THE STRENGTH ASSESSMENT OF THE HORIZONTAL LEVER IN THE BRAKE TRANSMISSION OF A FREIGHT WAGON BOGIE

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Resume

In this article are discussed the features of selecting the geometric parameters and calculating the strength of the horizontal lever in the brake lever transmission of a freight wagon bogie. The results of the research show that the greatest stresses are concentrated in the areas where the holes for the rollers are located. Since the design stresses are 22% lower than the permissible value, thus the strength of the horizontal lever is obeyed.
This research results could be useful in the design of modern brake lever transmission systems.

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1 Introduction

The railway traffic safety is a key factor in the efficiency of railway transport [1-3]. Brakes are the most critical unit of the rolling stock, upon the reliability of which the train traffic safety depends. Most modern 1,520-mm gauge freight rolling stock is equipped with single-acting brake lever systems using wheel-mounted brake pads [4-5]. Importantly, the horizontal lever of the brake lever transmission is one of its most critical components (Figure 1). The horizontal lever is designed to transfer force from the brake cylinder rod to the brake pads. It forms a part of the system that applies the brakes the wagon, allowing pads to press against wheels. The horizontal lever provides the reliable and efficient force transmission, which is a key component of the braking system.

In operation, the horizontal lever is subjected to bending stresses due to its fastening diagram and the load applied to it. To ensure the traffic safety, it is important to study the strength of the horizontal lever under operational loads, to identify the most heavily loaded components of its structure and propose solutions aimed at improving it.

To assess the current state of the research into the strength of horizontal levers, an analysis of scientific publications on this topic was carried out.

The operating processes of the brake lever transmission, as well as the wear of the wheel and brake pads in the wheel-shoe braking system of freight wagons using composite pads, are investigated in [6]. The tribological interaction is analysed by means of a bench simulation of the brake lever transmission under the actual braking conditions. The results obtained demonstrate that the use of high-friction composite pads changes the distribution of contact stresses and can lead to accelerated wear of specific areas of the wheel. However, the study does not address the issue of studying the strength of the brake lever transmission components in operation.

The operation of the brake assembly and thermal processes in cast iron pads during the braking is investigated in [7]. Using the numerical simulation, the thermal behaviour of the brake assembly at various braking modes is analysed. The influence of speed, braking duration and the thermal conductivity of the material on the temperature distribution in the contact zone is examined. The achieved results show the formation of significant temperature gradients in the brake pad, which can cause thermal deformations

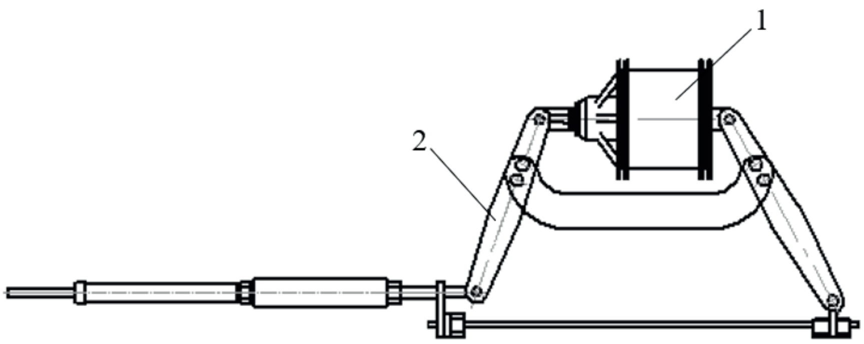

Figure 1 *A location of the horizontal lever in the brake system: 1 - brake cylinder; 2 - horizontal lever*

and accelerated wear of the friction surface. The study was focused on thermal processes, but the strength of the components of the brake lever transmission is not considered.

The operational issues of using the brake lever transmission and composite pads in freight wagons are analysed in [8]. The authors studied their interaction with wheels, the impact of operating conditions on the wear intensity and potential negative consequences of using composite materials. Particularly, it is noted that such brake pads are more sensitive to braking patterns and uneven load distribution, which can lead to accelerated localised wear and changes in the friction coefficient. However, the study does not address the issue of the strength of the brake lever transmission components under operational loads.

The braking system parameters and the conditions governing the generation of the pressing force between the brake pads and the wheel surface are analysed in [9], where the influence of structural and operational factors on the braking efficiency and stability of brake equipment were studied, particularly, the issue of ensuring the necessary brake pressure in the brake systems of freight wagons. The results obtained are used to determine the dependencies between the pressure in the brake cylinder and the pressing force of the pads. However, the authors did not research the strength of the elements of the brake lever transmission that bear the load when braking forces are applied.

The results of numerical optimization and experimental verification of the disc brakes for the freight wagons are presented in [10]. The distribution of stresses and temperatures in the disk under braking is investigated, and a modified profile is proposed using numerical simulation, that improves the heat dissipation and reduces stress concentrations. The experimental tests conducted confirmed an increase in durability and a decrease in the risk of thermal damage to the brake disc. However, the issue of strength and load on the brake components was not studied.

The factors influencing the braking force, transmitted by the brake lever transmission, and the effect of the brake pad material type on the wear rate are described in [11]. The obtained results demonstrate that an increase in the braking force significantly accelerates wear, while the choice of the brake pad material determines the nature of the tribological interaction. However, in the study was not examined the operation of the brake lever transmission components that transmit braking forces to the wheel set.

An experimental study of properties of the organic composite brake pads with a modified friction composition is presented in [12]. It describes a series of laboratory tests to determine the material's mechanical, tribological and thermal properties. It is found that changes in the composition of the friction material can significantly affect the friction coefficient, braking stability and wear intensity. The results obtained confirmed that it is possible to increase the service life of brake pads by optimizing their material composition. However, the authors did not analyse the strength of the brake lever transmission components that transfer braking forces to the wheel set.

The way the elements of the shoe brake affect the wear and fatigue damage of wheels made of different steel grades and used in high-speed railway transport is investigated in [13]. Authors conducted the experimental tribological tests to determine the wear intensity and progression of microdamage in the surface layers of the wheel. It is found that the wheel material significantly affects the nature of the damage and the service life of the wheel-pad interaction. The results obtained made it possible to assess the wear resistance of various steels under braking conditions. However, the strength of the brake lever transmission components under braking conditions was not investigated.

The specifics of conducting the field experiments and numerical modelling of temperature processes are presented in [14]. The authors measured the temperatures of the wheel surface during braking and compare them with the results of numerical calculations. It is established that the contact surface temperature can reach significant values, which profoundly affects the wear intensity and formation of the friction layer. However, the authors did not analyse the strength of the brake lever transmission components.

A comprehensive analysis of the causes of brake system failures associated with the use of metal and composite materials is covered in [15]. It presents a technical and economic analysis of failures of components

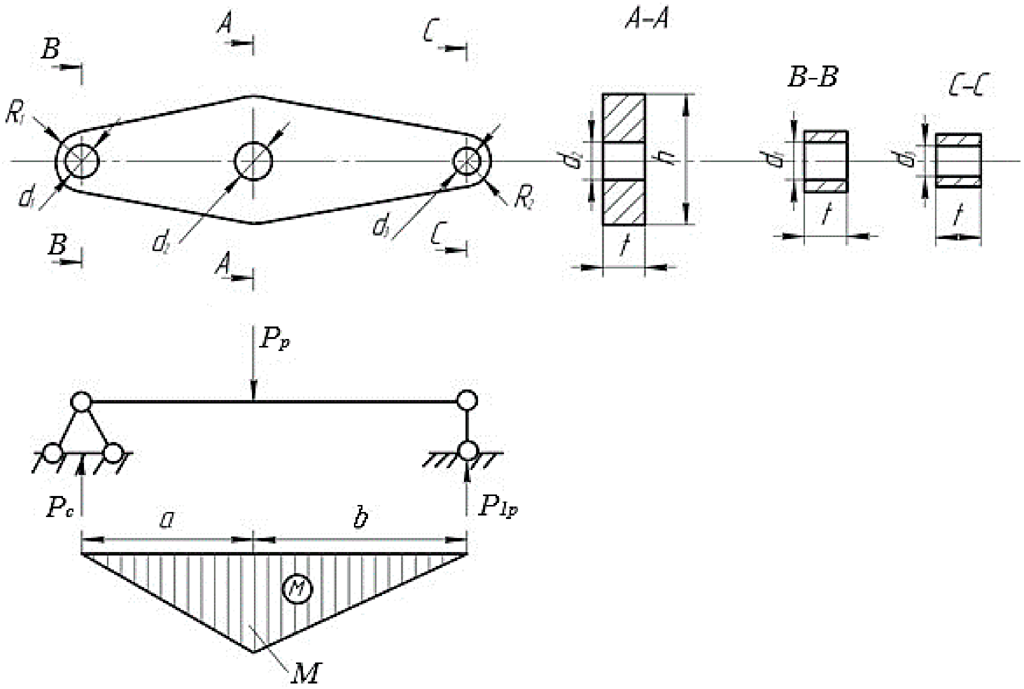

Figure 2 The design diagram of the horizontal lever: a and b are the lever arms; h is the maximum width; t is the thickness; d_1, d_2, d_3 are the hole diameters; R_1 and R_2 are the end radii; P_c is the cylinder rod force; P_{1P} is the reaction of the brake transmission of the wagon; P_p is the reaction force of the horizontal levers

of the mechanical part of brakes, particularly brake pads, considering their design features and material. The main factors leading to a reduction in braking efficiency were identified; they include wear, overheating and deterioration of the frictional properties of materials. However, the issue of the strength of the mechanical brake components was not analysed.

An overview and development of mathematical models of pneumatic brake systems of freight trains is presented in [16]. The authors generalized modern approaches to modelling the operation of the brake cylinders and the generation of braking forces in the train. The models designed can be used to analyse the braking dynamics of the train and assess the pneumatic system efficiency. Meanwhile, the study was focused on modelling the pneumatic processes, while the mechanics of the brake lever transmission components subjecting to operational loads during braking was not considered.

The review of scientific publications [6-16] makes it possible to conclude that at present the issue of studying the strength of horizontal levers of the brake lever transmission has yet to be given due attention. Therefore, there is a need for research in this area. This article is devoted to assessing the strength of the horizontal lever of the brake lever transmission. The following research objectives were set:

- to substantiate the geometric parameters of the horizontal lever, and
- to investigate the strength of the horizontal lever using the finite element method (FEM).

2 The substantiation of the geometrical parameters of a horizontal lever

The loading diagram of the horizontal lever in operation was considered, provided that it is a rod on two supports [17]. The design diagram of the horizontal lever and its cross-section shown in Figure 2.

The width h of the lever is determined from

$$[\sigma] \geq \frac{M}{W}, \tag{1}$$

where $[\sigma]$ is the permissible stress arising in the lever during bending, MPa; M is the bending moment in the dangerous cross-section of the lever, Nm; W is the moment of resistance in the cross-section A-A, m^3.

The bending moment can be written as

$$M = P_c \cdot a = P_{1p} \cdot b. \tag{2}$$

For a two-plate lever, the bending moment must be halved.

Then,

$$M = 0.5 \cdot P_c \cdot a = 0.5 \cdot P_{1p} \cdot b. \tag{3}$$

For the section A-A the resistance moment is

$$W = \frac{t \cdot (h^3 - d_2^3)}{6 \cdot h}, \tag{4}$$

in turn, the moment of resistance can be determined from Equation (1) as:

$$W = \frac{M}{[\sigma]}. \tag{5}$$

Then, equating Equations (4) and (5), one obtains

$$\frac{t \cdot (h^3 - d_2^3)}{6 \cdot h} = \frac{M}{[\sigma]}. \tag{6}$$

After the corresponding transformations, an algebraic cubic equation for the width is obtained:

$$h^3 = \frac{6 \cdot M}{t \cdot [\sigma]} h + d_2^3. \tag{7}$$

According to Tartaglia's rule, the root of this equation is

$$h = \sqrt[3]{U} + \sqrt[3]{V}, \tag{8}$$

where U and V is the system solution

$$\begin{aligned} &U + V = d_2^3; \\ &U \cdot V = \left(\frac{6 \cdot M}{3 \cdot t \cdot (\sigma)}\right)^3 = \left(\frac{2 \cdot M}{t \cdot [\sigma]}\right)^3. \end{aligned} \tag{9}$$

Equation (8) can be written as $h^3 + p \cdot h + q = 0$,

where $p = -\frac{6 \cdot M}{t \cdot [\sigma]}, q = -d_2^3$.

When solving Equation (9), the discriminant of the cubic equation can be negative $\Delta = \frac{q^2}{4} + \frac{p^3}{27} < 0$. In that case, h is calculated as $h_1 = 2|\sqrt[3]{r}|\left(\cos\frac{\varphi}{3}\right)$,

$h_2 = 2 \cdot |\sqrt[3]{r}|\left(\cos\frac{\varphi + 2 \cdot \pi}{3}\right)$,

$h_3 = 2 \cdot |\sqrt[3]{r}|\left(\cos\frac{\varphi + 4 \cdot \pi}{3}\right)$,

where $r = \left|\sqrt{-\frac{p^3}{27}}\right|$ $\varphi = \arccos\left(-\frac{q}{2 \cdot r}\right)$.

It is possible to determine the width h by specifying the standard thickness t of a sheet from the rolled steel product range and the diameter d_2 of an opening from Equations (1) and (8).

Thus, it is possible to determine its geometric parameters for given force effects based on the bending moment acting in the cross-section of the horizontal lever.

The main parameters were determined (Table 1) considering the fact that the lever is a component of the brake lever transmission of the open wagon bogie equipped with an air distributor (No. 483-000). The symbols shown in the header of Table 1 correspond to those shown in Figure 3.

However, the localized effects of the rollers, stress concentrations around the horizontal lever holes, and possible out-of-plane effects on it are not considered in this analytical approach of determining the geometric parameters of the horizontal lever. This is a limitation of this approach.

The next stage of the study included the construction of a spatial model of the horizontal lever and calculation of its strength.

3 The investigation into the horizontal lever strength using the FEM

The strength of the horizontal lever was calculated using the FEM in SolidWorks Simulation. The model of the horizontal lever was built in SolidWorks (Figure 4).

The continual model of the horizontal lever was constructed with tetrahedra (Figure 5). This choice was based on the fact that the mesh was created on a solid body [18-19].

The graph analytical method was used to determine the optimal number of model's elements [20-22]. The model had 4,280 elements. The number of nodes was 7,718. The construction material of the horizontal lever

Table 1 *The main parameters of the horizontal lever, mm*

l	$h \times t$	a	b	d_1	d_2	R
574	110 × 14	195	305	40	45	32

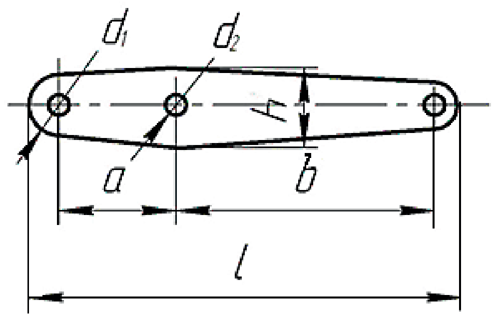

Figure 3 *The geometric parameters of the horizontal lever*

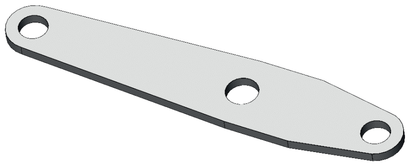

Figure 4 *The spatial model of the horizontal lever*

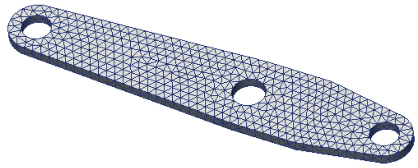

Figure 5 *The finite element model of the horizontal lever*

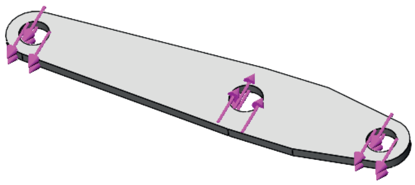

Figure 6 *A calculation scheme of the horizontal lever*

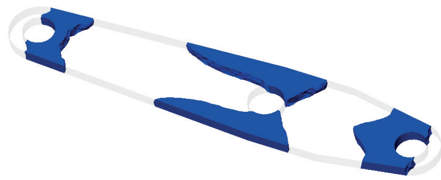

Figure 7 *Concentration zones of the stresses in the horizontal lever*

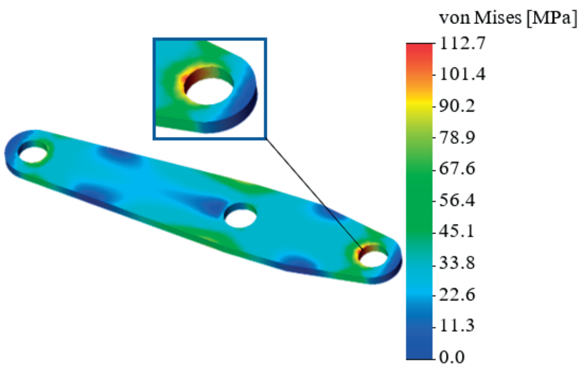

Figure 8 *The stress state of the horizontal lever*

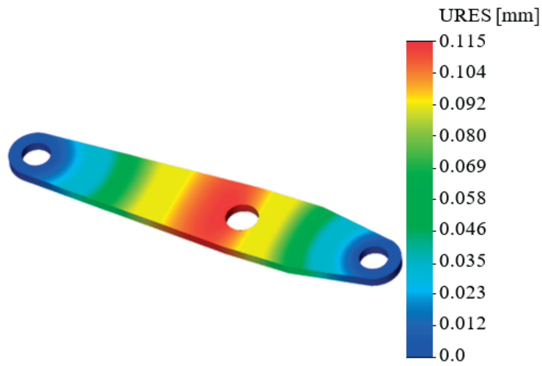

Figure 9 *The displacements in the horizontal lever assemblies*

was steel St. 3 with permissible stresses of 145 MPa [23].

Rigid connections were installed at the points of contact with the rollers. The diagram of the application of forces to the model is shown in Figure 6.

Calculations showed that maximum stresses occur in the areas where the roller holes were located (Figure 7). The maximum stresses were 112.7 MPa (Figure 8). Thus, the calculated stresses are 22% lower than the permissible ones.

The middle part of the lever is subjected to the greatest displacement, which is 0.1 mm (Figure 9).

The calculations made it possible to conclude that the strength of the horizontal lever with the specified geometric parameters was obeyed.

It is important to say that the above approach to calculating the horizontal lever can be used for any type of freight car. Since currently all the types of freight cars with a gauge of 1520 mm are equipped with air distributors of the No. 483-000, which have certain operating modes depending on the loading of the rolling stock: empty, average or loaded, therefore, taking into account the application of a load to the lever that corresponds to one of these modes, the appropriate calculation can be carried out.

At the same time, in conditions of excessive load modes that are not specified in regulatory documents, this approach must be adjusted. In the event of wear of the horizontal lever, its actual geometric dimensions must be taken into account when building a spatial model. In the event of the use of a material with properties different from that of steel of St. 3, the stress calculation criterion according to the finite element method must be replaced by the appropriate one.

The advantage of this study over existing ones is that the authors not only calculated the horizontal lever of the brake system lever, but also identified specific features that influence the determination of its geometric dimensions.

However, the study has its drawbacks. The main one is that the fixing of the horizontal lever was modelled as rigid, that is, the potential friction forces in the areas where the horizontal lever interacted with the rollers were not considered. This will be addressed in the further research.

The research will be useful in the design of modern brake lever transmission systems.

4 Conclusions

1. The rationale for the selection of the geometric parameters of the horizontal lever in the brake lever transmission is presented. It is considered that the lever is a component of the brake lever transmission on the bogie of an open wagon equipped with air distributor No. 483-000. According to the results of the calculations, the geometric parameters of the horizontal lever are determined and its spatial model is built.
2. The strength of the horizontal lever is studied by the FEM. It is established that the stresses are mainly concentrated in the areas where the holes for the rollers are located. The maximum design stress is 112.7 MPa, 22% lower than the permissible value. The greatest displacement is experienced by the middle section of the horizontal lever, with the maximum displacement being 0.1 mm. Therefore, the strength of the horizontal lever is obeyed.

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Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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