Diagnostics of the airless wheel by the combined method

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Abstract. For construction and road machinery, tubeless tires made on the basis of elastic polyurethanes are being used more often. The diagnosis of airless tires made of elastic polymer materials in order to determine the conditions of their safe operation is becoming more and more relevant. The use of roller stands does not give accurate results, because the round support surface of the rollers introduces distortion. A method of obtaining basic parameters and characteristics on simple stands is proposed. Use their values for tire research and diagnostics in software environments such as Ansys, Solidworks, AutoCad. For the designed and manufactured sample of an airless wheel on the stands, the dependences of the change in the static radius of the wheel depending on the load and the change in the deflection of the wheel depending on the lateral force at different loads on the wheel were obtained. They became the basis for the initial parameters and characteristics of the wheel modeled in the Solidworks environment. Its properties were simulated for three cases of wheel rolling: "driven wheel", "driving wheel" and "free wheel". The obtained results show that the most difficult mode is the movement of the wheel on the deformable support base. In this mode, the opposite sides of the spokes work in tension and compression when blowing the spokes to a vertical state. The values of stress do not exceed the critical allowable ones during rupture or during compression for polyurethane. Therefore, it can be diagnosed that the wheel is in satisfactory condition.

1 Introduction

The variety of construction and road machinery is large, and a large part of it is equipped with wheeled vehicles. Such designs have a number of advantages, but the main problem is the possibility of their damage, as a result of which the wheel requires long and expensive repairs, and the equipment is often idle, which reduces its productivity.

A wheel with a traditional pneumatic tire has a significant drawback: in case of loss of excessive air pressure in the tire, the movement of the wheeled machine stops, and when the machine moves at high speed, a traffic accident with serious consequences is possible. Other disadvantages of the pneumatic tire are the complexity of technological processes and high energy costs for its disposal, as a result of which the world has accumulated a huge number of used and substandard car tires. Modern achievements in the chemistry of polymers make it possible to create automobile tires of a new design, the performance of which is ensured not by the pressure of compressed air, but by the physical and mechanical properties of structural materials, for example, elastic polyurethanes. The world's leading car tire

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manufacturers, such as Michelin, Amerityre, Yokohama, Bridgestone, Hankook, Resilient Technologies, Polaris, are actively engaged in the creation of airless polyurethane tires.

The research and diagnosis of airless tires made of elastic polymer materials in order to determine the conditions for their safe operation is relevant.

2 Problem statement

Diagnosing the technical condition of a vehicle's braking and suspension system (ATZ), which includes a tire, is one of the most important aspects of ensuring its active safety. It is performed on power brake stands with running drums. As research shows [1], power stands do not always reliably and objectively assess the technical condition of these ATZ systems, since the mechanics of the tire's interaction with the road surface is significantly different from the mechanics of its interaction with the rollers of the diagnostic stand [2,3]. One of the options for solving the problem is the experimental determination of the main characteristics of the wheel with subsequent modeling and diagnostics in software environments such as Ansys, Solidworks, AutoCad.

3 Analysis of recent research and publications

This includes investigations and diagnostics of balm systems and suspensions, mainly on drum-type stands. However, as the authors say, the results obtained may be inaccurate.

When the wheel rolls along the rollers of the stand, a closed circuit is formed in which a power flow can circulate. The circuit consists of: support rollers, a chain drive connecting them and, of course, a tire. Power circulation arises from kinematic mismatch [4], caused by the fact that the power rolling radii of the wheel (rolling radii of the wheel in driven mode) along the front and rear rollers are not equal, and the support rollers of the stand cannot rotate at different angular speeds, since they are interconnected chain transmission.

An important factor is the displacement of the car wheel relative to the axis of symmetry of the support rollers, since when the car is braking on the rollers of the stand during its diagnosis, the resulting tangential forces tend to shift the wheel towards the rear support roller [5]. In this case, the exact positioning of the wheel, and, as a rule, the entire car on the diagnostic stand, is disrupted, so the braking process is carried out mostly on the rear roller, which significantly affects the diagnostic results [6].

When using hybrid stands for diagnostics, the results have less inaccuracy and allow expanding the range of diagnostic parameters that can be determined [7].

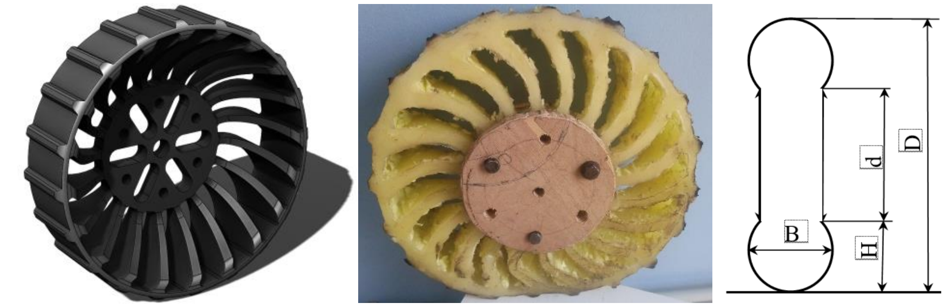
To check the accuracy of diagnostics, it is suggested to duplicate measurements on roller stands in the MATLAB® Simulink software environment [8].

The authors [9-11] state that the parameter values obtained on diagnostic stands differ in different literary sources. The simultaneous use of different diagnostic methods is suggested to clarify the obtained results.

4 Presenting mainmaterial

On the basis of the conducted review, it is suggested that when testing and diagnosing wheels in general and airless wheels in particular, the main parameters and characteristics should be obtained on diagnostic stands, and further research should be carried out in software environments.

A sample of an airless wheel was designed and manufactured at the Department of Machine Design and Automotive Engineering of the Lviv Polytechnic National University (Fig. 1).



a b c

Fig. 1. Airless wheel: a – 3D model, b – experimental sample, c – geometrical parameters.

To determine the change in its static radius depending on the load, a stand was used, the diagram of which is shown in fig. 2.

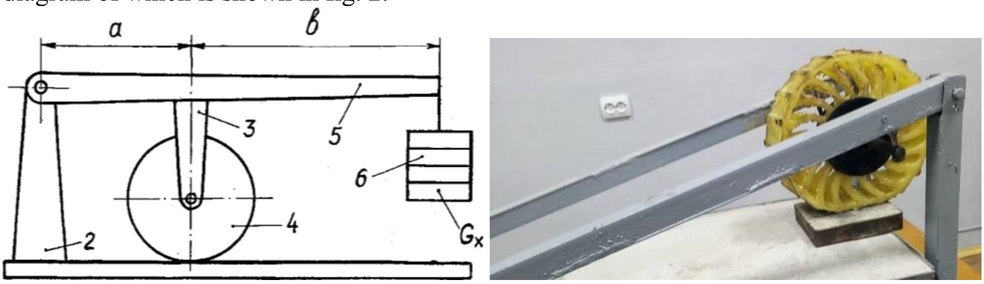


Fig. 2. A stand for determining the radii of a car wheel.

The free radius of the wheel is determined by the geometric dimensions of the given tire according to formula 1. This radius can also be determined by measuring the length of the running track of the wheel with a tape measure and dividing it by 2π.

$$\mathbf{r_0 = \frac{d}{2} + H,} \tag{1}$$

where d is the disc diameter, H is the tire height.

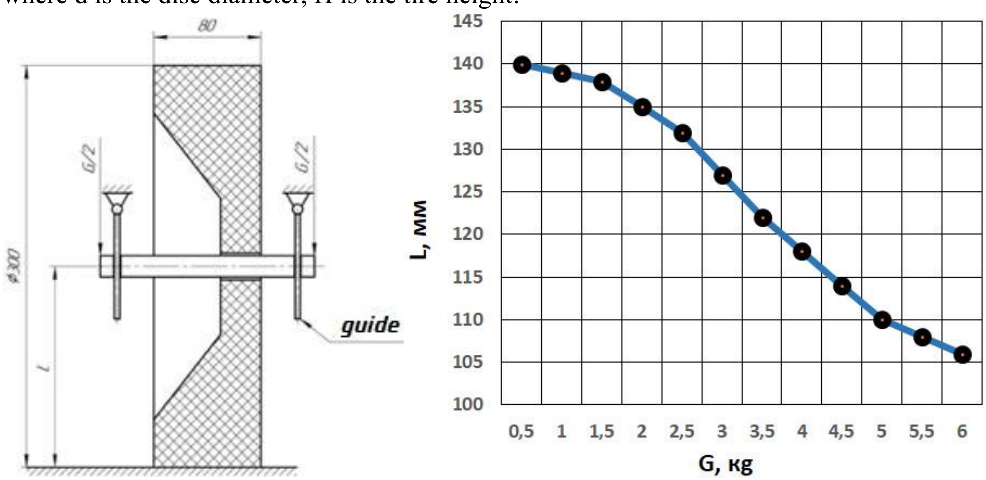


Fig. 3. Changing the static radius of the wheel depending on the load.

The stand consists of a frame 1, to which a bracket 2 is rigidly fixed. A lever 5 is connected to the bracket 2 by means of an axis, to the free end of which weights 6 can be suspended, which load the test wheel 4 through the bar 3. Arms "a" and "в" are selected so as to ensure the load of the wheel from the minimum to the maximum allowable static load at a given mass of goods 6. The wheel is loaded in steps so as to obtain 7...10 points. For each load, the static radius of the wheel is determined by the rod altimeter.

The resulting dependence of the change in the static radius of the wheel relative to the load is presented in Fig. 3.

To determine the removal of the airless wheel, a stand was used, the diagram of which is shown in fig. 4. The stand allows you to investigate the relationship between the lateral force and the wheel deflection angle at different vertical loads on the wheel.

The design of the laboratory stand is based on the phenomenon of reversibility of the removal process, which consists in the fact that the rolling of a wheel turned at an angle δ to the plane of its rotation causes the appearance of a lateral force Pδ. The directional action of the steering wheels of the car is based on the same, when they turn, lateral forces from the road arise, which mix the direction of the car.

The stand has a continuous running track, which is a flexible belt 1 with steel plates 2 attached to it.

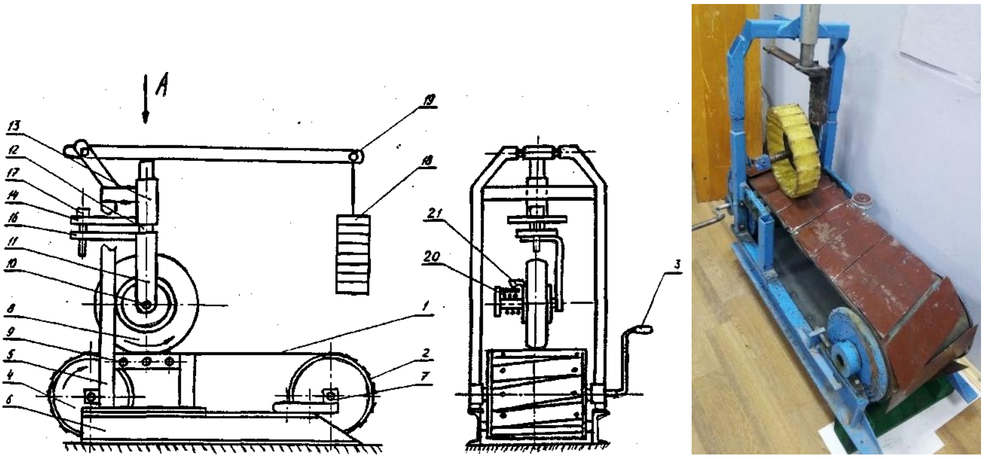


Fig. 4. Diagram of a laboratory stand for the study of wheel deflection.

The tape is rewound using the handle 3 on two drums 4 installed in rolling bearings. The body of one of the drums is attached to the rack 5, and the other to the frame 6. The tape tension is regulated by moving the bearing housings 7 together with the bars attached to them.

The investigated wheel 8 rolls on the outer surface of the tape plate over the rollers 9, which also rotate in rolling bearings and support a continuous tape. The horizontal axis 10 of the wheel is fixed to the bracket 11, which can be rotated relative to the vertical axis 12 in the sleeve 13 by the angle of deviation. To establish and fix this angle, a circular sector 14 with holes 15 is provided, which is welded to a fixed bushing 13, and a plate 16 with holes fixed to the bracket 11. The angular position of the plate 16 relative to the circular sector 14 is fixed by a finger 17 inserted into the corresponding holes 15.

The vertical load on the wheel is created by the load on the axle 10 or with the help of loads 18, hung on the pull of the lever 19, the second end of which is hingedly connected to the rack bracket. Gear ratio of the lever Iv=10.

Under the action of the lateral force, the wheel under study has the ability to shift in the axial direction during rotation, compressing the spring 20. It is by the magnitude of the deformation of the spring, measured by the displacement sensor 21, that the magnitude of the acting lateral force is determined using a calibration graph.

The resulting dependence of the change in wheel deflection depending on the lateral force at different loads on the wheel is presented in Fig. 5.

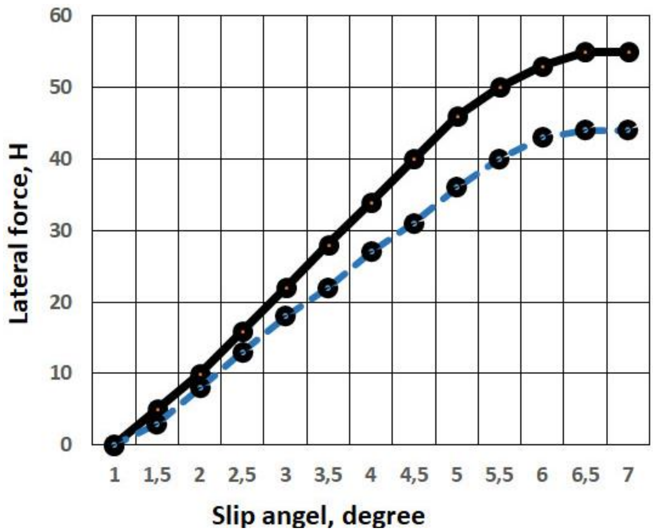


Fig. 5. Change of wheel deflection depending on the lateral force when the load on the wheel is 30 N (dashed line) and 40 N (straight line).

The obtained measurement values were used when setting the parameters and characteristics of the airless wheel designed in the Solidworks environment.

The next stage of testing the wheel was the study of its rolling modes (Fig. 6).

Despite its apparent simplicity, the wheel is a complex device, the operation of which, depending on the goal and degree of accuracy, can be described using different models.

As is known [12,13], in the general case of rectilinear movement of the wheel, various forces and moments act on it: Rx and Rz – respectively, the longitudinal and vertical reaction in the spot of contact of the wheel with the supporting base; Px and Pz – respectively, the longitudinal and vertical force applied to the wheel axis; Mk is the torque supplied to the wheel; Mf is the moment of rolling resistance arising from internal losses in the wheel material. Depending on the nature and direction of these forces and moments, the following modes of uniform motion of the wheel on a solid base are distinguished [13].

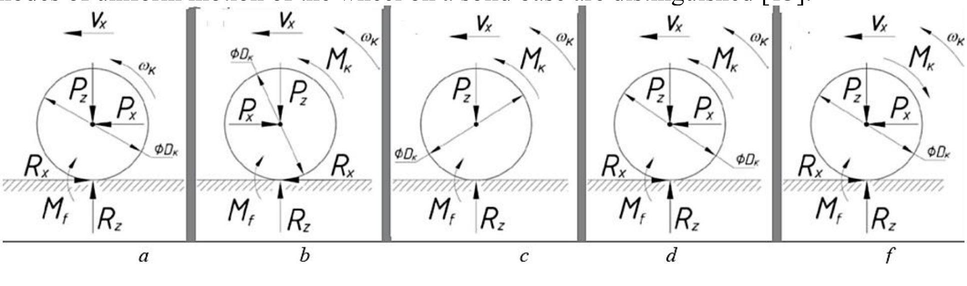


Fig. 6. Modes of uniform movement of the wheel: a – driven wheel; b – driving wheel; c – free wheel; d – Mr – neutral wheel; f – brake wheel.

1) Driven wheel (Fig. 6, a) – the wheel is driven into rotation by the longitudinal force Px applied to the axis of the wheel and coincident in direction with the speed Vx of its longitudinal movement. The torque of the wheel M is equal to zero.
2) Guide wheel (Fig. 6, b) – the wheel is driven into rotation by a torque Mk, the vector of which coincides with the vector of the angular velocity wk, and is loaded with a longitudinal force Px.
3) Free wheel (Fig. 6, c) – the wheel is rotated by the torque Mk, and the longitudinal force Px is zero.

4) Neutral wheel (Fig. 6, d) – the wheel is driven into rotation simultaneously by the torque Mk and the pushing force Px.
5) Brake wheel (Fig. 6, f) – the wheel is driven into rotation by a pushing force Px and loaded with a torque Mk, the vector of which is opposite to the vector of the angular velocity ωk.

The elastic wheel, as an object of research, has various properties that are manifested in quite complex physical phenomena accompanying the rolling process. A large number of works have been devoted to the study of the phenomena occurring during the rolling of a pneumatic tire, while the rolling of a wheel made of polyurethane-based composite materials remains insufficiently researched.

The elastic polyurethane wheel has the following material values: modulus of elasticity of the first kind when bending E = 6.1 MPa; shear modulus G = 2.9 MPa; material density ρ = 1000 kg/m3 [14,15]. The process of movement of an elastic wheel on a solid support surface is modeled using the finite element method in the Solidworks software environment, designed for solving three-dimensional dynamic nonlinear problems of the mechanics of a deforming solid body, mechanics of liquids and gases, heat transfer, and similar problems. You can find out more about the method of finite elements and the Solidworks environment in the available literature, only a brief description of the finite elements used in solving the given problem is given below.

In fig. 7 shows examples of modeling various cases of movement of an elastic polyurethane wheel.

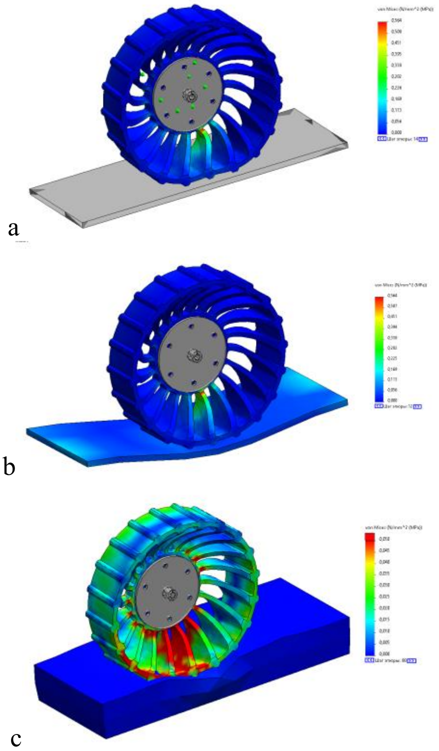


Fig. 7. Various cases of modeling the movement of an elastic polyurethane wheel: a – on a solid base; b – by inequalities; c – on a deformable support base.

Fig. 7 shows the results of simulation of three cases of polyurethane wheel rolling: "driven wheel", "driving wheel" and "free wheel", which are of greatest interest.

The coefficient of friction for each element of the model of the elastic polyurethane wheel, coming into contact with the element of the support surface, is given using the Coulomb formulation [16]:

$$\mu = \mu d + (\mu s + \mu d) e - c \mid v| \quad (2)$$

where μd is the coefficient of friction of full sliding; μs – coefficient of rest friction; c – empirical coefficient; v is the sliding speed at the node, which is calculated by the formula:

$$v = \Delta e / \Delta t \quad (3)$$

Δ e is the displacement of the node that enters the contact.

To avoid shock loads and jerks, forces are applied gradually, as shown in fig. 8, 9. In the first second, a vertical load is applied to the axis of the wheel drive. Then, in the second second, longitudinal force and torque are applied depending on the rolling mode.

The obtained results show that the most difficult mode is the movement of the wheel on the deformable support base. In this mode, the opposite sides of the spokes work in tension and compression when blowing the spokes to a vertical state. The values of stresses do not exceed the critical allowable ones during rupture or during compression for polyurethane [15,17]. Therefore, it can be diagnosed that the wheel is in satisfactory condition.

5 Conclusions

For construction and road machinery, tubeless tires made on the basis of elastic polyurethanes are being used more often. The diagnosis of airless tires made of elastic polymer materials in order to determine the conditions of their safe operation is becoming more and more relevant. The use of roller stands does not give accurate results, because the round support surface of the rollers introduces distortion.

A method of obtaining basic parameters and characteristics on simple stands is proposed. Use their values for tire research and diagnostics in software environments such as Ansys, Solidworks, AutoCad.

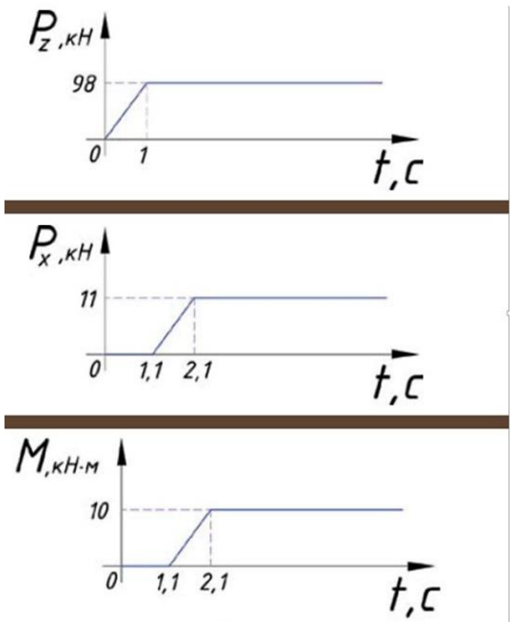


Fig. 8. Load application schedules: a – vertical force; b – longitudinal force; c – torque.

For the designed and manufactured sample of an airless wheel on the stands, the dependences of the change in the static radius of the wheel depending on the load and the change in the deflection of the wheel depending on the lateral force at different loads on the wheel were obtained. They became the basis for the initial parameters and characteristics of the wheel modeled in the Solidworks environment. Its properties were simulated for three cases of wheel rolling: "driven wheel", "driving wheel" and "free wheel".

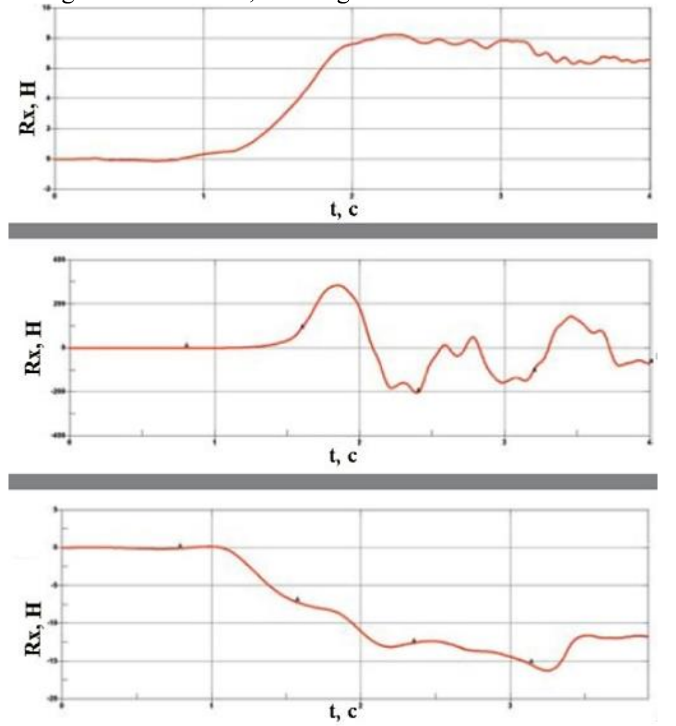


Fig. 9. Graphs of changes in the longitudinal reaction Rx in the contact spot: a – led mode; b – free mode; c - is the leading mode.

The obtained results show that the most challenging mode is the wheel's movement on a deformable support base. In this mode, the opposite sides of the spokes work in tension and compression when the spokes are bent to a vertical position. The stress values do not exceed the critical limits for polyurethane in tension or compression. Therefore, it can be diagnosed that the wheel is in a satisfactory condition.

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