Improvement of brake lever transmission for dump cars

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Abstract. The article deals with issues of improved structures of brake lever transmission for industrial rail cars. The improved dump car structure is an important engineering problem aimed at higher reliability and better technical and economic characteristics of vehicles. The authors evaluated the forces acting in the lever transmission of a dump car at various types of brake shoes. The research is concerned with the capacity calculation of the most important transmission elements with the finite element method. By applying the software suite Solid Edge, an example of the improved structure of a lever transmission was implemented. The authors evaluated the forces and stresses in a standard transmission structure of these cars at different modes. With the software suite Autodesk Inventor the authors made a capacity test for specialized levers for composite shoes. The results of capacity calculations for the elements of lever transmission for dumpcars made it possible to recommend an application of composite materials in place of iron ones. It will considerably decrease car weight and material intensity in technical service and increase the total reliability of the car.

1. Introduction
Dump cars (hopper wagons) are specialized industrial rail transport cars. They are used at enterprises of mining and processing industries (metallurgy, chemical industry, construction, etc.). Their basic function is provision of freight transportation for internal and technological purposes.

Special aspects of use:
- short-distances transportation (10-15 km at the average);
- limited speed (15–25 km/h on mine tracks and 30–60 km/h on regular and station tracks);
- out-of-gauge freight by geometric and mass characteristics (especially for mining industry);
- rather harsh operational environment due to intricate rail track profile (sharp steepness and long gradients), and others.[1].

Difficult operational conditions set up strict demands for reliability of structural elements of cars, traffic safety and freight security. Safe and efficient technological transportation directly depends on the state of the braking system in dump cars.

Iron and composite brake shoes are commonly used for freight rail vehicles. Horizontal brake levers have holes which can change the reduction ratio. With iron brake shoes the brake lever has a higher reduction ratio. Its elements transmit greater forces and have bigger dimensions, weight and cost. Additional holes for shifting the reduction ratio weaken the levers and make it possible to mistakenly establish an increased reduction ratio for composite shoes. Higher pressure on composite brake shoes may damage the rolling surface of the wheels and lead to their jamming. Defects on the rolling surface of the wheels destroy both wheel and rail track, which hazards the safety of traffic.

Problems of improving brakes for rail vehicles, calculating properties of wheel gear with rails are discussed in articles by Anisimov P.S. [2], and problems of designing the mechanical part of the
braking system for cars are discussed in articles by Asadchenko V.R. [3]. The principle of operation, calculations and operational characteristics of brakes for rail vehicles are considered in studies by A.M. Babayev, D.V. Dmitriev [4], theoretical basics of design and operation of brakes are considered in studies by V.M. Kazarinov [5] and other scientists. It should be mentioned that problems of a lower mass of brake lever elements are not covered in the studies mentioned.

Studies by V.H. Inozemtsev and L.O. Vukolov [6, 7] encouraged a wide spread of composite shoes for rail vehicles. However, the studies did not touch upon improvements in mechanical elements of the brakes.

Problems of modernization and optimization of car body elements are covered in studies by O.V. Fomin, A.O. Lovska [8, 9, 10] and others. Besides, problems of lower material intensity of brake lever elements are not dealt with by the researchers.

The analysis of the above-mentioned studies demonstrate that most of them are aimed at research and improvements in air brake elements, braking shoes, tests on various materials for shoes, simulation of their work, and structure of significant car body parts. Thus, the problem of improved structure for brake lever elements requires additional research.

On the basis of the experience of brake application, there is a possibility to provide needed reliability of the mechanical part of a braking system by using only composite brake shoes [4].

With this engineering solution it is possible to:
- simplify the lever transmission structure and brake kinematic diagram;
- decrease the car weight;
- optimize the diagram of force distribution in braking;
- improve efficiency of braking processes;
- increase brake sensitivity;
- extend the operational life of levers;
- decrease the maintenance and technical service cost of cars.

2. Evaluation of forces on the lever equipment of a six-axle dump car at various types of brake shoes

Dump cars have the following diagram of the mechanical part of brake equipment Figure 1 [11].

![Figure 1. Diagram of the brake leverequipment of a six-axle dump car](image)

On the Figure 1: \( P_i \) - forces on the brake cylinder rod, \( P_{1i} \) - forces on levers 1 along the brace, \( a, b \) - the sizes of the horizontal lever arms, 1 - horizontal lever, 2 - brace.

In order to substantiate the research into reasonable improvements for brake lever equipment the authors evaluated the forces acting in the structure of leverequipment of a dump car at various types of brake shoes. The capacity calculations for important elements of the equipment were made with finite element method and the software suite Autodesk Inventor. By applying the software suite Solid Edge the authors realized an example of the optimal shape of elements for lever equipment. The maximum forces on the brake cylinder rod at the \( i \)-th type of shoes can be determined according to [12] by the formula
where $p'$ – the pressure in the brake cylinder at the $i$-th type of shoes, kPa, according to [11] the allowable pressure for composite shoes is $P_{\text{comp}} = 340$ kPa, for iron shoes $P_{\text{cast-iron}} = 450$ kPa; $d$ – the diameter of the brake cylinder rod, m, for a six-axle dump car $d = 0.4$ m.

The forces $P_i$ (Figure 1) on levers 1 along the brace for various types of brake shoes were defined as

$$P_i = p' \frac{\pi d^2}{4},$$

(1)

where $a', b'$ – the sizes of the horizontal lever arms at the $i$-th type of a shoe, m. For a standard lever structure [11] $a_{\text{comp}} = 0.222$ m, $b_{\text{comp}} = 0.268$ m, $a_{\text{cast-iron}} = 0.29$ m, $b_{\text{cast-iron}} = 0.2$ m.

The results of calculation by formulae (1-3) are assembled in Table 1 according to the shoe type; disparities of the forces are also given.

**Table 1.** Forces in the lever equipment of a dump car with iron and composite brake shoes, kN.

| Factor | Shoe type | Force | Force disparity, % |
|--------|-----------|-------|--------------------|
| Forces on the brake cylinder rod, $P_i$ | Iron | 56.55 | 42.7 | 24.5 |
| Forces on the brake, $P_i$ | Composite | 42.7 | |
| Forces on a lever at the brace level, $P_i/2$ | Iron | 69.27 | 39.05 | 43.6 |

**3. Capacity calculation for brake lever elements of a dump car**

The results of capacity calculation for an existing horizontal lever and a brace are given in Figure 2. The hinged support of a lever at the end holes and above-mentioned loads in the shaft hole were chosen as boundary conditions. The brace was considered fixed near the hole on one side and loaded with stretching force near the opposite hole.

**Figure 2.** Force distribution in the existing lever structure of a dump car

Analysis of the stresses obtained demonstrated that capacity requirements were satisfied. As far as nowadays composite shoes are in wide use, let us calculate a specialized lever for them. According to [12] the bending deformation is the basic type of deformations for levers. And the capacity condition for such a lever is:

$$[\sigma] \geq \frac{M}{W},$$

(3)
where $\sigma$ - the allowable stress in a lever under bending, MPa; $M$ - the maximum bending moment, kNm; $W$ - the moment of resistance in the maximum stressed cross-section, $m^3$.

The maximum stressed zone was a cross-section where the lever connected with the brace, and for a horizontal lever the maximum bending moment could be determined as $M = 0.5P_d \cdot d$. The moment of resistance for the maximum stressed cross-section of a rectangular form with a hole of the diameter $d_h$ for a sleeve and shaft is

$$W = \frac{t(h^3 - d_h^3)}{6h},$$

where $t$ - the lever width, m; $h$ - the lever height, m.

Formulae (3-4) give the allowable lever height in the form of an equation of third order

$$h^3 - \frac{6M}{t[\sigma]_s} h = d_h^3.$$  

By solving equation (5) we obtain allowable values of the minimal lever width for certain types of shoes; the lever width is standard $t = 0.014$ m, the hole diameter $d_h = 0.045$ m, the allowable stress for steel St.3 equals to $[\sigma] = 0.95 \sigma_t$ [13] $[\sigma] = 190$ MPa.

The results of capacity calculation for the specialized horizontal lever and brace are given in Figure 3.

**Figure 3. Stress distribution in specialized levers**

The stresses obtained did not exceed the admissible ones, i.e. the capacity was ensured.

### 4. Shape improvements in lever elements

Using new features of the software suite Solid Edge for building a generative design of elements and improvements in their shape, and also considering the positive experience in application of pressed levers of changeable forms on European railways the authors improved the shapes of the horizontal lever and brace. Besides, the support parts of the lever and brace were taken as constant to avoid bearing deformations. The elements were loaded with forces presented in Table 1. The results of improvements are given in Figure 4.

**Figure 4. Changed lever and brace shapes**
The mass characteristics of improved and existing levers and braces are given in Table 2.

| Element       | Existing structure | Specialized for composite shoes | Improved with software suite | Total, % |
|---------------|--------------------|---------------------------------|------------------------------|----------|
| Horizontal lever | 5.8                | 5.1                             | 4.1                          | -30      |
| Brace         | 30.168             | 27.692                          | 21.854                       | -27.6    |

5. Conclusions:

1. The authors evaluated the forces in the lever equipment of a dump car at various types of brake shoes. It has been demonstrated that application of composite shoes in place of iron ones has decreased the forces on the brake cylinder rod, brace and levers;
2. The authors also conducted capacity calculations for the existing horizontal lever and brace of the brake system of a dump car. The results obtained for design stresses did not show any increase in allowable loads, thus with composite shoes the capacity is ensured;
3. With the software suite Solid Edge and the generative design of elements and their optimal shape, the authors improved the shapes of the horizontal lever and brace.

References

[1] Loginov AI 1975 Vagony-samosvaly (Cham: Mashinostroenie)
[2] Anisimov P S 2005 Raschet i proektirovanie mehanicheskoi i pnevmaticheskoi chastei tormozov vagonov: ucheb. posobie (Cham: Marshrut)
[3] Asadchenko V R 2004 Raschet pnevmaticheskix tormozov zheleznodorozhnogo podvizhnogo sostava (Cham: Marshrut)
[4] Babaev A M 2007 Princip dii, rozrunki ta osnovi ekspluatacji galm ruxomogo skladu zaliznic: navchalnuiaposibnik (Cham: DETUT)
[5] Kazarinov V M 1968 Teoreticheskie osnovy proektirovaniya i ekspluatacji tormozov (Cham: Transport)
[6] Inozemcev V G 1981 Avtomaticheskie tormoz (Cham: Transport)
[7] Vukolov LA 1987 Frikcionnye karakteristiky tormoznyx kolodok iz kompozicionnyx materialov bez asbesta Transport VNIIZhiT 27–33
[8] Fomin OV 2013 Optimizacijne proektuvannya elementiv kuzoviv zaliznicnih napivwagoniv ta organizaciyi iix virobnictva (Cham: DonIZT UkrDAZT)
[9] Oleksij Fomin, Juraj Gerlici, Alyona Lovskaya, Kateryna Kravchenko, Pavlo Prokopenko, Anna Fomina and Vladimir Hauser 2018 Research of the strength of the bearing structure of the flat-wagon body from round pipes during transportation on the railway ferry MATEC Web of Conferences 2351–5
[10] Oleksij Fomin, Juraj Gerlici, Alyona Lovska, Kateryna Kravchenko, Pavlo Prokopenko, Anna Fomina, and Vladimir Hauser 2019 Durability determination of the bearing structure of an open freight wagon body made of round pipes during its transportation on the railway ferry Communications-Scientific letters of the University of Zilina 2(128–34)
[11] Instrukciya z remontu galmvinnogo obladenannya vagoniv 2005 (Cham: TOV Vidavnichij dim «SAM»)
[12] DSTU 7598:2014 2014 Vagoni vantazhni. Zagalni vimogi do rozrahunkiv ta proektuvannya
[13] Lukin V V 2000 Konstruirovanie i raschet vagonov (Cham: UMK MPS Rossii)