Influence of rolling condition and geometry of tire tread on its wear intensity

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Abstract. Wheel tire wear annually takes hundreds of thousands of rubber tons. In this regard, the issue of reducing this negative phenomenon is urgent, for which it is necessary to know what and how affects tire wear. Factors affecting the wear of elastic wheels can be different: recipe of the rubber compound, the amount of traction (or braking) force in contact with the road, the type of movement is straight or cornering, the installation angles of the wheels (camber and toe-in angles), tire design, driving mode - uniform or with acceleration (braking). In this paper, we consider the influence on tire wear of such parameters as the value of the longitudinal force acting in the contact, the camber and toe-in angles, the radius of the motion trajectory and such a structural parameter as the convexity of the tread. When assessing the wear intensity, as is accepted by most researchers, we proceed from the fact that wear is proportional to the friction power in the contact of two interacting bodies.

1. Introduction

Wheel tire wear annually takes hundreds of thousands of rubber tons. In this regard, the issue of reducing this negative phenomenon is urgent, for which it is necessary to know what and how affects tire wear. Factors affecting the wear of elastic wheels can be different: recipe of the rubber compound, the amount of traction (or braking) force in contact with the road, the type of movement is straight or cornering, the installation angles of the wheels (camber and toe-in angles), tire design, driving mode - uniform or with acceleration (braking). Let us consider the influence on the tire wear of such parameters as the value of the longitudinal force acting in the contact, the camber and toe-in angles, the radius of the motion trajectory and such a structural parameter as the convexity of the tread.

2. Problem statement

The solution of these problems is possible from consideration of the wheel interaction mechanics with the supporting surface. This was done, in particular, in [1–8], in which there are dependencies that allow one to determine the force and kinematic characteristics including the power of friction losses in the wheel contact with the supporting surface.
The wear rate is proportional to the work or power \( P_P = F \xi V \) \([1, 2]\), spent on friction in the contact. Since the relative loss of speed (slip) of the wheel \( \xi \) depends on the tangential force \( F \) realized in the contact, the dependence \( P_P = f(F) \) has the form of a parabola of \( n \)-order. Moreover, with relatively small tangential forces \( F < (0.2 \ldots 0.3) \mu F_n \), where \( \mu \) – coefficient of sliding friction, \( F_n \) – normal load on the wheel), the friction loss power in the contact \( P_P \sim F^2 \).

An increase in the saturation of the treadmill pattern increases its wear resistance both due to the larger abrasion area of the treadmill and due to a decrease in the tangential elasticity and a decrease in the relative loss of speed and power of friction losses in the contact, respectively.

At the same time, the question of the positive effect of reducing the tangential elasticity coefficient of the wheel is not so clear, since from the point of view of reducing the powertrain load when the axles of an all-wheel drive vehicle are blocked, it is desirable to have tires with greater tangential elasticity, which reduces the uneven distribution of tangential forces over the axles, and therefore and uneven tire wear on different axles.

Another structural parameter of elastic wheels that affects their wear (although to a much lesser extent) is convexity, i.e. curvature of the treadmill of the wheel in the transverse direction (toroidality).

The physical picture of the phenomena occurring during rolling of a toroidal wheel is described in [3]. It also gives the derivation of equations that quantitatively describe the force and kinematic dependences for toroidal wheels and, in particular, equations that allow one to calculate the linear (i.e., in longitudinal section) and the total power of friction losses in the contact, and, therefore, evaluate the unevenness of the wear rate using the width of the treadmill of the toroidal wheel and give an integrated assessment of the wear rate.

Figure 1 shows the distribution of linear friction power in contact across the width of the treadmill for a wheel with a massive rubber tire having a curvature radius of treadmill in the transverse plane \( \rho = 2r = 260 \text{ mm} \) (the height of the rubber layer \( h = 24 \text{ mm} \), width \( B = 47 \text{ mm} \), normal load \( F_n = 3000 \text{ N} \)) for various braking torque.

![Figure 1. Distribution of linear friction power in contact across the width of the treadmill of the wheel with the convex shape of the treadmill](image)

The decrease of the treadmill curvature radius \( \rho \) in the transverse plane increases the unevenness and intensity of wear along its width, especially when \( \rho < (2 \ldots 3)r \); the greatest wear of the driven wheel should take place near the edges of the contact spot, which leads to a decrease in the radius \( \rho \), and, consequently, to an increase in the intensity of wear, i.e. to progressive treadmill wear. With an increase in the moment of rolling resistance (or torque), the distribution of the linear power of the friction losses in the contact in different longitudinal sections is equalized, and the total wear rate increases.

Figure 2 shows the dependence of the total frictional power loss in contact on the curvature radius of the elastic massive wheels in the transverse plane, and Figure 3 shows the influence ("significance") of the treadmill convexity on the total friction loss in the contact.
As follows from these figures, power losses increase with wheel treadmill curvature in the transverse direction increasing, and most intensively at \( \rho < (2 \ldots 3)r \); with torque increasing (braking or traction) on the wheel. The fraction of friction losses in the contact due to the toroidality of the wheel decreases many times and is practically insignificant at high values of the torque.

Tire wear to a large extent depends on the amount of the angle of the drive with which the wheel rolls [4–6]. Its influence is illustrated by the graphical dependencies shown in Figures 4–5. The friction power losses in the contact of the wheel rolling with the wheel withdrawal increases sharply with an increase in the withdrawal angle; the type of this dependence has the form of a parabolic curve.

If we compare the influence on the tire wear intensity of the camber and toe-in angles with which the wheel is mounted on the car, we can conclude that the role of the toe-in angle is many times greater than the influence of the camber angle.

Among the poorly studied is the question of the elastic wheel wear during its curvilinear movement, including rolling with a draw [7, 8].

Figure 5 shows the graphical dependences of the friction loss power in the contact characterizing the wear intensity on the withdrawal angle and the traction force realized during the curved motion of the wheel with a turning radius of one meter.

The performed studies show [9] that, with a decrease in the curvature radius of the trajectory, the wear intensity of the wheel increases, especially sharply at small radii. Moreover, the wear of the treadmill along its width is uneven: for driven and braking wheels, the outer edges (with respect to the

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**Figure 2.** Dependence of the friction power losses in contact on the wheel toroidality (radius of wheel treadmill curvature in the transverse plane)

**Figure 3.** Dependence of the friction power losses in the contact on the transmitted moment for cylindrical and toroidal \((\rho = 2r)\) wheels
center of rotation) are subjected to the greatest wear, while the leading ones have internal ones. However, this unevenness appears noticeably only at small turning radii and for wide wheels (and for twin wheels).

Figure 4. Dependence of the friction power losses in the contact on the withdrawal angle for various tangential forces in the contact

Figure 5. Dependence of the friction power losses in contact on the withdrawal angle and the realized traction force during curvilinear motion of the wheel with a turning radius of one meter

The rolling of a wheel with a draw along a curved trajectory increases the friction power losses in the contact, and its value depends on the sign of the withdrawal angle (Figure 5).

When rolling with the draw along both a curved and a straight trajectory, the friction power losses in the contact, and hence the wear intensity, does not depend much on the toroidality of the wheel.

3. Conclusion
The materials presented in this work allow us to more reasonably analyze the influence of rolling conditions and tire design on the performance indicators of both the tires themselves and the wheeled vehicle as a whole. This, in turn, improves the quality of tire and vehicle design.

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