladding is made of a composite material with heat-resistant properties.

The introduction of new features in interaction with the known ones ensures an increase in the strength of the load-bearing structure of the hopper wagon by reducing the load under the action of operational loads.

The essence of the useful model is explained by the drawings, where

in fig. 3.12 shows the general view of the proposed hopper wagon;

in fig. 3.13 – hopper wagon body module;

in fig. 3.14 – hopper wagon frame module;

in fig. 3.15 - cross-section of the spinal beam.

The proposed hopper wagon (Fig. 3.12) consists of the crew part module 1, which contains two two-axle trolleys, the self-coupling module 2, the brake equipment module 3, the body module 4 and the frame module 5. The body module includes the side walls with the top 6 and lower 7 binding, vertical 8 and inclined 9 racks (Fig. 3.13), and end walls with upper 10 and lower 11 binding, which have sheathing with heat-resistant properties. The frame module (Fig. 3.14) includes a spinal beam 12, which consists of two W-shaped profiles 13 (Fig. 3.15), covered from above with a horizontal sheet 14, in the areas of interaction of the spinal beam 12 with the pivot beams 15, angles 16 are placed to strengthen it (Fig. 3.14). The frame structure also includes end beams 17 and intermediate transverse beams 18 (Fig. 3.14).

The proposed hopper wagon works as follows. To form a freight railway train, the hopper wagon is connected to the rear wagon and the front wagon (or locomotive) through the coupling device module 2 (Fig. 3.12), and to the train brake line through the brake equipment module 3. Vertical loads from the transported cargo, which placed in the hopper wagon, are transmitted to the frame module (Fig. 3.13) and then to the axles of the wheel pairs of two two-axle trolleys (Fig. 3.12) of the crew unit 1 module.

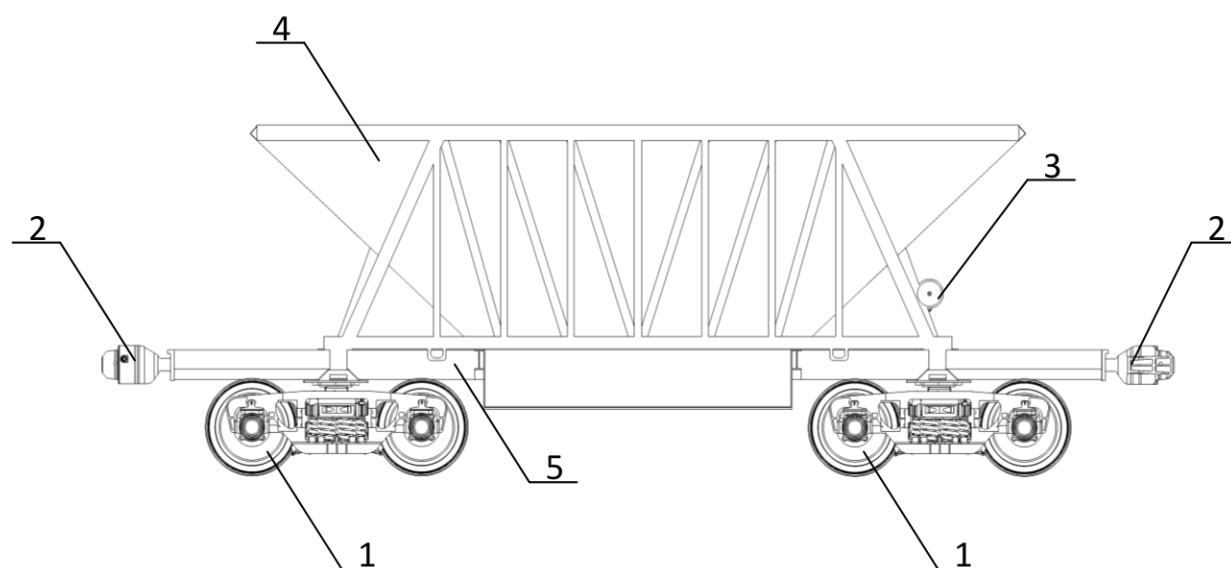


Fig. 3.12 Hopper wagon

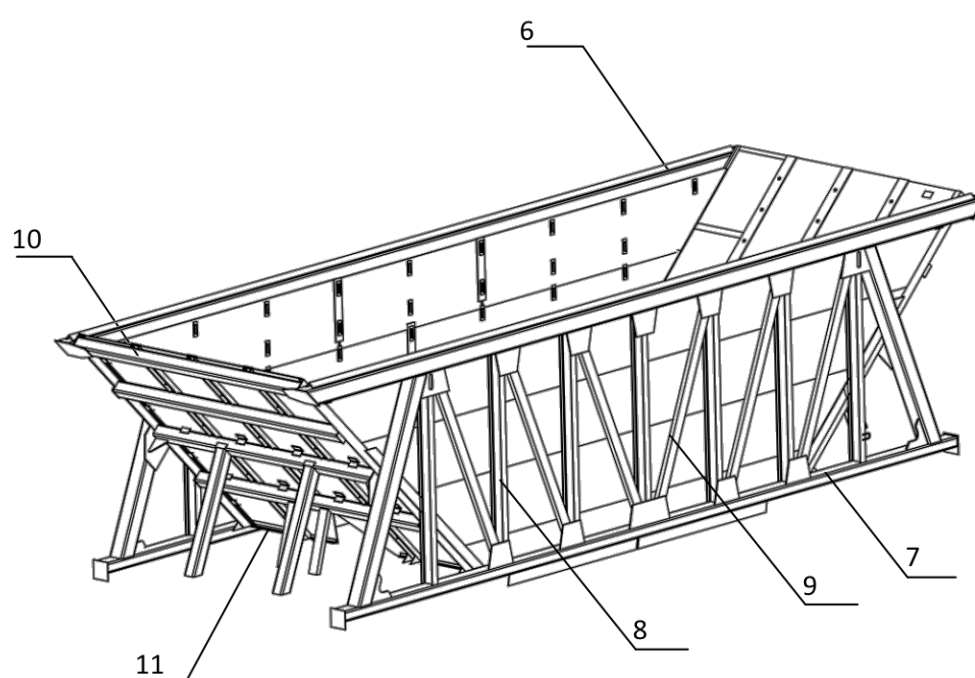


Fig. 3.13

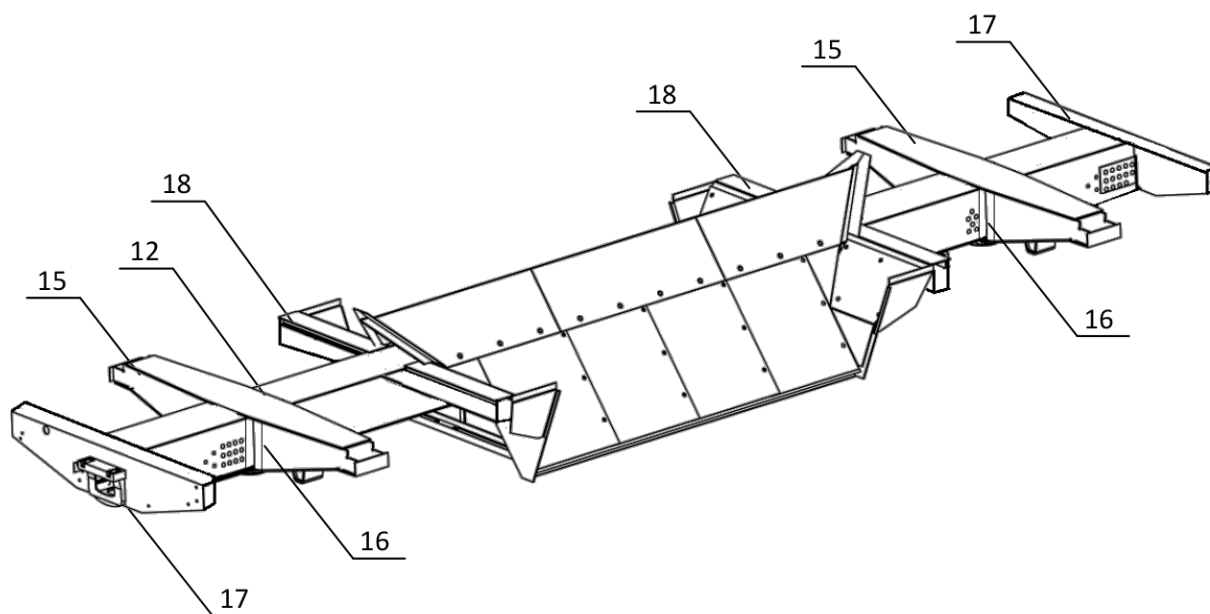


Fig. 3.14

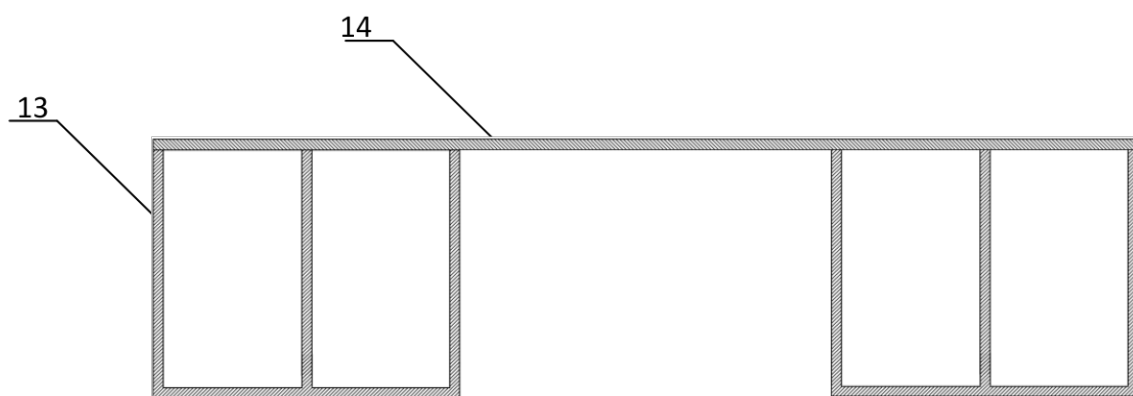


Fig. 3.15

3.6 Universal covered wagon

The utility model refers to railcar construction and can be used for rail transportation of single, taro-unit cargo, boxed cargo, bulk cargo, devices, various mechanisms, machine tools, machines and other cargo that needs protection from atmospheric precipitation.

A well-known design of a covered wagon, which is mounted on trolleys, equipped with an auto brake and an auto coupling, which has a body containing side walls with doorways and end walls, a floor, a roof, which is distinguished by the fact that in each side wall there are two doorways located from each other at a certain distance, each of which is closed by a door (UA 105736 U, 11.04.2016).

Also known is a covered wagon mounted on running bogies, which has a body that includes a frame with a longitudinal spine and transverse end, pivot and intermediate beams, fixed to the frame by side and end walls, on which a roof is installed, and the end walls include a frame of racks, upper and lower binding covered with sheathing, and the frame of the end walls also includes horizontal girders, while the lower parts of the racks of the end wall protrude downwards beyond the lining of the end wall and are fixed on the front sheet of the end beam, the racks are reinforced with horizontal scarves installed in the lower parts of the racks (RU 174422 U, 12.10.2017).

The disadvantages of these covered wagons are the insufficient strength of the supporting structure under the action of operational loads, and as a result, the appearance of cracks in it.

The closest to the claimed object is a covered wagon[model 11-217, see: Freight wagons: Textbook. allowance: In 2 h. Part 1: Half wagons and covered wagons/ M.I. Kharitonov, V.N. Pankin. – Khabarovsk: Izd-vo DVGUPS, 2004.

– p. 52-53], the structure of which consists of a crew part module containing two two-axle bogies, an auto coupling device module, a brake equipment module, a frame module with spine, side, transverse, longitudinal, main transverse, end beams, braces, short and long console beams and a body module , containing two side walls having cladding and a frame consisting of top binding, body pillars, door pillars, corner pillars and two end walls having cladding and a framework consisting of top binding, pillars and a roof that has sheathing and a frame that consists of arches.

The reasons that prevent obtaining the required technical result are the insufficient strength of the supporting structure under the action of operational loads, and as a result, the appearance of cracks in it.

The basis of the useful model is the task of increasing the strength of the load-bearing structure of the covered wagon under the action of operational loads.

The task is solved by the fact that in a universal covered wagon, the structure of which consists of a crew part module containing two two-axle trolleys, a self-coupling device module, a brake equipment module, a frame module with spinal, side, transverse, longitudinal, main transverse, end beams, braces, short and long beams of consoles and a body module, containing: two side walls with cladding and a frame, which consists of the upper strapping, body pillars, door pillars, corner pillars and two end walls with cladding and a frame , which consists of the upper binding, racks and roof, which has a sheathing and a frame consisting of arches, the ridge beam consists of two W-shaped profiles, covered from above with a horizontal sheet, in the areas of interaction of the ridge beam with the hinged ones, corners are placed for its reinforcement, and the roof sheathing is made of composite material.

The introduction of new features in interaction with the known ones ensure an increase in the strength of the load-bearing structure of the covered wagon under the action of operational loads.

In fig. 3.16 shows the general view of the proposed covered wagon; in fig. 3.17 – frame module of the covered wagon; in fig. 3.18 – section of the spinal beam; in fig. 3.19 – module of the body of a covered wagon.

The proposed universal covered wagon (Fig. 3.16) consists of a crew part module 1, which contains two two-axle trolleys, an autocoupling device module 2, a brake equipment module 3, a body module 4 and a frame module 5 (Fig. 3.17), which includes a backbone beam 6, which consists of two W-shaped profiles 7 (Fig. 3.18), covered from above with a horizontal sheet 8, in the areas of interaction of the spinal beam 6 with the pivot beams 9, angles 10 are placed for its reinforcement (Fig. 3.17). The frame also includes two lateral 11, transverse 12, longitudinal 13, main transverse 14, end 15 beams, braces 16, short and long console beams 17. The body module (Fig. 3.19) contains two side walls that have a sheathing and a frame, which consists of an upper casing 18, body struts 19, door struts 20, corner struts 21 and two end walls having cladding and a frame which consists of a cladding of the top 22, struts 23 and a roof 24 having a cladding of composite material and a frame consisting of arcs.

The proposed universal covered wagon works as follows. To form a freight railway train, the covered wagon is connected to the rear wagon and the front wagon (or locomotive) through the coupling device module 2 (Fig. 3.16), and to the train brake line through the brake equipment module 3. Vertical loads from the transported cargo placed in a covered wagon, are transmitted to the frame module (Fig. 3.17) and then to the axles of the wheel pairs of two two-axle trolleys (Fig. 3.16) of the module of the crew unit 1.

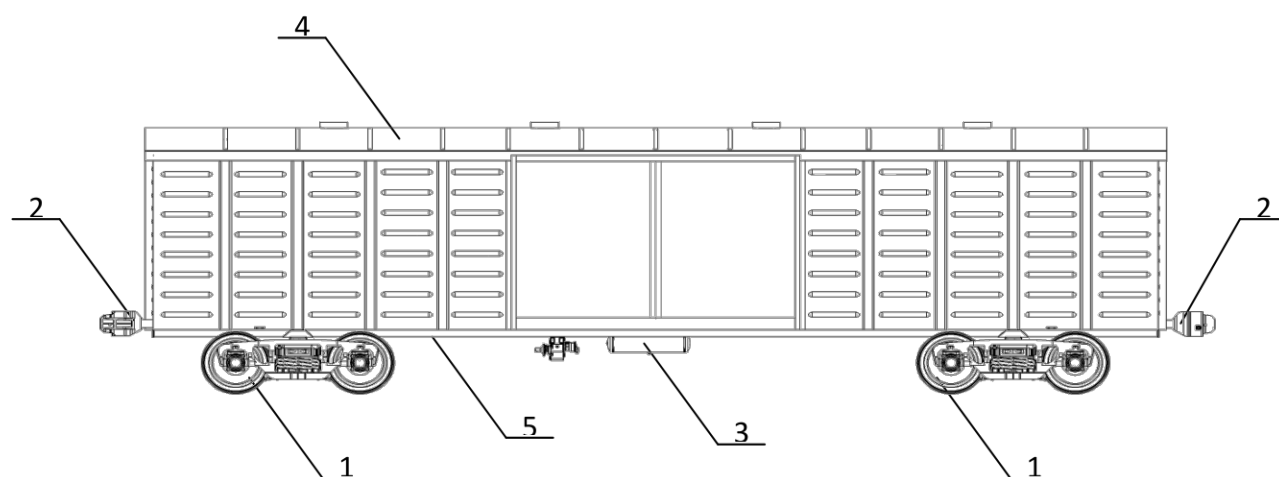


Fig. 3.16 Universal covered wagon

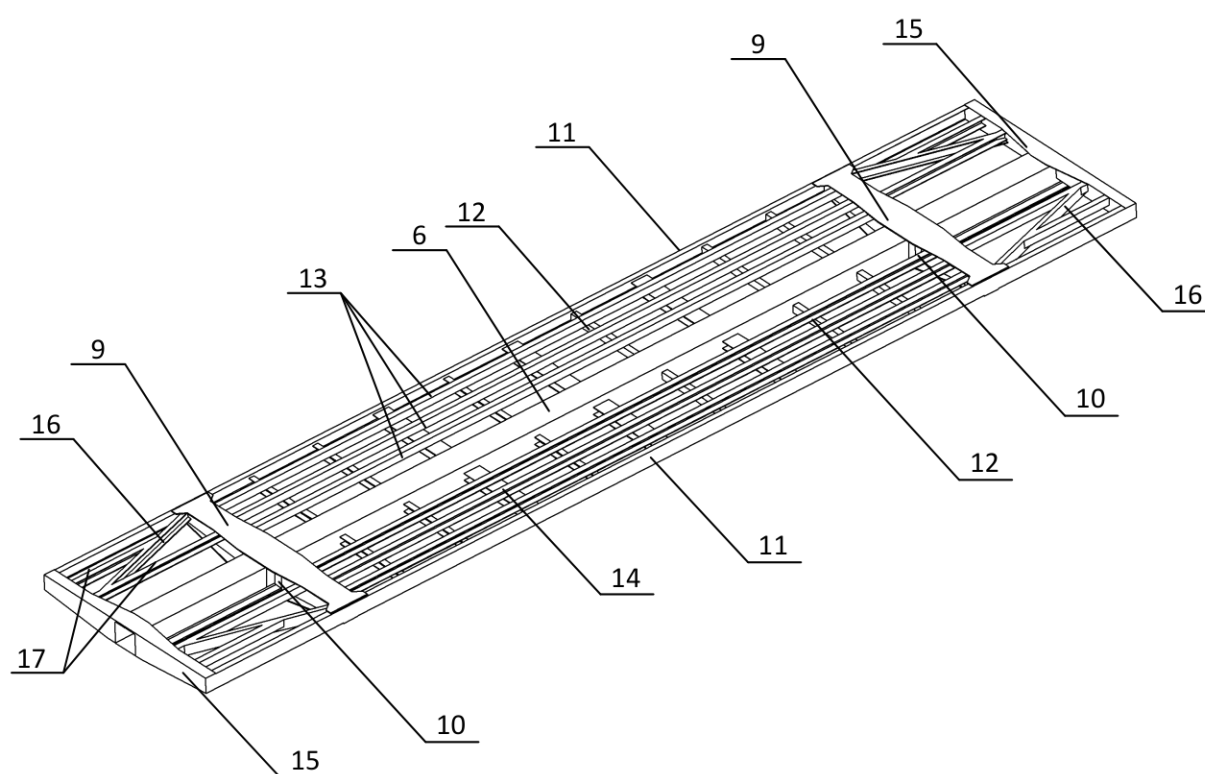


Fig. 3.17

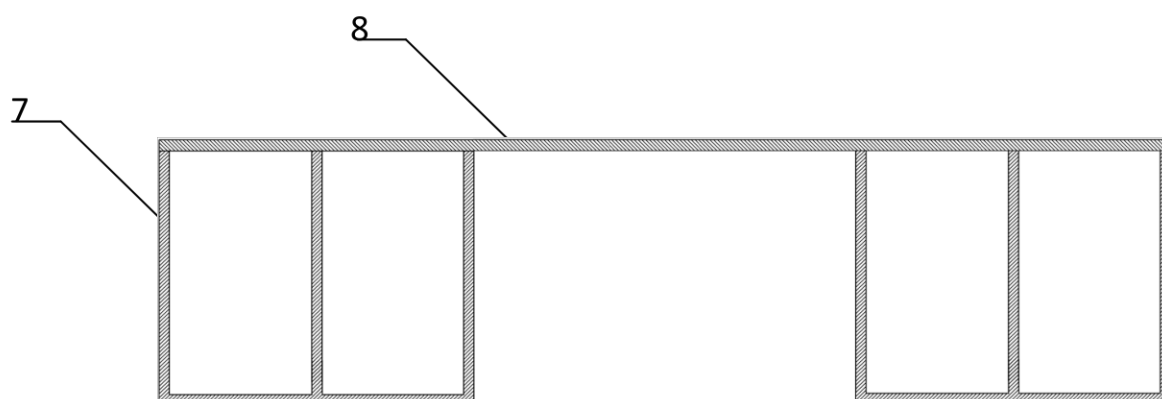


Fig. 3.18

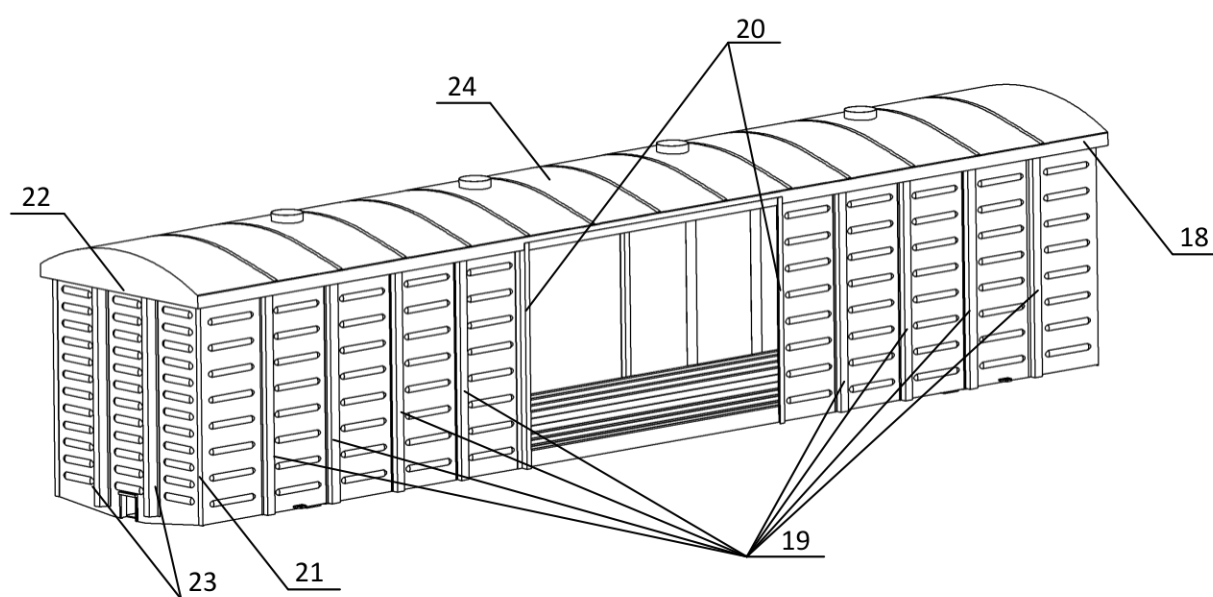


Fig. 3.19

3.7 Universal semi-wagon hatch cover

The useful model refers to wagon construction and can be used in the designs of railway universal semi-wagons.

The hatch cover of a half-wagon is known, consisting of straps, cover fabric, locking brackets and hinges. At the same time, the canvas is made with seven corrugations, and the extreme corrugations are located in close proximity to the edge of the canvas. The distance from the extreme corrugations to the edge of the canvas is the minimum possible when the hatch cover is adjacent to the upper overlapping sheets of the intermediate and pivot beams. The distance from the extreme corrugations to the edge of the canvas is preferably no more than 95 mm. The extreme and middle corrugations are made shorter than the others on the side of fastening the loops. The length of the extreme and middle corrugations is mostly at least 990 mm (UA 51339 U, 12.07.2010).

Also known is the design of the hatch cover of the semi-wagon, which includes a rectangular deck, lock brackets, supporting transverse and longitudinal elements, a reinforcing U-shaped longitudinal element, hinged hinges with elongated shanks, connected by welding to the rectangular deck and to the reinforcing U- a similar longitudinal element. Hinged hinges with elongated shanks are made with a stepped base (UA 68708 U, 10.04.2017).

The disadvantage of such manhole covers is insufficient strength under operational load conditions.

The closest thing to the claimed object is the hatch cover of a universal semi-wagon, which consists of a canvas to which the harness, locking brackets and hinges are attached [TU U 35.2-01124454-018-2003].

The reasons preventing the obtaining of the required technical result are the insufficient strength of the manhole cover under operational load conditions.

The basis of the useful model is the task of increasing the strength of the manhole cover at operational load modes.

The task is solved by the fact that in the hatch cover of the universal semi-wagon, which consists of a canvas to which the harness, locking brackets and hinges are attached, the canvas has the appearance of a smooth sheet and is made of composite material, and the harness is made of channels. covered on the side adjacent to the canvas with horizontal strips and filled with material with energy-absorbing properties.

The introduction of new features in interaction with the known ones ensure the improvement of the strength of the manhole cover by reducing its dynamic load under operational load modes.

The essence of the useful model is supplemented by illustrative material, where fig. 3.20 shows the general view of the proposed hatch cover; in fig. 3.21 – cross-section of the manhole cover harness.

The proposed hatch cover (fig.3.20) consists of web 1, to which a strap 2 is attached, made of channel 3 (Fig. 3.21), covered on the side of the web with a horizontal strip 4 and filled with material with energy-absorbing properties 5, locking brackets 6 (Fig. 3.20) and hinges 7.

The hatch cover works like this. The loads from the cargo transported in the universal semi-wagon act on the canvas 1, and from it are transmitted to the harness 2. During operational modes, these loads are partially extinguished by a material with energy-absorbing properties 5, placed in the harness 2. Locking brackets 6, which are fixed on straps 2, provide fixation of the hatch cover of the semi-wagon in a horizontal (closed) position. Hinges 7, fixed on the strap 2, ensure the retention of the hatch cover in the structure of the semi-wagon and the possibility of its opening and closing.

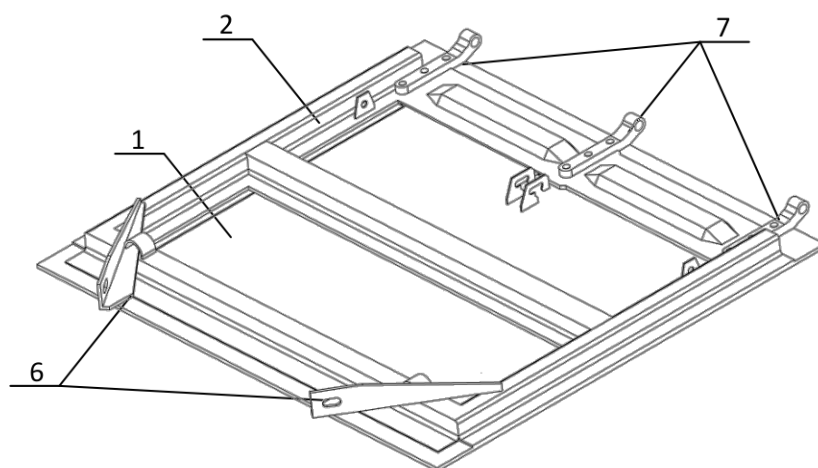


Fig. 3.20 Universal semi-wagon hatch cover

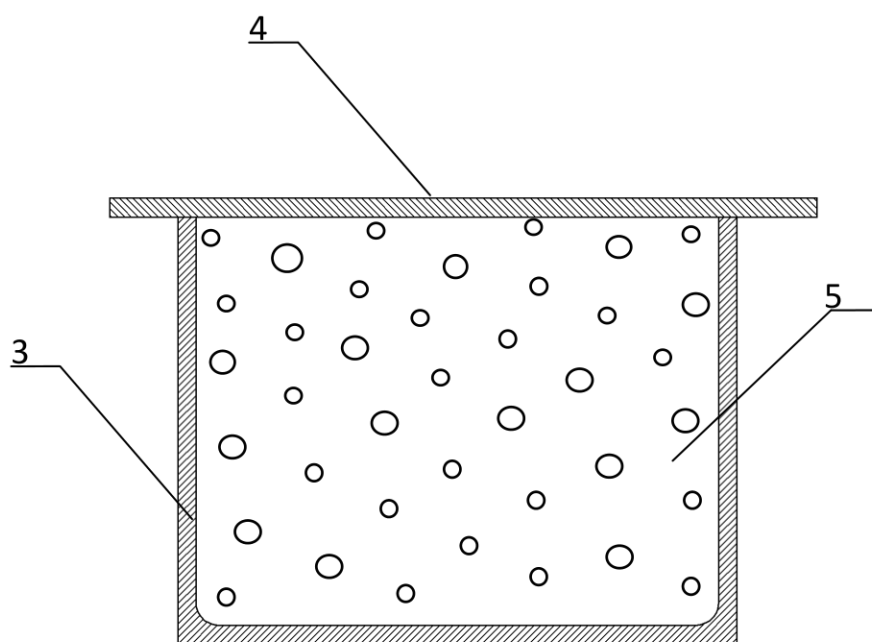


Fig. 3.21

3.8 Universal semi-wagon

The useful model refers to wagon construction and can be used for rail transportation of bulk and bulk cargoes that do not require protection from atmospheric precipitation.

A semi-wagon design is known, containing a body with a frame, side and end walls, trolleys and couplings, while the upper part of the end wall is made flat and extended beyond the frame by a distance of 50 to 400 mm, measured horizontally from the upper part of the end wall to the end wall the surface of the end beam of the frame at the place of installation of the shock socket, and the lower limit of the extended end wall is formed by an inclined section, which turns into a vertical one, and is connected to the frame, forming a niche above the hitch (UA 119248 U, 25.09.2017).

A semi-wagon design is known, comprising a body with end and side walls forming a closed circuit, which are connected by means of a strap with side wall struts, according to a useful model, the body is mounted on a modernized railway platform frame, which includes a running part and a rigid a frame consisting of a spinal beam, longitudinal and side beams and buffer beams, on which a hollow floor is installed, and side walls made of vertical racks, upper strapping and sheathing sheets are attached to the side beams of the frame. Rigidity boxes are welded into the side beams, to which the vertical racks of the side walls are welded, and on the inner side, rigidity boxes are installed along the vertical racks (UA 6119 U, 04.15.2005).

The disadvantages of these designs of semi-wagons are the insufficient strength of the supporting structure under the action of operational loads, which contributes to the appearance of cracks in them.

The closest to the proposed object is a specialized half-wagon with a hollow body [model 12-1580, see: Грузовые вагоны: Учеб. пособие: В 2 ч. Part 1: Half wagons and covered wagons/ M.I. Kharitonov, V.N. Pankin. - Khabarovsk: Publishing House - in DVGUPS, 2004. - p. 29], the design of which consists of a crew part module containing two two-axle bogies, a self-coupling device module, a braking equipment module, a frame module with backbone, end, intermediate beams, and a body module, which contains two side walls having a skin and a frame , which consists of upper and lower bindings, vertical racks, and two end walls, which have sheathing and a frame, which consists of upper and lower bindings, horizontal belts, side and intermediate racks.

The reasons preventing the achievement of the required technical result are the insufficient strength of the supporting structure of the semi-wagon under the action of operational loads.

The useful model is based on the task of increasing the strength of the supporting structure of the semi-wagon, and as a result, the service life, by reducing the load on the supporting structure.

The task is solved by the fact that in a semi-wagon, the construction of which consists of a module of the crew part containing two two-axle bogies, a module of an autocoupling device, a module of braking equipment, a frame module with a backbone beam, consisting of two Z-shaped profiles covered with an I-beam, end beams , of a closed section, with intermediate beams welded from sheets, and a body module, which contains two side walls having cladding and a frame consisting of upper and lower girders, vertical struts, and two end walls having cladding and the frame, which consists of upper and lower ties, horizontal belts, side and intermediate racks, the backbone beam consists of a U-shaped profile covered with a horizontal sheet, the intermediate beams have a closed box section, and the cladding is made of composite material.

The introduction of new features in interaction with the known ones ensures an increase in the strength of the load-bearing structure of the semi-wagon by reducing the load.

The essence of the useful model is explained by the drawings, where
in fig. 3.22 shows the general view of the proposed semi-wagon;
in fig. 3.23 – semi-wagon body module;
in fig. 3.24 – semi-wagon frame module;
in fig. 3.25 – cross-section of the backbone beam of a semi-wagon;
in fig. 3.26 – section of the intermediate beam of a semi-wagon.

The proposed universal semi-wagon (Fig. 3.22) consists of a crew part module 1 containing two two-axle bogies, a self-coupling module 2, a braking equipment module 3, a body module 4 and a frame module 5. The body module (Fig. 3.23) contains two side walls, having a sheathing made of composite material and a frame consisting of upper 6 and lower 7 bindings, vertical posts 8, and two end walls having a sheathing made of composite material and a frame consisting of upper binding 9 and lower 10, side 11 and intermediate racks 12. The frame module (Fig. 3.24) contains a backbone beam 13, which consists of a U-shaped profile 14 covered with a horizontal sheet 15 (Fig. 3.25), two pivot beams 16 (Fig. 3.24), two end beams 17, as well as intermediate beams 18, which have a closed box section (Fig. 3.26).

Proposed universal semi-wagon works like this. To form a freight railway train, the semi-wagon is connected to the rear wagon and the front wagon (or locomotive) through the coupling device module 2 (Fig. 3.22), and to the train brake line through the brake equipment module 3. As a result of loading the body (Fig. 3.23) in bulk or bulk cargo, vertical loads through the covers of the loading hatches and the backbone beam 13 (fig. 3.24) are transferred to the over-spring beams of the trolleys 1 (fig. 3.22) and the axles of the wheel pairs.

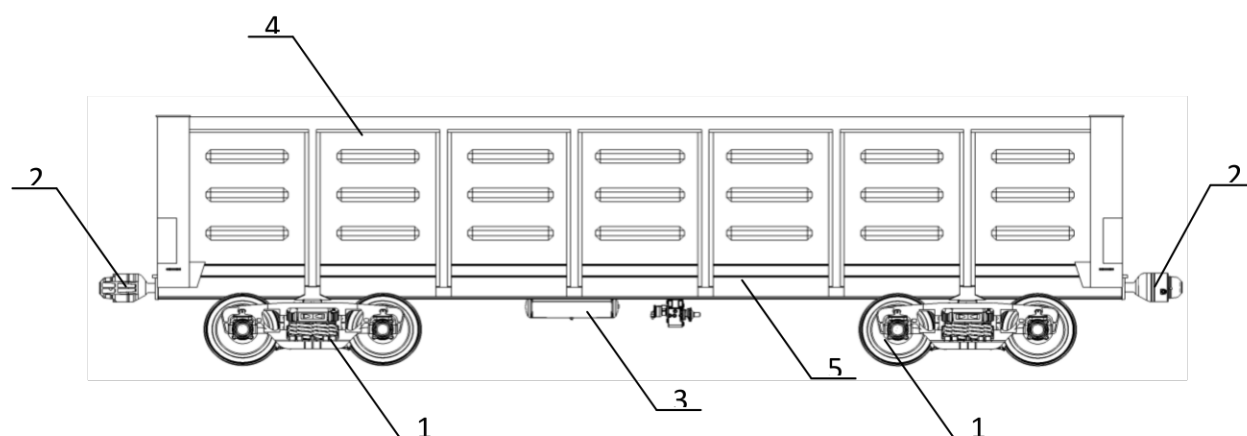


Fig. 3.22 Universal semi-wagon

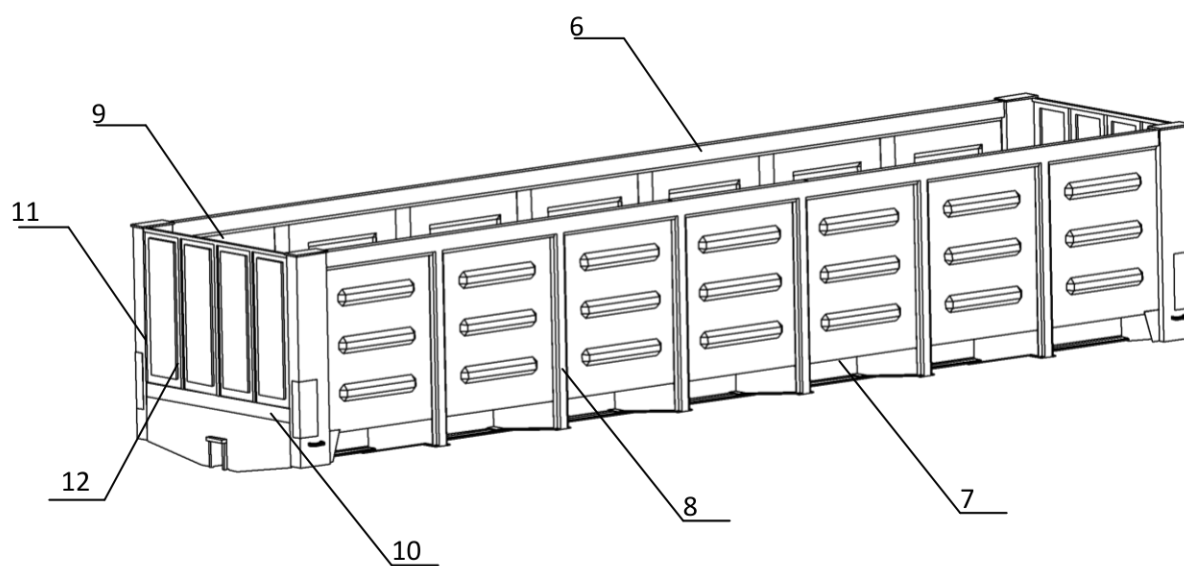


Fig. 3.23

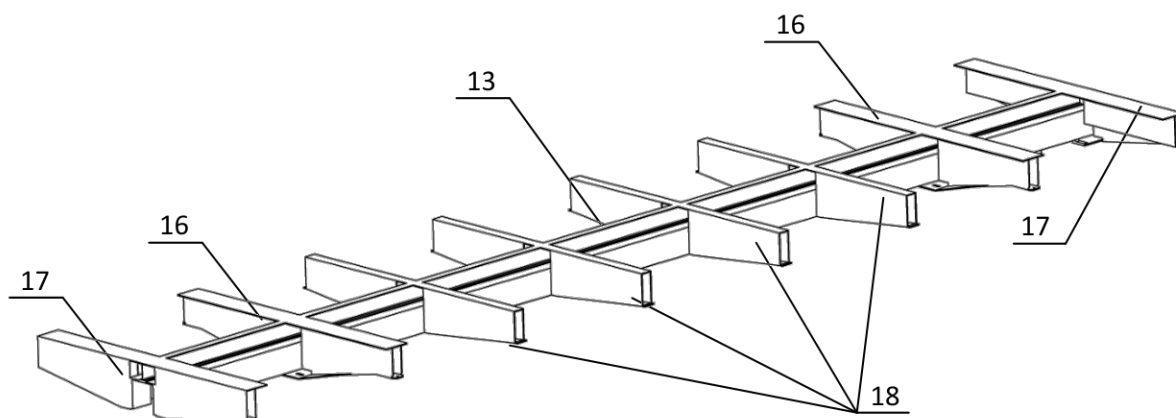


Fig. 3.24

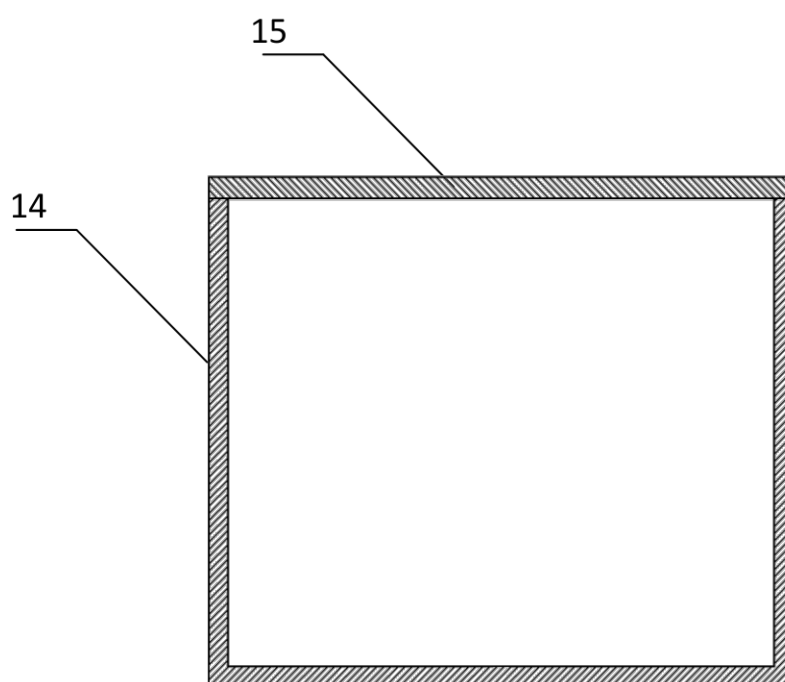


Fig. 3.25

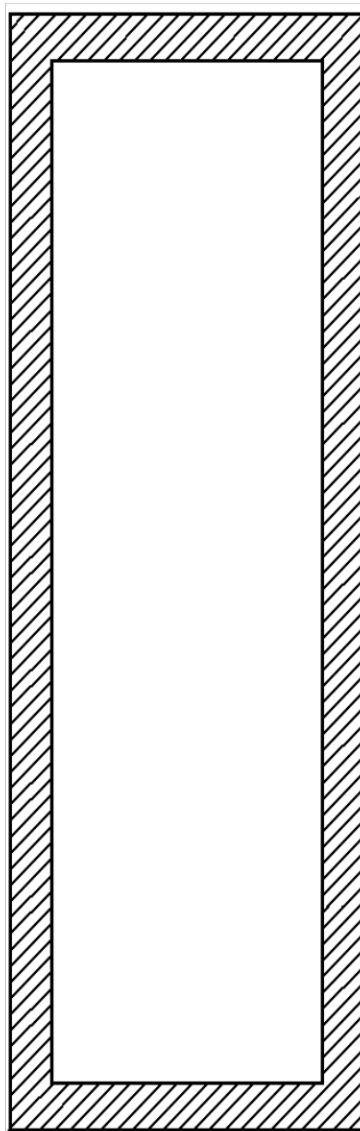


Fig. 3.26

3.9 Detachable roof of a semi-wagon

The useful model belongs to railway transport, in particular to removable roofs of semi-wagons.

The design of the removable roof of a railway freight transport is known, which includes an interconnected lower frame, transverse beams with a sheathing fixed on top, and nodes for fastening the roof to the upper lining of the walls of the freight transport body. The roof is made in one piece. Its lower frame around the entire perimeter is U-shaped with the possibility of interaction with the upper lining of the body walls. Transverse beams form an arched structure that unites the upper arched beam, the lower horizontal beam and at least one vertical post. The nodes for attaching the roof to the upper body trim consist of loops fixed on the lower frame and tightening devices (UA 97717 U, 03/25/2015).

Also known is the design of a removable roof for a semi-wagon, which contains transverse beams with a sheathing fixed on top, loading hatches, fastening elements for pressing the roof to the upper lining of the side walls of the semi-wagon, a lower frame, a central longitudinal force beam consisting of longitudinal tubular elements, transverse and vertical connections from below at the ends of the central longitudinal power beam with the possibility of movement in the longitudinal direction and made in the form of thrust plates. Each thrust plate is connected by means of screws immovably fixed in it at one end with a bracket rigidly fixed on the central longitudinal force beam. The bracket has holes in which the indicated screws are freely placed. Nuts are installed on the screws on both sides of the bracket (RU 2094268, 10/27/1997).

The disadvantages of these removable roofs are that they have a metal structure, which contributes to the increase of the wagon's tare and, accordingly,

its sprung weight. In addition, the considered designs of removable roofs do not have the possibility of adjusting the length of the wagon bodies to adapt their use to different models.

The closest thing to the claimed object is a removable roof, which is made in one piece and contains an interconnected lower frame, transverse beams with a sheathing fixed on top and nodes for fastening the roof to the upper lining of the walls of the truck body. The lower frame along the entire perimeter is made with the possibility of interaction with the upper strapping of the body walls, and the transverse beams form an arched structure that unites the upper arc-shaped beam, the lower horizontal beam and the reinforcing element. Additionally, a loading hatch was introduced (UA 119901 U, 10.10.2017).

The reasons that prevent obtaining the necessary technical result are that the removable roof in question has a metal structure, this contributes to the increase of the wagon's tare, and accordingly its sprung mass, as well as the largeness of the possibility of adjusting the length of the wagon bodies to adapt the use under different models.

The basis of the useful model is the task of reducing the tare of the removable roof and, accordingly, the sprung mass of the semi-wagon while ensuring the conditions of operational strength and reliability, as well as the possibility of using the roof on different models of semi-wagons by adjusting the length of their bodies.

The task is solved by the fact that in the removable roof, which is made in one piece and contains the lower frame connected to each other, transverse beams that form an arched structure that unites the upper arched beam, the lower horizontal beam and the reinforcing element, with the sheathing fixed on top and nodes of fastening of the roof to the upper lining of the walls of the freight transport body, the lower frame and transverse beams are made of pipes, rectangular cross-section, the skin is made of composite material, and the

cantilever parts of the roof have the ability to move relative to the longitudinal axis to adjust the length of the roof according to the length of the wagon body .

The introduction of new features in interaction with the known ones ensures a reduction of the tare of the removable roof, and accordingly the sprung mass of the semi-wagon while ensuring the conditions of operational strength and reliability, as well as the possibility of using the roof on various models of semi-trailers.

The essence of the useful model is explained by the drawings, where

in fig. 3.27 shows the general view of the removable roof (bottom view);

in fig. 3.28 – cross section of the removable roof;

in fig. 3.29 shows the general view of the removable roof (top view);

in fig. 3.30 – section of rectangular pipes that form the lower frame and transverse beams.

The proposed roof (Fig. 3.27) consists of the lower frame 1, transverse beams 2 with a top-mounted cladding 3, arc-shaped beams 4, reinforcing elements 5 (Fig. 3.28) and roof attachment nodes 6 to the upper lining of the walls of the truck body. Cantilever parts of the roof 7 (Fig. 3.29) have the ability to move relative to the longitudinal axis for adjustment of the length of the roof according to the length of the wagon body and interact with the main part of the roof according to the telescopic principle. At the same time, the lower frame 1 and transverse beams 2 (Fig. 3.27) are made of pipes with a rectangular cross-section (Fig. 3.30).

The design of the removable roof can be supplemented with deflectors, loading hatches, as well as devices for maintenance and storage.

For the possibility of transporting goods that need protection from atmospheric precipitation in a semi-wagon, a removable roof is installed on it with the help of lifting and transport equipment. For the possibility of adjusting

the length of the roof according to the length of the wagon body, its cantilever parts 7 (Fig. 3.29) can be moved relative to the longitudinal axis. Fixing of the roof to the body of the semi-wagon is carried out with the help of fastening nodes (Fig. 3.28).

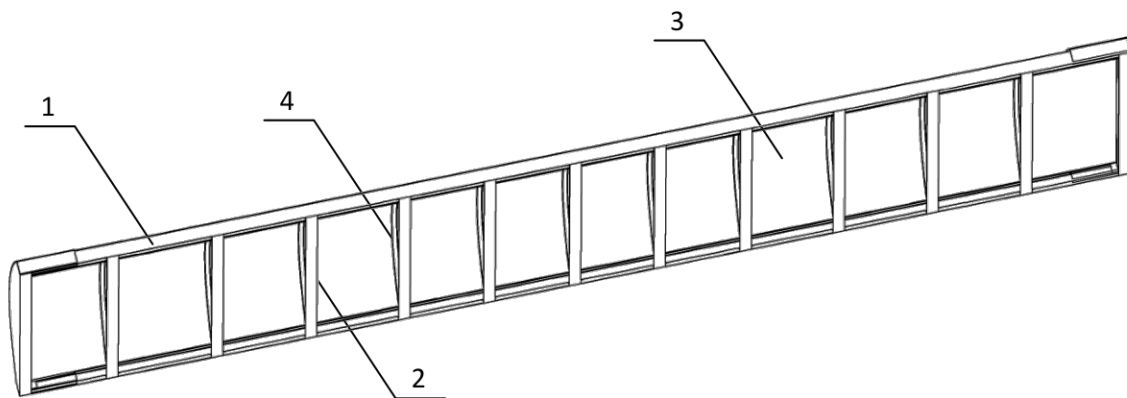


Fig. 3.27

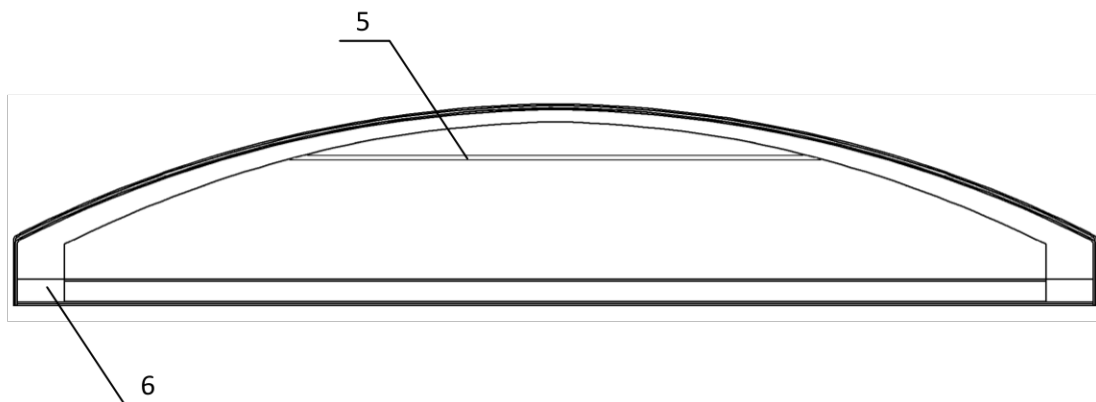


Fig. 3.28

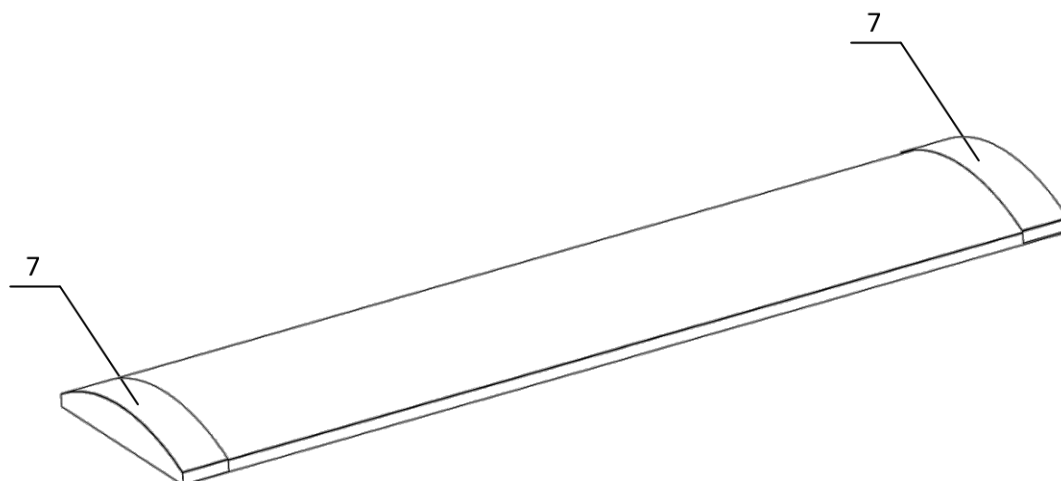


Fig. 3.29

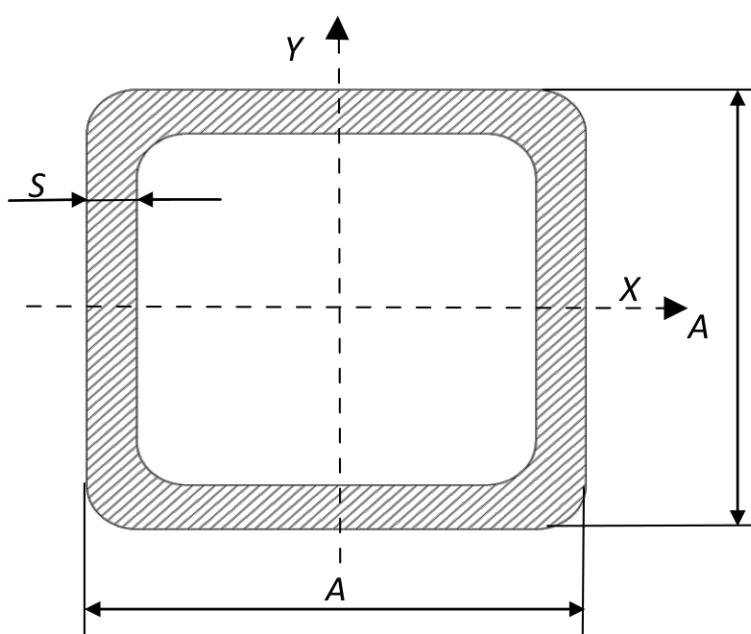


Fig. 3.30

3.10 Railway tank

The useful model belongs to railway transport, namely railway tanks and can be used for the transportation of liquid cargo.

A well-known railway tank, which contains trolleys, a frame, braking equipment, auto coupling devices, a boiler, fixing the boiler to the frame and supports of the boiler to the frame (see Lukyn V.V., Anisimov P.S., Fedoseev Y.P. Wagons. General course: Textbook for railway transport universities / sub-ed. V.V. Lukina. - Moscow: Route, 2004. - 424 pp. pp. 143-144 - prototype).

The disadvantage of such a design is that during the transportation of liquid cargo, the dynamics of a railway tank is worse than that of most other types of wagons, which in turn imposes additional features and restrictions in terms of train transportation.

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

The task is achieved by the fact that in the railway tank, which contains trolleys, frame, braking equipment, auto coupling devices, boiler, fastening of the boiler to the frame and supports of the boiler to the frame, according to the useful model, the supports of the boiler to the frame are made in the form of rubber-metal elements.

The advantages of the proposed technical solution are the improvement of the dynamics of the railway tank.

The essence of the useful model is explained by illustrative material, where in fig. 3.31 shows a railway tank, which contains carts 1, frame 2, braking equipment 3, self-coupling devices 4, boiler 5, fastening of the boiler to the

frame (not marked), supports 6 of the boiler to the frame, made in the form of rubber-metal elements (Fig. 3.32).

The proposed railway tank works as follows.

During movement, the vertical and horizontal forces from the boiler 5 are transmitted to the frame 2 partly through the fasteners and through the supports 6, which are made in the form of rubber-metal elements that partially absorb the vibration energy and improve the dynamics of the railway tank. The movement of the railway tank wagon is provided with the help of trolleys 1. Braking of the railway tank wagon is provided by braking equipment 3. The connection of the railway tank wagon with other wagons is provided by self-coupling devices 4.

The application of the proposed technical solution will improve the dynamics of the railway tank.

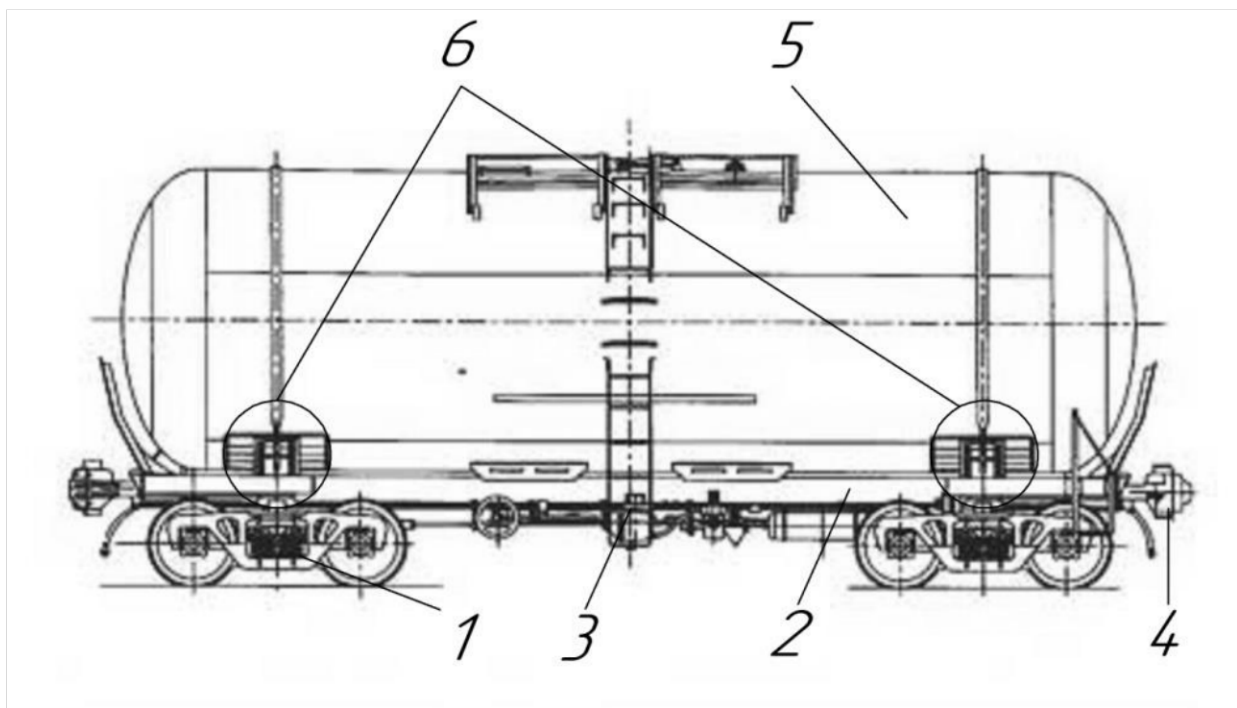


Fig. 3.31 Railway tank

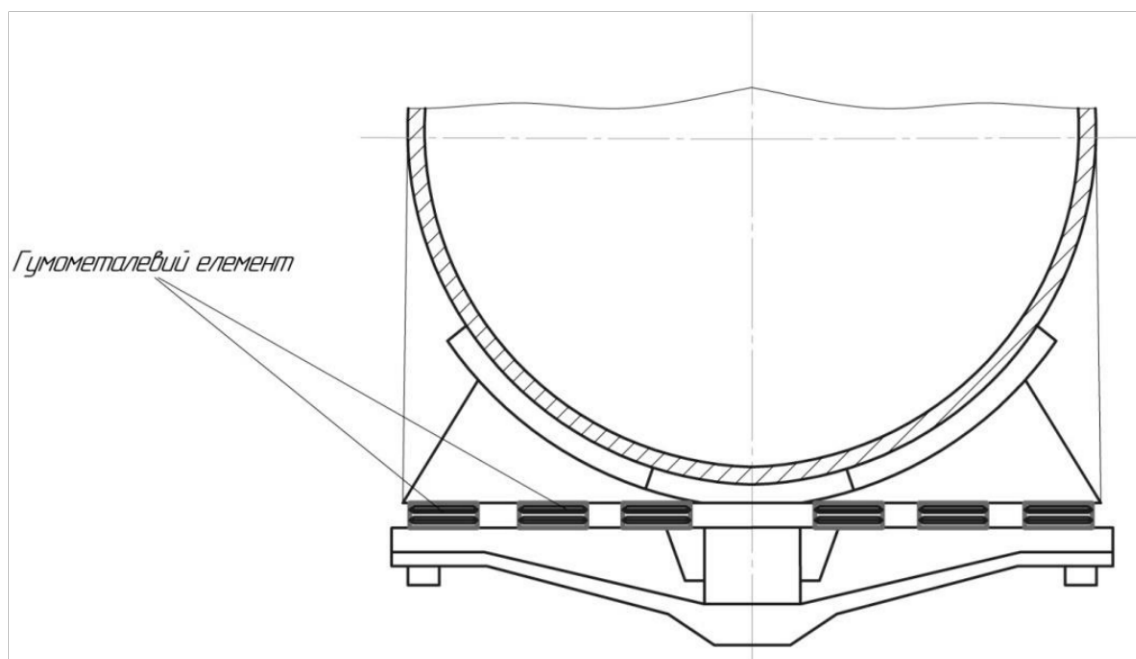


Fig. 3.32

3.11 Platform wagon for bulk cargo transportation

The useful model refers to wagon construction and can be used for rail transportation of bulk cargoes.

A known platform wagon, which is made elongated with an increased floor area, its transverse beams of variable cross-section connecting the backbone beam to the side beams and having a greater height in the middle part of the frame near the base of the backbone beam compared to the beams installed in the end part of the frame . The longitudinal side beams of the frame of the platform wagon are made of a box section and swivel racks of variable section with hooks are installed on them [RU 11077, 15.12.2005].

Also known is the design of a platform wagon for the transportation of goods of different lengths, which includes a supporting frame mounted on running trolleys with side support brackets, equipped with movable end stops and limiter supports against lateral shifts of the load, which is distinguished by the fact that the movable end stops and limiter supports mounted on a removable base fixed to the frame, and in the lower parts of the movable end stops and in the locations of the limiter supports on the removable base, grooved connecting transverse elements are mounted with installation in the last non-metallic bars for placing the load, while attaching the removable base to the side supports the frame bracket is made collapsible (UA 23046, 10.05.2007).

The disadvantages of these designs of platform wagons are the impossibility of rail transportation of bulk cargoes.

The closest to the proposed object is a railway platform wagon with a tare of 20.9 tons and a carrying capacity of 70 tons[see: Freight wagons: Textbook. allowance: In 2 h. Part 2/ M.I. Kharitonov, V.N. Pankin. – Khabarovsk: Publishing House of the DVGUPS, 2006. – p. 9, 10], the structure

of which consists of a crew part module containing two two-axle bogies, an autocoupling device module, a braking equipment module, a frame module with a backbone beam with main and cantilever parts, main longitudinal beams with main and cantilever parts, intermediate longitudinal, intermediate transverse beams, braces and body module containing metal sides and floor covering.

The reasons that prevent obtaining the necessary technical result are the impossibility of rail transportation of bulk cargoes.

The basis of the useful model is the task of increasing the efficiency of the platform wagon by adapting it to the transportation of bulk cargoes.

The task is solved by the fact that in a railway platform wagon, the structure of which consists of a module of the crew part containing two two-axle trolleys, a module of an autocoupling device, a module of braking equipment, a frame module with a backbone beam from the main and cantilever parts, main longitudinal beams from the main and cantilever parts, intermediate longitudinal, intermediate transverse beams, braces and a body module containing metal sides, the spinal and main longitudinal beams of the frame have a closed section, and supports are installed on the pivot beams, on the grooves of which wooden bars are laid, on which the boiler rests from composite material.

The introduction of new features in interaction with the known ones ensures an increase in the efficiency of the platform wagon by adapting it to the transportation of bulk cargoes.

The essence of the useful model is explained by the drawings, where
in fig. 3.33 shows the general view of the proposed platform wagon;
in fig. 3.34 – platform wagon frame module;
in fig. 3.35 – section of the spinal and main longitudinal beams of the frame;
in fig. 3.36 – a boiler on metal supports.

The proposed platform wagon (Fig. 3.33) consists of a crew unit module 1, which contains two two-axle trolleys, a self-coupling module 2, a braking equipment module 3, a supporting structure module 4 and a boiler module 5. The supporting structure module is represented by a frame (Fig. 3.34) , which includes a spinal beam 6, which has a closed section (Fig. 3.35), end beams 7 (Fig. 3.34), braces 8, pivot beams 9, main longitudinal beams 10, which have a closed section (Fig. 3.35), intermediate longitudinal beams 11 and transverse 12 (Fig. 3.34). The boiler module (Fig. 3.36) is installed on the pivot beams 9, which includes metal supports 13 on which wooden bars 14 are placed. The boiler 15, made of composite material, rests on the wooden bars 14.

The proposed platform wagon works as follows. To form a freight railway train, the platform wagon is connected to the rear wagon and the front wagon (or locomotive) through the coupling device module 2 (Fig. 3.33), and to the train brake line through the brake equipment module 3. Vertical loads from the boiler module 5 (fig. 3.36), placed on the platform wagon, are transmitted to the frame module (fig. 3.34) and then to the axles of the wheel pairs of two two-axle trolleys (fig. 3.33) of the crew unit module 1.

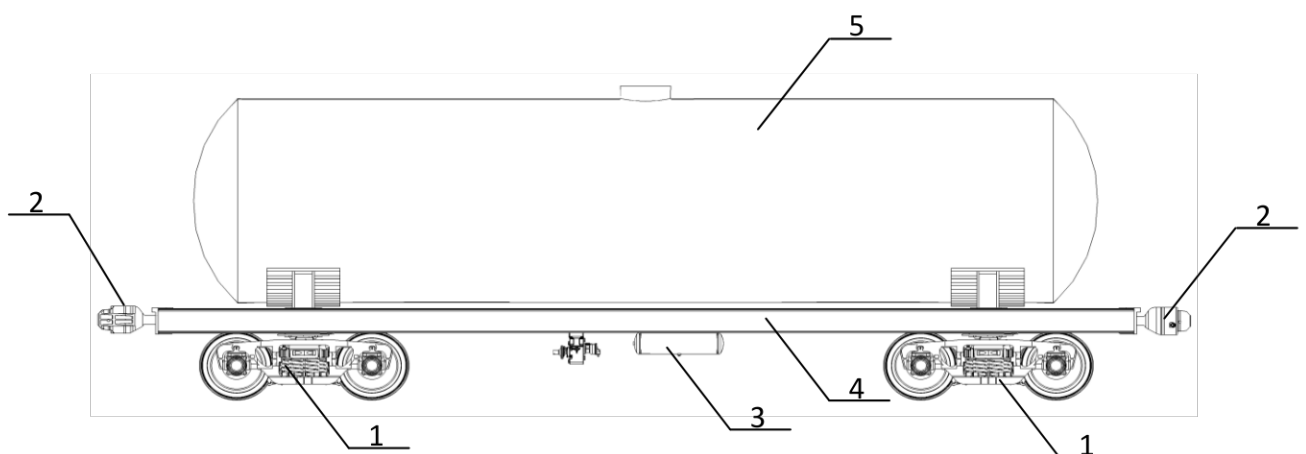


Fig. 3.33

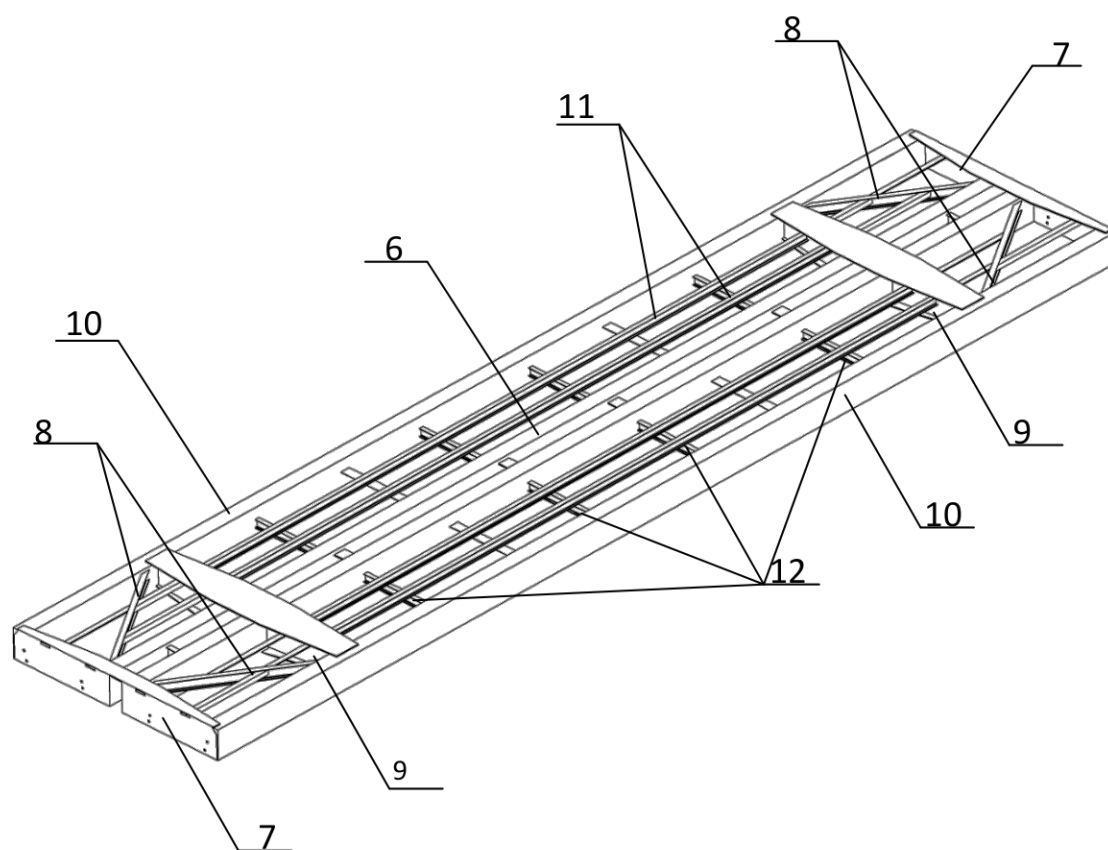


Fig. 3.34

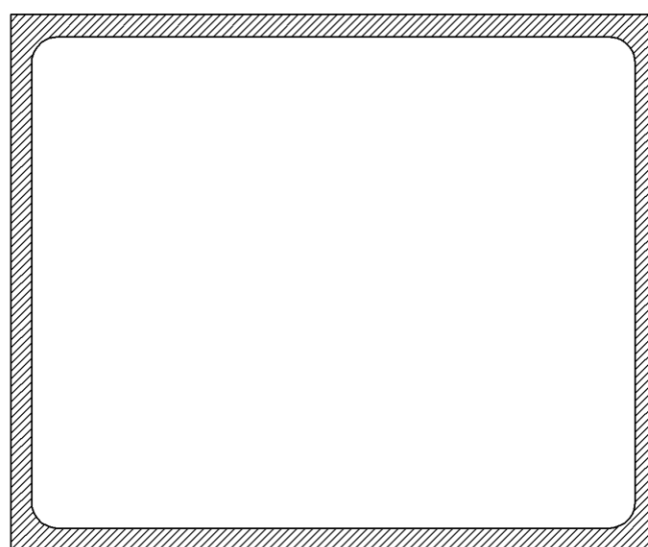


Fig. 3.35

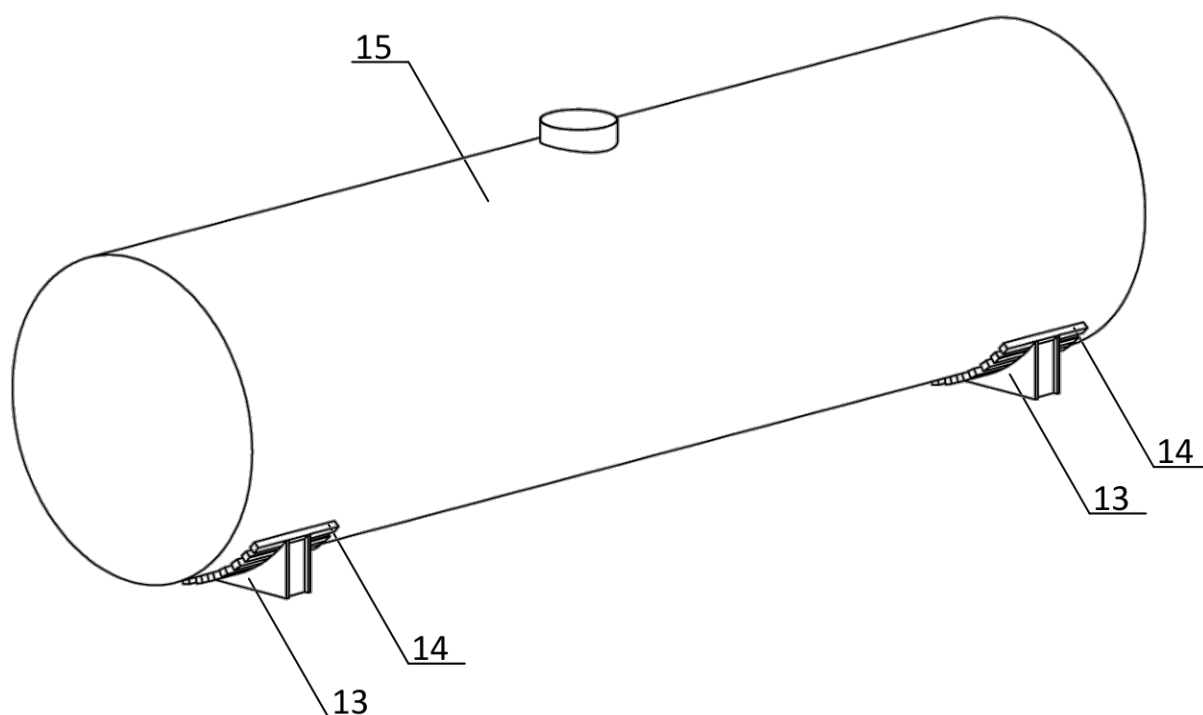


Fig. 3.36

GENERAL CONCLUSIONS

Measures are proposed to improve the structures of freight wagons by making them from composite materials.

The development of conceptual solutions for the manufacture of components of freight wagons load-bearing systems made of composites (microstructures based on composite materials, in particular: carbon fiber, fiberglass, metal shell (hollow and layered), etc.) will allow domestic freight wagon designs to achieve technical and economic indicators of the new generation level and thereby significantly improve the profitability and competitiveness of rail freight transportation, reduce resource consumption and improve traffic safety. This, in turn, will significantly improve the economic efficiency of cargo transportation by domestic railways both in the domestic market and in interstate transit. It will also allow numerous domestic railcar engineers to compete in the relevant global market.

Scientific goals of creating composite load-bearing modules of wagon structures:

- ✓ to change the existing stereotypes of the design of freight cars not only at the domestic, but also at the world level;
- ✓ saving resources and means in the structures under construction thanks to a more optimal way of perceiving operational loads;
- ✓ increasing the bearing capacity of structures due to increased loads;
- ✓ reducing the deformability of the entire structure or its individual elements, reducing the frequency or amplitude of oscillations;
- ✓ increasing the stability of individual elements or the entire structure as a whole;

- ✓ increasing the endurance of individual elements under cyclic loads due to the improvement of the cycle characteristics;
- ✓ a favorable change in the properties of the structure (dynamic characteristics under dynamic influences, aerodynamic characteristics under wind influences, increased resistance to temperature loads (for example, frost resistance, increased corrosion resistance under atmospheric influences and their aggression from cargo);
- ✓ ensuring the convenience of installation, service and, in this connection, the reduction of labor costs;
- ✓ prevention of the occurrence of negative residual deformations from technological factors.
- ✓ reduce the wear and tear of the railway track by improving the "friendship" of the rolling stock to the track, namely by reducing the vertical and transverse loads on the rails;
- ✓ to expand the knowledge of relevant specialists by using the results of work in the initial process of specialized higher educational institutions in the preparation of bachelors, masters, doctors of philosophy, doctors of science and students of advanced training courses in the relevant specialties;
- ✓ to provide appropriate scientific and applied tools for specialists engaged in research and development activities;
- ✓ use the obtained scientific and applied developments for other means of heavy transport engineering;
- ✓ to ensure the high authority of domestic transport and mechanical engineering science and technology in the world.

What will allow them to reach the technical and economic indicators of the new generation level, in particular, it is predicted: a reduction of the own weight (tare weight) of the structures of freight wagons by three times with a corresponding increase in the carrying capacity, and as a result, an increase in

the profitability of railway transportation; an increase in the service life/resource of freight wagons, and as a result, a corresponding reduction in costs, periodic updates of the wagon park; reduction/elimination of physical corrosion processes in the structures of freight wagons, and as a result corresponding reduction of costs for repairs of wagons in operation; improving the reliability properties of freight wagons: reliability, durability, maintainability, etc. The development of the specified foundations, provisions and solutions will be created taking into account the possibility of their effective implementation on other transport engineering structures, in particular: armored vehicles, military and civilian wagons, airplanes, sea and river vessels, lifting and transport machines.

The research will help to increase the efficiency of rail transport, the transportation process through international transport corridors, as well as create developments in the design of multifunctional railcar structures.

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SCIENTIFIC EDITION

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CONCEPTUAL SOLUTIONS FOR THE MANUFACTURE OF CARGO WAGON BEARING SYSTEMS FROM COMPOSITES (PART 1)

Monograph

The monograph will be useful for scientists, designers, engineers whose activities are related to the improvement of technical, economic and operational indicators of non-traction rolling stock at various stages of its life cycle.

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Published (PDF): 30.11.2023.

Conventionally printed sheets 20,69.

Publisher ^[ISBN]: Primedia E-launch LLC.
TX 75001, United States, Texas, Dallas.

E-mail: info@primediaelaunch.com | URL: www.primediaelaunch.com