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Creation of the Image of the New Generation Freight Car Bogie

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Abstract

Analysis of the operating problems of freight car bogies are carried out, analysis of the reasons for low dynamic qualities, which do not allow to increase the speed of movement. The main directions of the development of the bogies constructions are substantiated. The image of the new generation freight car bogie is formulated based on analysis, ideas of car building projects using the method of intellectual decision support. Concept image and patented technical solutions for implementation are solving the problem of minimizing the weight of the bogie (increasing of coefficient of mass utilization) by using a modular design, application of elastic-damping structures, prestressed state of structural elements. Technical solutions improve the strength characteristic and dynamic properties of the freight car bogies on the basis of the above principles of engineering.
KEY WORDS: *freight car, bogie, pre-stressed structures, creation of a specialized profile, elastic-damping multifunctional elements*

1. Introduction

Improvement of dynamics and strength of freight car bogie is an actual task for industrial and scientific organizations. Studies are carried in the mainstream of the EU Road Map, according to which, in order to reduce the energy dependence of the transport sector and to reduce emissions of harmful substances into the atmosphere, it is planned that by 2030 30% of goods transported by road will be redirected to river and railway transport, and by 2050 50% of freight will be transported by river and railway transport [1]. This background requires the introduction of significant innovations and modernization of the fleet of cars, for example, the working program Shift2Rail [2] aims to achieve:

- reducing the weight of the body up to 30% and the weight of the bogie (reducing unspring weight, which allows to reduce wear, noise and vibration and will reduce by 20% the life cycle cost of the bogie);
- reducing the dynamic impact on the track through the use of active suspension;
- reducing maintenance costs by 20% through the introduction of monitoring systems, mechatronic systems, etc.;
- reducing wheel and rails wear by 25%, including when passing the curved track sections;
- increasing the speed of movement, especially for freight rail transport demonstrates the dynamic development of passenger rail transport and the “stagnation” of freight rail transport in terms of speed on the example of Sweden [3].

Constantly used in the European Union and Commonwealth of Independent States countries bogie designs, such as Y25, G-type, UIC Link suspension, Barber (type 18-100), have a long history and have undergone only minor transformations during their existence, their schematic development history is shown in Fig. 1 and was created by article authors. The innovation matrix created as a part of SUSTRAIL project [4] has shown that the leading research centers in Europe consider Y25 bogie as the basis of the freight bogie of the future. Within the framework of the conventional approach, it should be modified in the primary spring suspension, use two Lenoir dampers, material with good damping properties, new wheel contour and new wheel steel type. Within the futuristic concept, in addition to the outlined, the use of wedges, hydraulic dampers, and changes in the stiffness of the supports are supposed. Yet it should be noted that the Y25 bogie is very sensitive to the track irregularities, and also requires the improvement of the dynamic qualities for the passage of curved track sections (Fig. 2) [5].

Unlike the authors [4], S. Stichel and P. A. Jonsson consider it promising to use Link suspension bogie with hydraulic dampers [8], which allows to achieve speeds of up to 160 km/h. Authors in their previous works suggest the development of the Barser cart (18-100), as well as the use of elastic-dissipative bearing elements [6, 7].

In the countries of Central and Eastern Europe, a three-piece bogie is widely used (18-100 type or Barber) which is no better: maximum operating speed does not exceed 90-100 km/h, the high dynamic impact on the railway track is one of the main causes of its wear and damage, high dynamic loading of the supporting members, absence of the pedestal bogie primary suspension, cast bogie frame [9]. In different years, attempts have been made to optimize the characteristics of bogie suspension [10], the use of elastic elements in the pedestal [11, 12], transition from cast to welded elements [13], but no significant breakthrough and tangible results have been achieved.

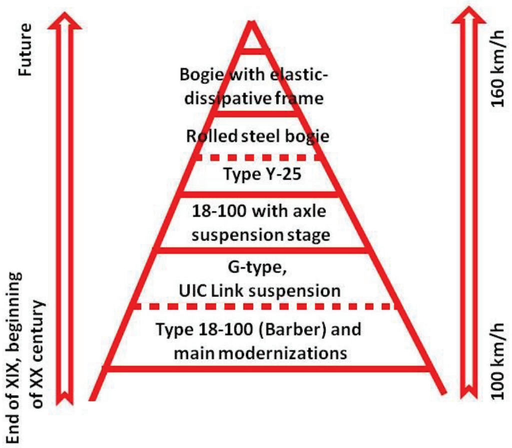

Fig. 1 Development of bogie constructions

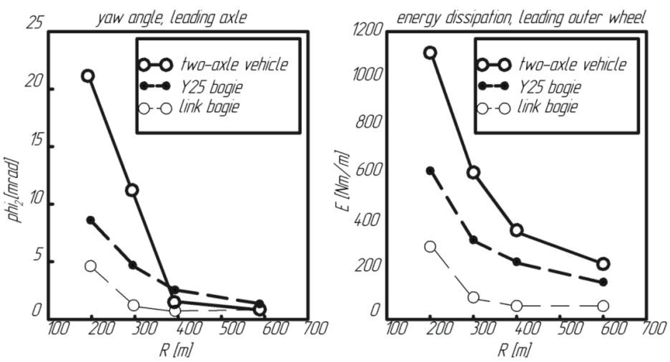

Fig. 2 The angle of attack and the dissipation energy of the first wheel pair of different types of bogies when passing curves of different radii [6, 9]

2. Methods for Creating a New Design for a Freight Car Bogie

In this way and relying on [6], actual task is to introduce new concepts and technologies, to create a new bogie design, with the implementation of advanced construction techniques, such as multi-functional components, design modularity, the use of innovative materials, the use of pre-stressed elements. In the near future, it is almost impossible to introduce significant changes in the design of widely used bogies due to the repair base, therefore there is a need for creating a new design for a freight car bogie and upgrading a freight car bogie.

The authors of the article suggest a number of ways to improve freight car bogies of different types on the basis of the approach outlined above:

- using of pre-stressed structures;
- using of rolling materials, the creation of a specialized profile;
- using of elastic-damping multifunctional elements with modularity units.

2.1. Methods for Upgrading a Freight Car Bogie

The causes of lateral frame fractures are found out. Following reasons are known from the literature: 1. Excess value of load (impact loads) for jaws on the sorting roller coaster (up to 100 kN on the jaw). 2. Fatigue failures due to the running of the side frames (if technically faulty bogie). 3. The presence of internal defects in side frames. 4. Operation of bogies after stairs from rails. [7, 8] 5. Combination of longitudinal jaw loading and bends of the side frames. Skewed wheel pair during impact are accompanied longitudinal force on the jaw up to 100 kN and force moment 4.5 kNm. This reason is established experimentally during impact tests. Scheme of strain gages and the general view of the car are shown in Fig. 3.

Fig. 3 Scheme of strain gages and the general view of the car

The authors developed and patented constructions of pre-stressed elements of the bogie design: truck bolster (Fig. 4) [6], side frame (for upper and lower belts – Fig. 5) [6]; side frame pedestal jaw opening (Fig. 6) [6].

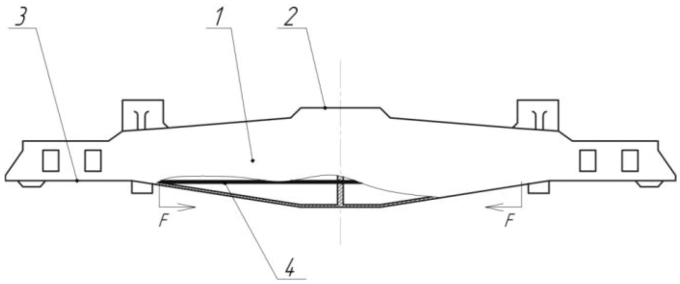

Fig. 4 Pre-stressed bolster of a three-piece bogie: *1* - truck bolster; *2* - bolster bowl; *3* - support bearing; *4* - rod

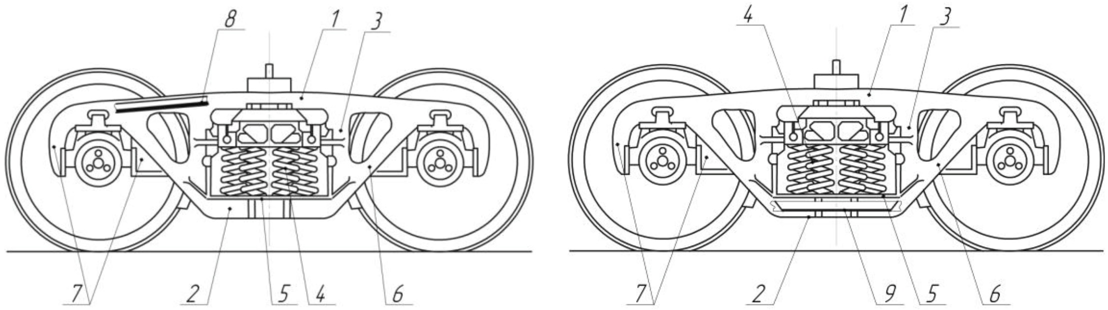

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Fig. 5 Pre-stressed side frame of three-piece bogie concept *1* - top sole bar member; *2* - lower sole bar member; *3* - vertical columns; *4* - spring opening; *5* - bearing surface; *6* - diagonal sole bar member; *7* - jaw pedestal; *8*, *9* - rod

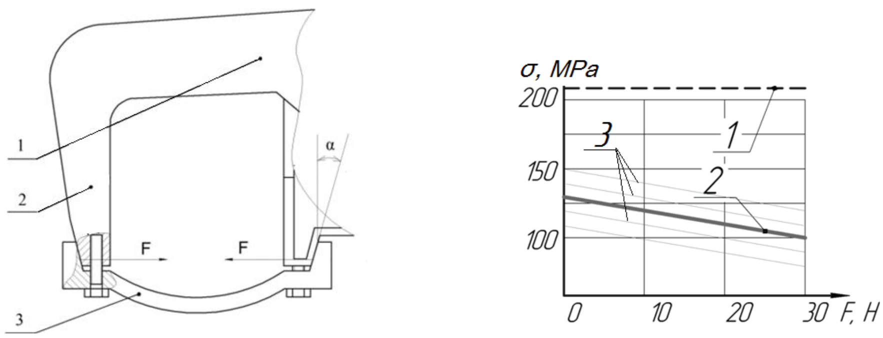

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Fig. 6 Pre-stressed pedestal jaw opening of a three-piece bogie concept: a) pre-stressing circuit in pedestal jaw opening, *1* - top sole bar member; *2* - pedestal jaw; *3* - pedestal brace; α - angle of inclination, providing the preliminary tension of the structure, F - force providing pre-stressed state of a structure; b) dependence of the level of maximum stresses in the zone R55 (at maximum vertical and axial loads) on the force of preliminary tightening of the jaws with pedestal brace (metal string), *1* - stress level in the existing side frame, *2* - stress level when using a pedestal jaw, cross-section 20 sm^2, *3* - dependence of stress level when changing the cross-section of the pedestal jaw

As a result of strength calculations, by the finite element method (general view (a) and side frame (b) of calculation model is presented in Fig. 7), it was found out that by changing the force creating a preliminary stress in the pedestal jaw opening, it is possible to reduce the level of maximum stresses in the most stressed zone by 1.5 to 2 times - Fig. 8.

As the development of the idea of using a load-bearing element that closes the pedestal jaw opening, the authors developed technical solutions for the creation of primary bogie suspension in a three-piece bogie. An examples of a design with coil springs is shown in Fig. 9 [7, 9]. A preliminary calculation of the distribution of equivalent stresses in the side frame of the created structure is shown in Fig. 8: the change in the scheme of application of forces did not lead to an increase in the level of stresses.

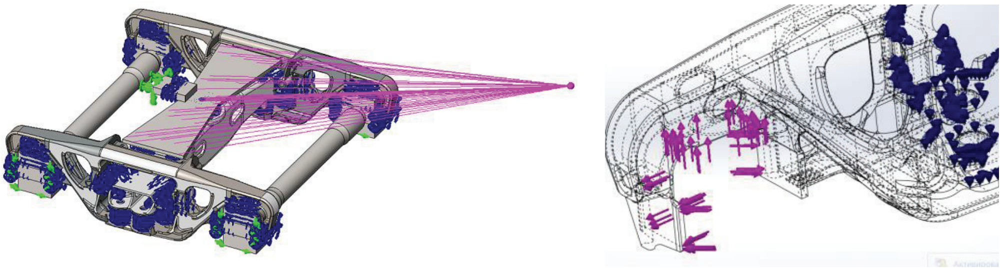

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Fig. 7 General view (a) and side frame (b) of calculation model

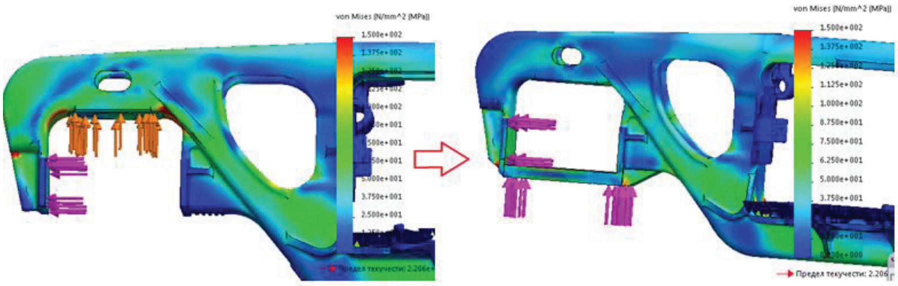

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Fig. 8 Distribution of equivalent stresses in the side frame: a - in existing bogie; b - in a bogie with a pre-stressed pedestal jaw opening

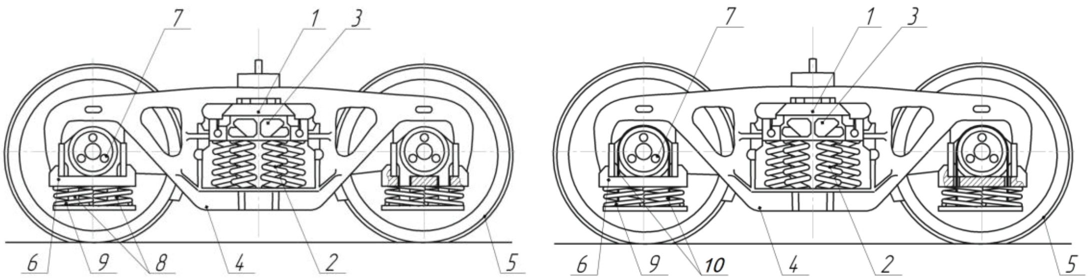

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Fig. 9 Three-piece bogie with the pedestal brace and primary bogie suspension (a - with rigid connection [6]; b - with flexible connection): *1* - bolster; *2* - bolster suspension; *3* - friction shock absorbers; *4* - side frame; *5* - wheelsets; *6* - pedestal brace; *7* - axle-box; *8* - rods connecting the bearing with a stiffener; *9* - primary spring suspension; *10* – cable

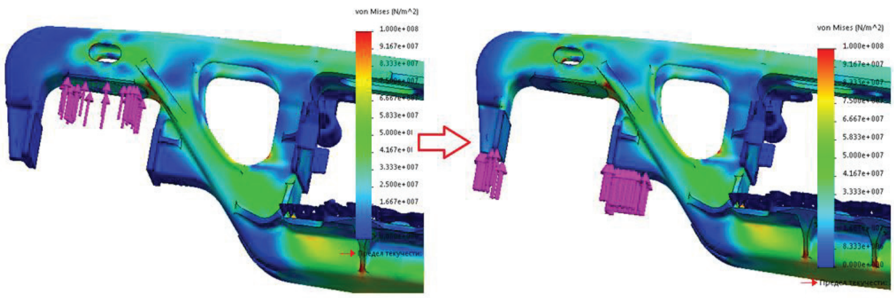

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Fig. 10 Diagrams of equivalent stresses for the existing (a) and prospective (b) schemes of vertical forces application

According to the previous calculation and other studies [7, 9], applying in the primary bogie suspension allows to reduce resistance to movement (increase of energy efficiency) of the freight car by 11%, and also to increase the speed of movement by 30% with an equivalent level of impact on the track. Visualization of the dynamic model is shown on Fig. 10, structural scheme of the model is shown on Figs. 11 and 12.

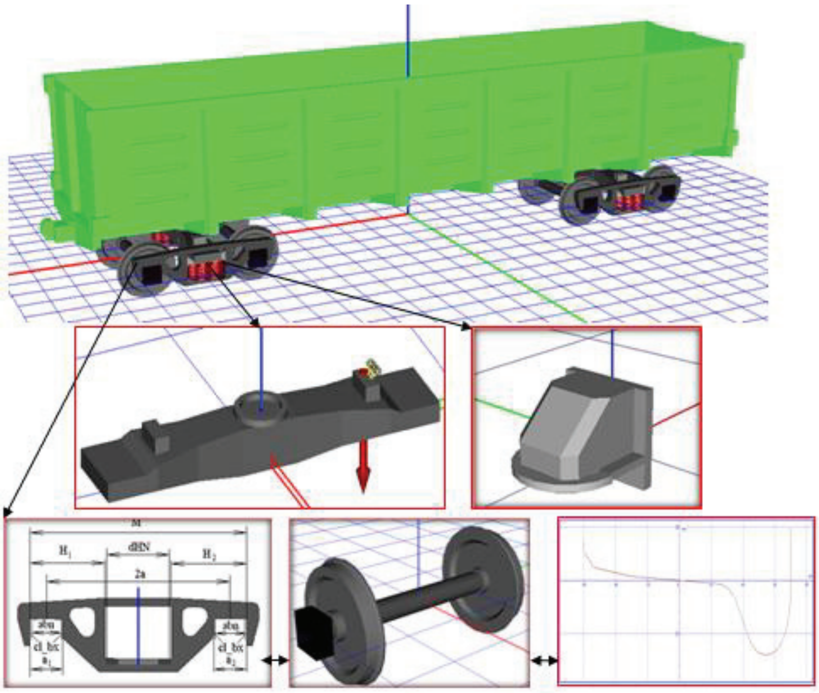

Fig. 11 Visualization of the dynamic model

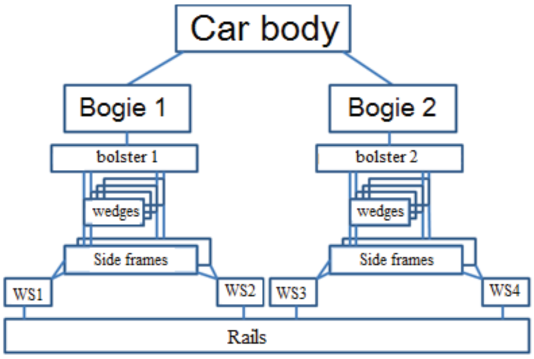

Fig. 12 Structural scheme of the model

The first stage of verification is using simple model:

$$m \cdot \ddot{z} + \beta \cdot \dot{z} + Ж \cdot z = 0\,,$$

where m – mass, β – attenuation coefficient of vibration, $Ж$ – elasticity.

The second stage of checking the computer model of the car's dynamics is comparison with testing results in an empty and loaded state. Places of installation of accelerometers in tests is shown on Fig. 13. As the estimates of the adequacy of the mathematical model, the difference coefficient is used:

$$\varepsilon = \frac{\sqrt{\sum_{i=1}^{n}\left(x_i^e - x_i^M\right)^2}}{\sqrt{\sum_{i=1}^{n}\left(x_i^e\right)^2} + \sqrt{\sum_{i=1}^{n}\left(x_i^M\right)^2}}\,,$$

where x_i^M and x_i^e – predicted and experimental values; n – the number of verifiable values.

Obtained values below 0.11, this indicates a slight difference in calculation and experimental data. The total relative average deviation of calculated and received by results of measurements of frequencies is 7.47%.

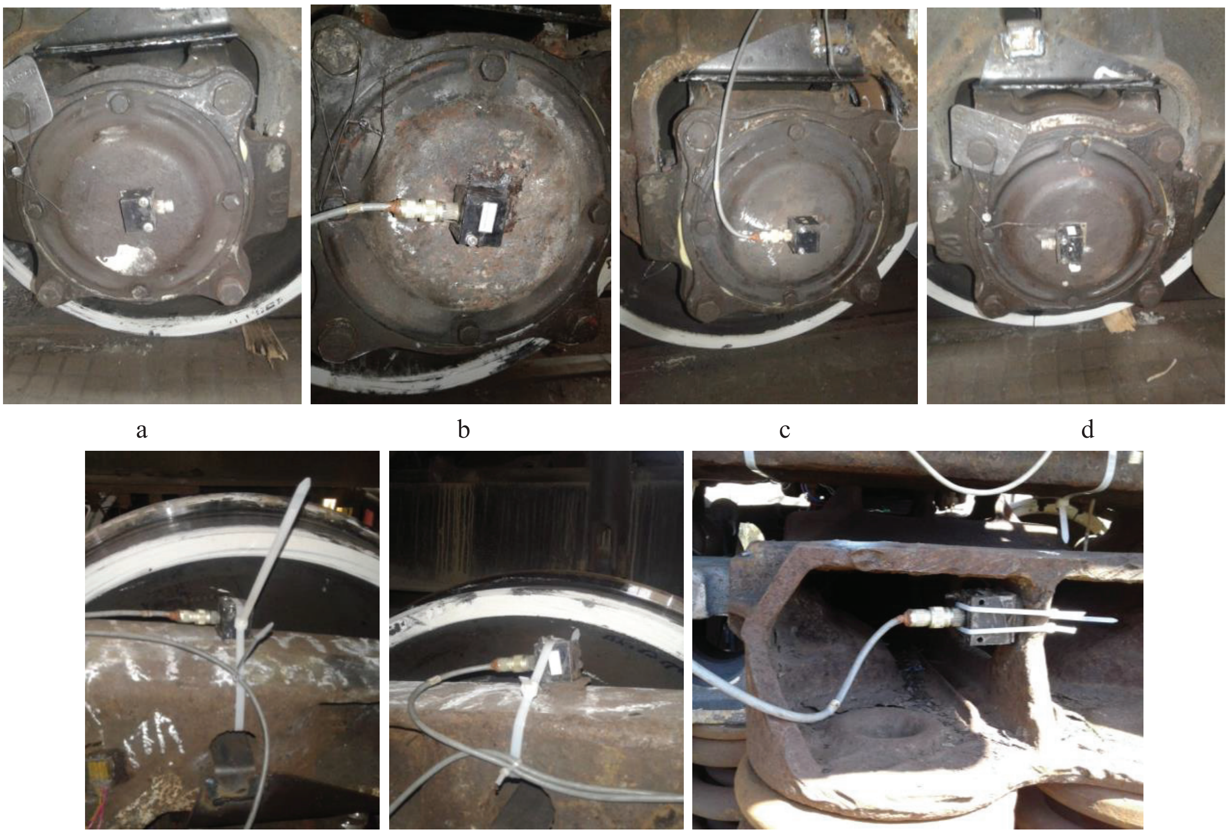

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Fig. 13 Places of installation of accelerometers in tests

The average value of reducing the resistance of the car is 11%. Reduction of the coefficient of side frame dynamics is 21%. Iincrease in the coefficient of stability of the wheel from rolling on the head of the rail for 3%.

2.2. Using of Elastic-Damping Multifunctional Elements with Modularity Units

The most promising approach to the creation of a freight car bogie from a number of technical solutions developed by the authors is the use of modular multifunctional load-bearing structural elements.

The authors developed new technical solutions and concepts:

- concept of bogie with an elastic-dissipative frame with cradle suspension – Fig. 14 [7];
- concept of bogies like type Barber/18-100 (a) and type Y-25 (b) with an elasto-dissipative frames – Fig. 15 [6].

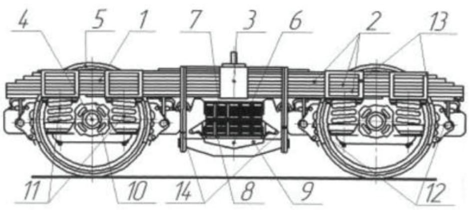

Fig. 14 Concept of bogie with an elastic-dissipative frame with cradle suspension: *1* - frame with *2* - leaf springs; *3* – clamp; *4* - axle-boxes; *5* – wheels; *6* - central suspension (*7* - springs); *8*, *9* - tie and balk; *10* - primary spring suspension (*11* - springs); *12* - braking equipment; *13*, *14* - support nodes

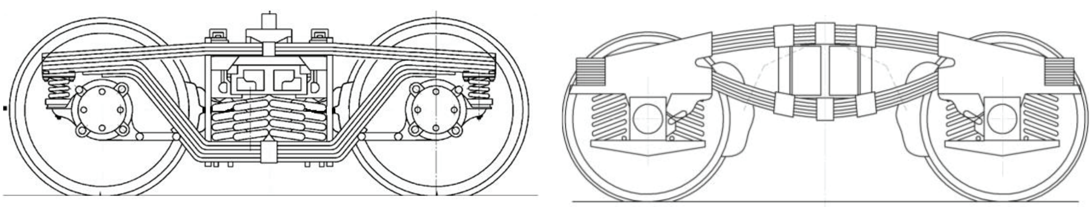

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Fig. 15 Concepts of bogies with an elastic-dissipative frame

Considering the international experience in the field of contact evaluation of wheel and rail stresses [14], bench and road tests of wheel-rail contact [15], dynamics modeling of a bogie etc., the object of further research is the simulation of the dynamics of cars with new types of bogies and their testing.

3. Conclusions

To achieve the priority tasks of transport formulated in the Shift2Rail work program, it is necessary to develop and implement new technical solutions.

The authors developed a technical solution for a bogie type 18-100 with pedestal jaw opening reinforcement by closing it with a pre-stressed element, which allows to reduce the level of maximum stresses in the most stressed zone R55 by 1.5-2 times, and also by creating on this basis a primary bogie suspension with a minimal change in the existing structure; this technical measures will improve the dynamics characteristics, reduce the resistance to movement by 11%.

The use of pre-stressed elements of the bogie makes it possible to reduce its weight and maximum operating stresses, increase reliability.

Perspective approach is the creation of freight car bogie is the use of elastic-dissipative elements (foe example leaf springs) as multifunctional bearing elements, with the aim of minimize the mass of the bogie, improve dynamics.

4. Acknowledgement

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