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## Research of possibilities of reducing the driving resistance of a railway vehicle by means of the wheel construction improvement

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### Abstract

The paper contains results of research of the driving resistance reducing of a railway vehicle by the modification of a railway wheel construction. The perspective railway wheel construction allows the possibility of the relative rotation of the guiding and supporting wheel surface. Based on current research of experts and specialists in the field of the railway transport and taking into account existing requirements and standards several technical solutions of such a wheel are developed. There are also presented results of stress and strain analyses of these technical solutions. Based on obtained data it is possible to conclude that proposed construction solutions meet requirements for the safety factor.

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### 1. Introduction

Problems of the railway wheel/rail contact represents a basic point of any analysis which is connected with the moment of a railway vehicle on a track, with safety, speed, with comfort of people and goods transport (Gerlici and Lack 2011, Smetanka et al. 2018).

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The main share of energy consumption in rail transport (up to 75% of electricity and fuel consumed) accounts for train traction. Reducing the amount of fuel and electricity consumed by a rail is a major task when it comes to increasing its competitiveness and further development perspectives. Energy costs for train traction are directly related to the level of resistance to motion of locomotives and cars (Blatnická et al. 2018a, Dižo et al. 2018, Hauser et al. 2018).

Today there is an extremely up to date need for the security of vehicles interoperability in its greatest extend in order to use in reality one of the greatest advantages of railway transport (economic transport of a huge volume of goods over long distances). The fulfillment of the need places a higher requirement on the sphere of usage (design or choice of the right, for the given railway company so-called optimum profile) (Gerlici et al. 2018, Gerlici and Lack 2009, Lack and Gerlici 2018a).

## 2. Description of a problem

When designing new types of rolling stock of the train, the primary attention is paid to aerodynamic characteristics of resistance to motion. In addition, special attention is paid to the problem of additional resistance, which emerges in the curved sections of a track and also to the problem related with vibration properties of rolling stocks (Melnik and Koziak 2017, Melnik and Sowinski 2013). However, theoretical and experimental studies carried out by domestic and foreign scientists are manly designed to investigate empirical formulas calculating the resistance to motion and the advantages of rolling bearings in comparison to sliding bearings.

At the same time, there was very little studies about the impact of peculiarities of the rail vehicles bogie elements design on resistance to movement, although this problem is very important in terms of reducing operating costs. Just these features determine the level of kinematic resistance to motion and according to the results of more studies amount up to 50 % of the total resistance to motion of a carriage in curves of main tracks, and up to 80 % for the urban rail transport in curves with radius from 20 to 60 m.

Findings of this data have conditioned the choice of the direction of research, i. e. reducing the resistance to motion of rail vehicles though improving properties of their bogie elements, which is intended to improve the efficiency of the use of rolling stocks.

The analysis of the existing scientific research shows that the processes related to the interaction of the flange of a wheel with a rail have a significant influence on the generation of the resistance forces of the rail vehicles, which is especially for the cases of the additional parasitic slippage occurs in the flange contact during a two-point contact of a wheel and a rail (Sapronova et al. 2017, Okorokov et al. 2018, Fomin et al. 2017). That is why, in order to reduce such negative consequences, it is proposed to improve the design of the rail wheel to ensure that the guide surface (flange) can rotate around the common axle independently from the rolling support surface of the wheel (hereinafter the perspective design scheme wheel, PDS wheel).

In contact of railway wheels and rails, there are acting forces which have with their effect on the contact area, on the size of the normal and tangential stress (Lack and Gerlici 2016), wear surfaces of the wheel and rail or directly on the anti-derailment stability (Lack et al. 2018b, Lack and Gerlici 2014).

According to the results obtained from the study of the characteristics of the motion on rails, it has become possible to reduce the friction of the flange contact for the PDS wheel, which determines the level of the differential component of the kinematic resistance to motion. According to the existing data under given modes of motion ( $V_k = 20$  m/s,  $P = 125$  kN and  $\psi = 0.015$ ), the reduction in friction forces in the flange contact reaches 32 % (Mikhailov et al. 2013), compared to the wheel of the traditional design scheme (TDS).

In order to confirm the effectiveness of the use of PDS wheels, the movement of a wheelset and a four-axle wagon with such wheels was studied. The study has used mathematical modelling techniques on advanced mathematical models that have enabled to take into account the independent rotation of the guide and bearing surfaces of the rolling wheels.

## 3. Experimental measurements of railway wheels

In the study of the movement of a four-axle wagon, values of the total specific resistance to motion for an empty and a loaded wagon with PDS wheels at different modes of motion are lower than similar values for a wagon with

TDS wheels under the same conditions. Thus, in the straight sections of a track, this solution has reached reducing the resistance to motion of 10 – 12 % for the loaded wagon and 13 – 15 % for the empty wagon depending on the speed. For curves with the radius of 350 m, 750 m and 1200 m the resistance of motion was reduced of 20 – 22 %, 16 – 18 % and 13 – 15 % for the empty wagon and of 23 – 25 %, 17 – 19 %, and 14 – 16 % for the loaded wagon, respectively. These results obtained using the mathematical modelling confirm, that application of PDS wheels for a rail vehicle structure allows to reduce the resistance to motion.

Experimental studies of rail carriages models carried out based on the planning of the experiment have allowed to obtaining empirical dependencies of the resistance to motion depending on factors affecting it.

For assessment of the influence of design schemes of the wheels on the resistance to their motion the modernization of a test stand installation (Fig. 1a) was realised. The bogie, which is the object of the testing, is a model of a two-axle bogie of a rail vehicle and has replaceable wheelsets with wheels of various design schemes scaled 1:5.

The PDS wheel (Fig. 1b) consists of (Fig. 1c) a hub with a disc (1), which has a recess (2) for installing a flange (5) with the possibility of the independent rotation with a rolling surface. The disk has threaded holes (3) for bolts of the pressure disk (4).

The flange (5) is made in the form of a ring and its cross section of the outer part corresponds to the cross section of the TDS wheel flange. The pressure plate (4) is attached to the hub disk with bolts (6).

When testing for each driving mode, the following parameters are recorded:

- a) the speed of the bogie model;
- b) the magnitude of the resistance to motion of the bogie model;
- c) the magnitude of the transverse force, which is transmitted to the frame of the bogie model.

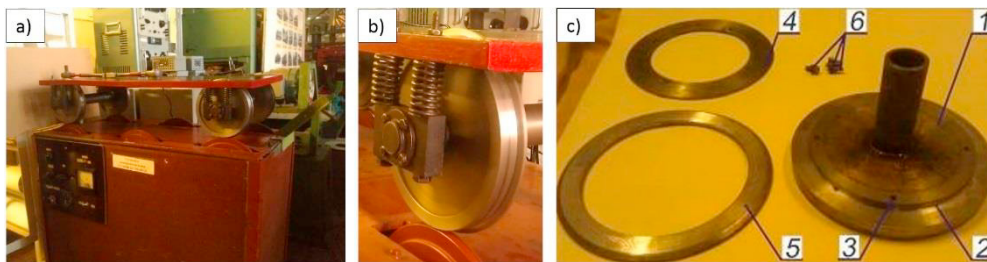


Fig. 1. General view of the test stand installation (a), axle box with a spring suspension of a bogie model (b), components of a wheel model (c).

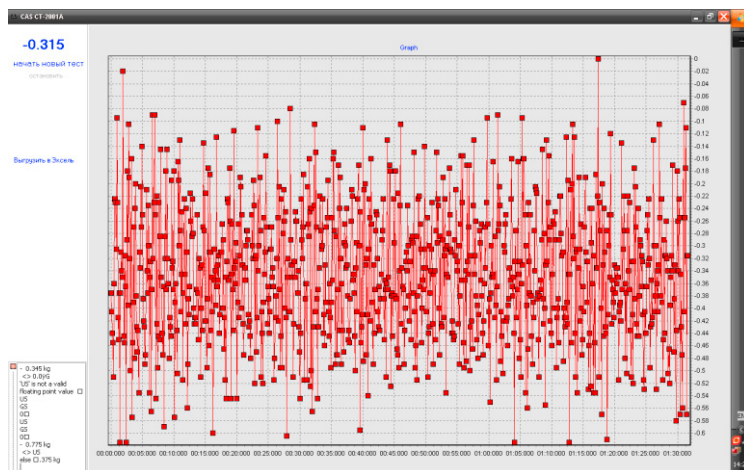


Fig. 2. "Graph" program window.

The original specialised software called “Graph” was developed for processing experimental data. The software provides not only real time visual displaying the level of sensor signals, but also changes received signals into digital form and presents them as a text file, that has a format compatible with the Microsoft Excel.

The window of the “Graph” program and a fragment of the implementation of research data are shown in Fig. 2.

The research results were drawn up in the form of the graphs of dependencies of the magnitude of resistance to motion of bogie models with wheels of various design schemes on influencing factors for the research modes described above and other dependencies connecting the obtained values.

Experimental studies were carried out using the similarity theory and dimensional analysis based on the method of orthogonal compositional planning:

- when driving a bogie model with PDS wheels:
  - on a straight section

$$y = 0.143 + 0.006 \cdot v + 0.013 \cdot Q + 0.02 \cdot Q^2 - 0.025 \cdot Mc^2 - 0.022 \cdot Q \cdot Mc$$

- in a curve with the radius of 350 m

$$y = 5.571 + 0.199 \cdot Q + 0.315 \cdot v + 0.108 \cdot Mc + 0.099 \cdot Mc^2$$

- in a curve with the radius of 750 m

$$y = 3.911 + 0.459 \cdot Q + 0.18 \cdot Q^2 - 0.356 \cdot Mc^2 + 0.268 \cdot v \cdot Mc - 0.208 \cdot Q \cdot Mc$$

- in a curve with the radius of 1200 m

$$y = 1.256 + 0.029 \cdot Q + 0.088 \cdot v + 0.041 \cdot Mc$$

- when driving a bogie model with TDS wheels:
  - on a straight section

$$y = 0.28 + 0.15 \cdot Q + 0.004 \cdot v + 0.005 \cdot Q^2 + 0.015 \cdot v \cdot Q$$

- in a curve with the radius of 350 m

$$y = 6.449 + 0.716 \cdot Q + 0.267 \cdot v - 0.299 \cdot Q^2 + 0.113 \cdot v \cdot Q$$

- in a curve with the radius of 750 m

$$y = 5.267 + 0.209 \cdot Q + 0.167 \cdot v - 0.092 \cdot Q^2$$

- in a curve with the radius of 1200 m

$$y = 1.808 + 0.08 \cdot Q + 0.062 \cdot v + 0.006 \cdot v^2$$

The graphs of the experimental dependences of the magnitude of the resistance to motion of a bogie model with TDS and PDS wheels on the speed of motion are presented in Fig. 3. Also these graphs present calculated values obtained according to the results of the regression equation.

Analysis of the obtained results shows that the value of the resistance to motion for the bogie model with PDS wheels under different driving conditions is less than similar values for a model of a bogie with TDS wheels under the same conditions. The decrease of the resistance to motion at low speeds in the straight part of the section is not

constant, and at high speeds (up to 4 m/s for the physical model) it is 5 – 8 %. When driving in curved sections of the track with radii of 350 m, 750 m and 1200 m, the reduction of the resistance to motion of a bogie model with PDS wheels at high speeds was 15 – 18 %, 8 – 12 % and 7 – 11 %, respectively.

Generally, the results of experimental studies confirm theoretical propositions regarding the efficiency of using PDS wheels in the vehicular part of rail vehicles to reduce the resistance to their motion.

#### 4. Design of innovative railway wheels

Based on the results of the research, taking into account the consultations and suggestions of specialists in the field of rail transport, taking into account existing requirements and current standards, a number of wheel design solutions have been developed. These solutions have special distinguishing characteristics, such as possibility of relative rotation of the wheel guide (flange) and its supporting surface (Patent UA 105612, Patent UA 113420, Patent UA 113968).

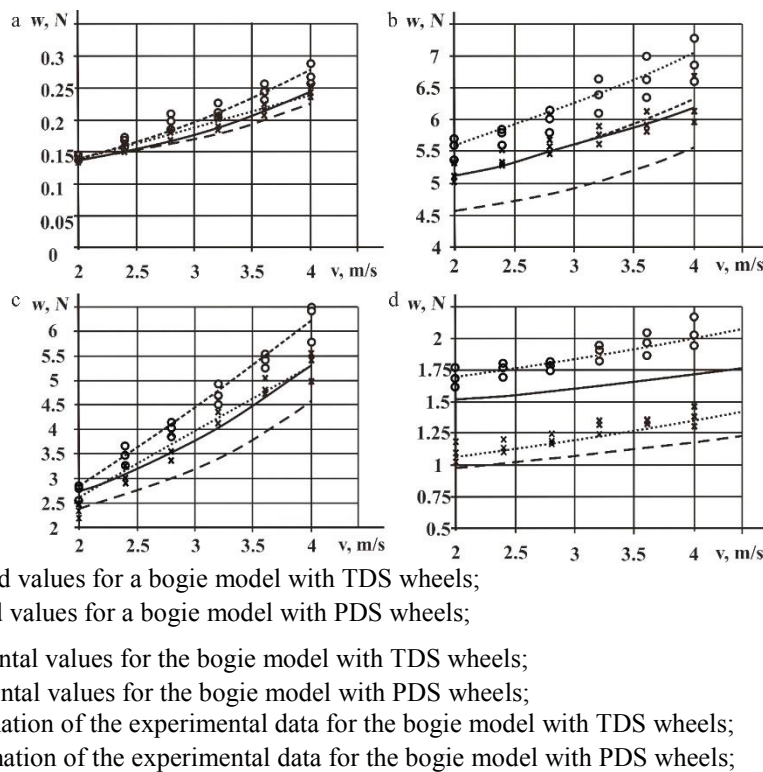


Fig. 3. Dependence of the resistance to motion of bogie models on the speed of motion ( $q = 1.55 \text{ kN}$ ,  $M_c = 0.8 \text{ N}\cdot\text{m}$ ): (a) straight section; (b) a curve with the radius of 350 m; (c) a curve with the radius of 750 m; (d) a curve with the radius of 1200 m.

Assessment of the strength of perspective wheels constructions at the design stage was performed using the computational methods for analysing their stress-strain state. The finite element method was used for solution of this kind problem, which is associated with the determination of the three-dimensional distribution of stresses and strains in the body of studied wheels. FEM is a numerical method for solving boundary problems (Blatnický 2015, Blatnická 2018b).

The corresponding 3D models were created (Fig. 4) for setting up the finite element model of the proposed wheel constructions based on the developed design documentation.

The following input data was used for calculations:

- the load represented by the vertical force  $F_N = 110$  kN;
- the load formed by the lateral force  $F_T = 90.4$  kN;
- unworn wheels profiles were used for the research.

For numerical calculations there were assumed, that wheel components were made from homogenous material. The study has adopted the main characteristics of the material, which is used for the production of TDS wagon wheels, namely the wheel steel of the 2<sup>nd</sup> grade according to GOST Standard 10791.

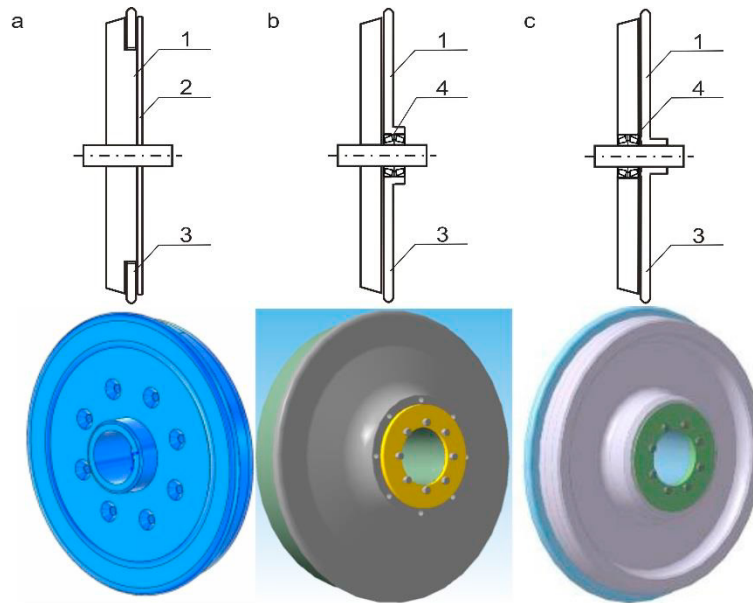


Fig. 4. Proposed design solutions and 3D- models of the wheels: 1 – wheel center; 2 – pressing disk; 3 – flange; 4 – bearing.  
a) wheel №1 (Patent UA 105612); b) wheel №2 (Patent UA 113420); c) wheel №3 (Patent UA 117968).

#### 4.1. Results of the research of individual railway wheel designs

For the strength analysis of the wheel model No. 1, the combined finite element (FE) model was developed (Fig. 5). The choice of the size of elements was determined by the specific geometrics of the wheel structure. Analysis of the equivalent stress plot shows that the maximum stress values was  $\sigma_{\max}=720$  MPa (Fig. 5b).

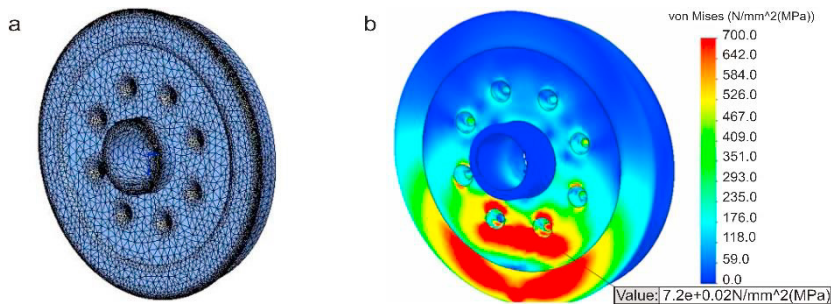


Fig. 5. Study of the wheel model No. 1: (a) Finite Element Model;  
(b) Stress Plot.

The FE model defined for the strength analysis of the wheel model No. 2 was developed using a similar algorithm (Fig. 6). Analysis of equivalent stress plots indicates that during the wheel model No. 2 moving, the maximum values of equivalent stresses are observed in the flange contact and reach the value  $\sigma_{max} = 516.9$  MPa.

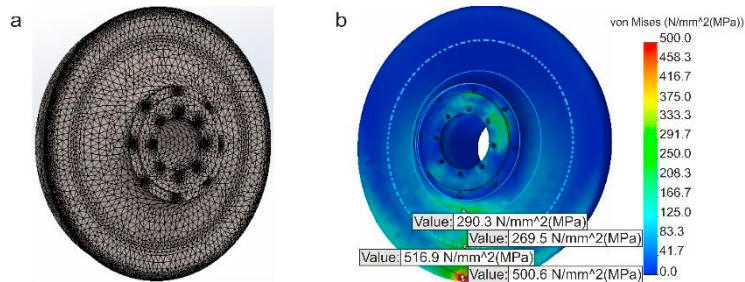


Fig. 6. Study of the wheel model No. 2: Finite element Model a), Stress Plot b).

Combined FE model was developed using a similar algorithm for study of the strength of the wheel model No. 3 (Fig. 7). The load modes, load conditions and input data were defined in the same way as for the wheel model No. 2.

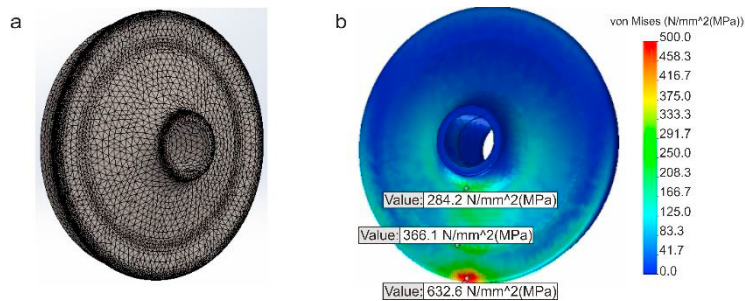


Fig. 7. Study of the wheel model No. 3: (a) Finite element Model; (b) Stress Plot.

Analysis of results of equivalent stresses indicates that under maximal load of the wheel model No. 3 acting on the wheel, the maximum values of equivalent stresses are observed in the flange contact and constitute  $\sigma_{max} = 633$  MPa.

The obtained values of the maximum stresses calculated for the proposed wheel models were compared to the maximum stresses for the ordinary wheel of a typical design (Ushkalov et al. 2013). Based on the above results of the analysis of the stress-strain state, it can be concluded that the design of the wheel No. 2 is the most effective in terms of durability.

#### 4. Conclusion

Preliminary theoretical studies have shown the possibility of reducing the resistance to motion of a rail vehicle wheel by modification its design scheme. Studies of the motion of models of carriages of rail vehicles were performed for the experimental evaluation of the influence of the structural schemes of the wheels on the resistance to motion. A regression equation has been drawn up for the dependencies of the resistance to motion force on the main factors influencing the rail carriage models with wheels of various design schemes when driving in a straight line and in curved track sections in accordance to the results of the experiment plan. Comparative experimental tests have defined the reducing of the resistance to motion when using PDS wheels in the undercarriage part of the rail carriage, which is achieved by changing the conceptual design of the wheel in a way to let its supporting and guide surfaces rotate separately.

A preliminary analysis of the stress-strain state for a number of PDS wheel designs was performed. The analysis showed that the proposed designs have a sufficient factor of safety.

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