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# IMPROVEMENT OF CAR TIRES TRIBOLOGICAL PROPERTIES IN MOTION

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**Abstract:** Modern trends in the development of car tires, in addition to the automation of the operation process, are also aimed at increasing their operational characteristics, one of the criteria that determines the state of tire behavior is tribological properties [1]. The indicated properties of the tire directly depend on its service life, fuel efficiency, and the comfort of the car, as well as traffic safety [2]. Therefore, the study of tribological properties of tires with the aim of further improving the efficiency of tires as a whole is currently a rather urgent task. The state of dynamic interaction in the "wheel-tire-road" system was studied, namely the car wheel rolling process, when its tire is subjected to deformation, which contributes to the creation of a moment of resistance to the rolling of the wheel and the actual adhesion of the wheel to the road. As a result of the research, ways to improve the tribological properties of car tires during movement are proposed.

**Keywords:** tribological properties, car tire, efficiency of tire, rolling process, moment of resistance.

## 1. INTRODUCTION

When the tire is deformed, normal and tangential stresses arise, and the tread elements slip relative to the supporting surface, which causes tire wear [3]. In addition to design parameters, operating parameters also have a significant impact on the wear process. This scientific work presents a more detailed study of both the design and operational parameters of the tire. According to its results, it is possible to formulate conclusions regarding the prospects for the development of the design of automobile tires and recommendations for operation to increase the improvement of operational characteristics and, first of all, traffic safety.

Since the process of interaction of car tires with the road surface during movement is complex, it is necessary to move to mathematical models that make it possible to more easily predict the processes of tire wear, and at the same time high accuracy will be achieved, that is, the results will be reliable.

## 2. METHODOLOGY

First, we will analyze the already existing mathematical models describing the interaction of car tires with the support surface during movement. Several models of tires are presented in [1]. In the simplest case, the interaction of the tire with the supporting surface can be considered as a special case of the contact of two elastic bodies that compress each other with a certain force. The road is taken for a smooth surface that does not deform (absolutely rigid), and the tire can be represented by any elastic model.

One of the first to consider the rolling of an elastic wheel on a solid base was O. Reynolds [4]. Based on the calculation scheme proposed by him, rolling friction is accompanied by sliding friction. The contact zone of the wheel with the support surface has areas of slippage and adhesion. Frictional forces proportional to the normal pressure arise in the area where sliding occurs. The first studies are devoted to the study of the interaction of the tire with the support surface, performed in static conditions. The distributions of specific pressures and tangential stresses in the contact zone of the tire with the supporting surface were investigated. The saddle-shaped nature of the distribution of specific pressures

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in the transverse contact plane is noted. The tangential stresses acting on the support surface in the contact zone near the tire are directed towards its center.

From the analysis of the data obtained during the operation of pneumatic tires, it was established that the internal air pressure and the load perceived by the wheel have a great influence on their service life. It was also noted that there is such a combination of these parameters that the maximum tire mileage (resource) can be achieved. The internal pressure was usually chosen according to the value of the relative deflection, accepted as the norm for this class of tires. However, this method of choosing the internal pressure does not consider all the design features of the tire and its operating conditions. Only approximate determination of the optimal pressure is provided.

For a more accurate determination of the optimal internal pressure, it is necessary to have data on the distribution of normal and tangential stresses over the area of the contact zone and slippage of the tread elements relative to the support surface.

One of the main causes of tire wear is the presence of frictional forces that arise in the contact zone during the sliding of the tread elements relative to the supporting surface. Therefore, the specific work of friction or the power exerted by the forces of friction is taken as a criterion for wear. There are examples where the ratio of loss of volume to the work of friction is taken as a criterion for evaluating abrasion.

Radial deformation of the tire causes deformations in circumferential and meridional directions. In work [1], it was found that within the contact area the frame is parallel to the support surface. But according to the tread pattern (Fig. 1), this condition is not fulfilled.

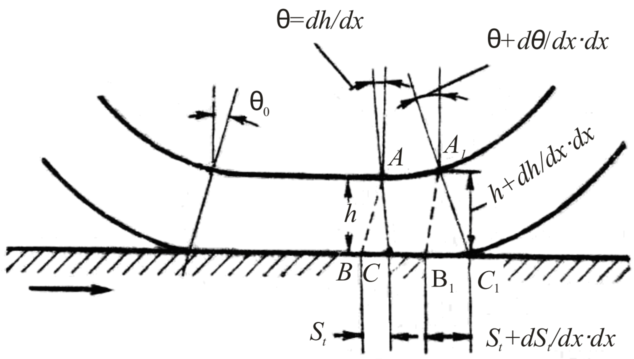



**Figure 1.** Scheme for determining the movement of tangential forces in the circumferential direction.

Based on the assumption that there is no slippage in the contact zone, the displacement of an arbitrary point of the tire frame relative to the supporting surface can be determined from the values of the circumferential and meridional deformations, which in turn makes it possible to determine the tangential stresses (1, 2):

$$\tau_t = \frac{h_0}{3\psi_1\psi_2}\left(\frac{\ddot{a}q_0}{\ddot{a}x} - \frac{\ddot{a}q}{\ddot{a}x}\right) + \frac{G}{h_0\psi_1}\int_0^x\left(\varepsilon_t - \frac{r_\kappa}{r_0} + 1\right)dx; \quad (1)$$

$$\tau_m = \frac{G}{h\psi_1}\int_0^y\left(\varepsilon_m - \varepsilon_m^o\right)dy - \frac{G}{3\psi_1\psi_2}\left(\frac{\partial q}{\partial y} - \frac{\partial q_0}{\partial y}\right), \quad (2)$$

where:
$h_0$ – thickness of the protector at the entrance to the contact; $h$ – current tread thickness value; $\psi_1$, $\psi_2$ – coefficients depending on the shape of the tread pattern; $h$ – current value of normal tension; $G$ – Young's modulus; $\varepsilon_t$, $\varepsilon_m$ – the current value of the circumferential and transverse deformation of the frame; $r_\kappa$ – rolling radius; $r_0$ – disposable radius; $\varepsilon_m^0$ – transverse deformation of the frame at the entrance to the contact.

Slippage in the sliding zone is proposed to be determined by the amount of displacement relative to the support surface (3, 4):

$$s_m = a_m + \Delta m \quad (3)$$

$$s_t = a_t + \Delta t \quad (4)$$

where:
$s_m$, $s_t$ – longitudinal and transverse movements of the frame point relative to the support surface, respectively; $\Delta m$; $\Delta t$ – tread deformation components; $a_m$, $a_t$ – sliding components.

The intensity of tangential forces in the sliding area is determined by the dependence (5):

$$\tau = \sqrt{(C_m \Delta m)^2 + (C_t \Delta t)^2} \quad (5)$$

where
$C_m$ – transverse stiffness of the tire tread pattern elements; $C_t$ – longitudinal rigidity of the elements of the tire tread pattern.

Since the direction of the infinitesimal slippage of the point during its transition from one position to the adjacent one coincides with the direction of the tangential force, we can write the expression (6):

$$\frac{da_m}{da_t} = \frac{C_m \Delta m}{C_t \Delta t} \quad (6)$$

Solving this equation, we obtain expressions (7, 8):

$$da_m = \frac{C_m \Delta m}{C_m^3 \Delta m^2 + C_t^3 \Delta t^2}\left(C_m^2 \Delta m ds_m + C_m^2 \Delta t ds_t - \phi^2 q dq\right) \quad (7)$$

$$da_m = \frac{C_t \Delta t}{C_m^3 \Delta m^2 + C_t^3 \Delta t^2}\left(C_m^2 \Delta m ds_m + C_m^2 \Delta t ds_t - \phi^2 q dq\right) \quad (8)$$

Knowing the values of slips and tangential forces, it is possible to determine the specific work of friction (9):

$$A_{mep} = \int \left(C_m \Delta m da_m + C_t \Delta t da_t\right) \quad (9)$$

In work [5], the crown part of the tire is modeled by a tape that is rigid in the cross section and flexible in the circumferential direction, and the role of the elastic base is performed by compressed air (Fig. 2) - a tape on an elastic base.

From consideration of the balance of the element of the crown part of the tire (Fig. 3), we obtain equation (10):

$$\Sigma F_Z = B_n dQ + N B_n \left(\frac{1}{r_0} + \frac{d^2 \omega}{dx^2}\right) dx - p_w B_n dx + K q B_n dx + 2 T i dx + 2 Q dx \quad (10)$$

$$\Sigma F_X = B_n dN - 2 T_X i dx - \tau B_n dx - 2 P_c dx = 0 \quad (11)$$

where:
$N$ – tensile force acting in the middle surface; $Q$ – vertical efforts; $P_c$ – horizontal efforts; $M$ – bending moment acting on the side faces; $K$ – proportionality coefficient; $r_0$ – disposable radius; $B_n$ – tire tread width; $i$ – circumferential density of cord threads; $T$ – cord tension; $p_w$ – internal air pressure in the tire.

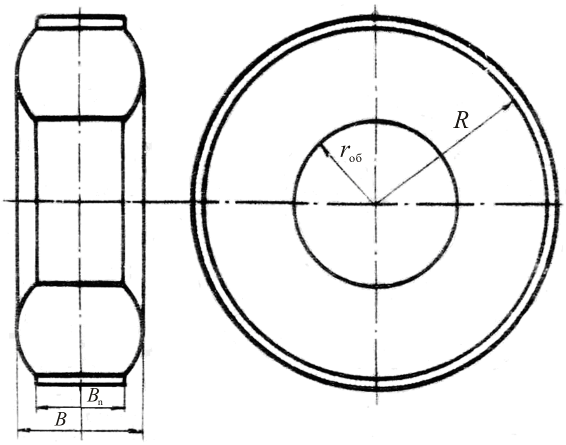



**Figure 2.** Tire model "tape on an elastic base"

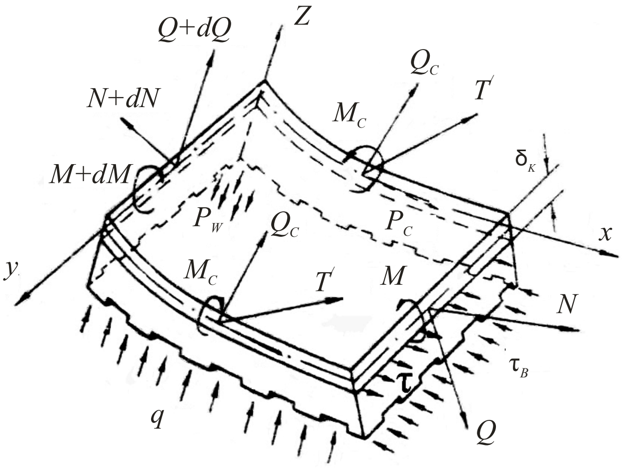



**Figure 3.** Loads acting on the strip elements of the model.

Considering the same tire model "tape on an elastic base" in work [5] also solves the problem of determining the distribution of longitudinal stresses in the contact plane of a rolling wheel.

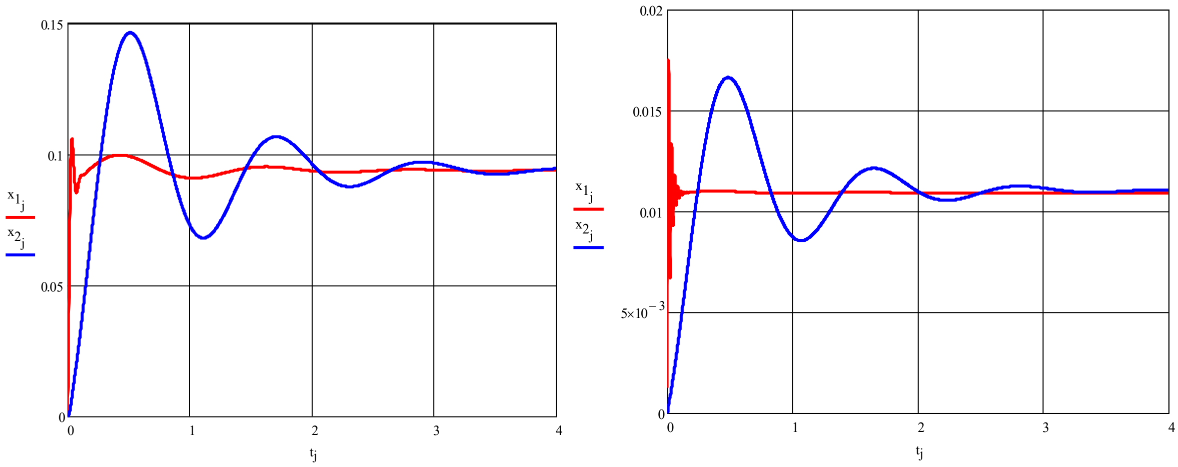
According to the well-known diagram of the distribution of vertical stresses, the tangential stresses in the slip zones are determined, where they cannot be greater than the limit behind the adhesion.

The paper [6] presents a contact problem for a radial tire pressed onto a plane. A model of a round, circumferentially extensible ring connected to the rim by springs is presented. On the outer surface of the ring there is an elastic layer that imitates a tire tread. In the cross-section, the ring with the elastic layer is a rectangle, and in the process of deformation, all points of the cross-section receive the same radial displacement to the wheel axis and the same circumferential displacement.

But since the real tire has a curvature in the cross-section, the results of the calculations based on the previously described model differed from the experimental ones.

When the tire is loaded with a vertical force, the frame and the tire breaker are deformed. These deformations cause the surface part of the tread elements to move relative to the supporting surface. As a result, tangential stresses act on the base of the tread, the direction of which is opposite to the movements. If we assume that the coefficient of friction is zero, then the value of sliding relative to the support surface will be maximum. It is equal to the displacement of the middle surface of the ring plus the displacement of a point lying on the surface of the tread element, caused by the rotation of the cross-section of the ring.

Also, the tribological properties of the tire can be indirectly evaluated through the parameters of tire stiffness and rolling resistance. The paper [7] presents the results of the analysis of the condition and behavior of the car tire during the starting motion. The peculiarity is that the main parameter for assessing the condition of a tire is its stiffness characteristics. Research was conducted in conditions that can often occur during the operation of car tires, namely at low ambient temperatures. To solve the problem, the authors use a numerical and analytical approach. Similar approaches to modeling the interaction of a car wheel are presented in [8]. Therefore, the initial data, which are necessary for performing the correct analysis in work [7], were obtained from the results of experimental studies in road conditions. Using the results obtained, it is possible to present recommendations regarding the features of the operation of automobile tires under "adverse" conditions. The main part of the work is devoted to solving the differential equations of motion of the mechanical system, which is presented in the form of a "mass-spring-damper" model. As a result of the research presented in the work, the hypothesis is confirmed that under adverse operating conditions, the operation of the tire and suspension differs from their behavior under normal conditions. In other words, the suspension as a whole is more rigid, which significantly affects such operational properties of the car as comfort and, first of all, driving safety. The results of the simulation of the operation of the suspension and car tire are presented in fig. 4 [8].




a b

**Figure 4.** Results of simulation of movement of the unsprung and sprung mass of the car: a – under normal operating conditions; b - under "adverse" operating conditions.

## 3. DISCUSSION

The problem of researching the influence of operational and design parameters of a tire on its wear, despite a huge amount of work, remains incompletely solved. Thus, in many scientific works, analyzing the influence of internal pressure, load on the wheel, angle of departure, it is noted that the design of the tire affects its interaction with the supporting surface, but no clear recommendations are given for optimizing the design of the tire.

The variants of mathematical models considered in the work are quite adequate, however, when choosing models, it is necessary to clearly define which assumptions are accepted when creating the model and consider all the shortcomings of the models.

The practical use of the proposed analytical expressions (1–9) is difficult, since it is rather difficult to determine many quantities included in these expressions. The nature of the deformation of the elements of the tread pattern has a more complex form than unilateral compression, as assumed when obtaining these formulas.

The disadvantage of the "tape on an elastic base" model is that it is necessary to have the reduced stiffness of the tire shell to solve the equation. The model does not take into account the uneven distribution of stiffness across the width of the tire and the distribution of movements of the middle surface in the slip zone.

## 4. CONCLUSIONS

When studying the tribological properties of tires, it is convenient to switch to mathematical models, which significantly simplifies the process of evaluating and determining tire wear resistance parameters.

As mentioned earlier, the tribological properties of car tires are significantly influenced by such an operating parameter as the value of the internal air pressure. With an increase in internal pressure, there is an increased activation of the central zone of the tread, and the stresses that stretch increase in the frame. Its decrease leads to an increase in the wear of the extreme areas of the tread and bending stresses in the frame.

The expressions obtained during the study of the "tape on an elastic base" model make it possible to determine the stress distribution depending on the load, internal pressure and tire design. The twisting of the tire caused by torque and braking moments is also considered. However, this model does not take into account the slippage of the tread elements at the beginning and end of the contact zone and the uneven distribution of tire stiffness in the transverse direction.

As a result of the experiments [1], plots of the distribution of tangential stresses and slips of the tread elements relative to the support surface were obtained. At the beginning and at the end of the contact zone, the work of friction increases, and in the middle zone, the work of friction remains almost constant. This indicates that at the beginning and at the end of the contact zone there are sliding zones, and in the middle - a zone of adhesion.

Also, when evaluating the tribological properties of the tire, you can use indirect methods of evaluating the operational parameters of the tire, for example, according to the method described in [7,9], you can evaluate the stiffness of the tire, which in turn directly affects the wear resistance parameters of the tire. The operating conditions of the tire also have a significant impact on these tire parameters, which is confirmed by research results.

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