The research into the rolling radius of a wheel when dealing with rollers of a roller tester

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Abstract. The paper focuses on one of the factors that significantly affect the occurrence of errors in the measurement of traction qualities of the car on the roller tester with two pairs of support rollers. It is hypothesized that the value of the rolling radius is significantly influenced by factors such as: the displacement of the wheel a relative to the symmetry plane of the support rollers of the tester, the load on the wheel and the air pressure of the pt in the tire. The change of these factors changes dramatically the value of the rolling radii rk01 and rk02 – wheel rolling radii in the driven mode. The authors propose a method for determining the rolling radius of the wheel and present the study results. The functional dependences obtained in the course of the experimental study were correctly approximated by equations, which allows one to perform calculations of the rolling radii rk01 and rk02 on two cylindrical support surfaces of the tester, taking into account the load on the wheel, its displacement a and the tire air pressure pt.

1. Introduction

Control of traction qualities of vehicles in operating conditions is carried out by the road and bench method. Testers of various designs are used to control the traction qualities of the car [1, 2]. The method of control on the roller testers is the most widespread as more accurate. Roller testers are designed so that each vehicle wheel bears on two support rollers.

The principle of traction control on these testers is the following. The driving wheels of the car are mounted on the rollers of the tester. The car is fixed with special fasteners. One warms up the engine, transmission and tires.

In the process of control, the drive wheels are accelerated in direct transmission and maximum engine speed. The loading system of the tester brings the brake torque to its support rollers until the rotation speed of the driving wheels is set at a predetermined level. Using this predetermined steady-state speed the measurement systems of the tester measure the traction on the vehicle drive wheels. The results of the measurement are indicators of wheel power and traction on the drive wheels [1, 2].

This method of vehicle control traction has a number of significant drawbacks. First, the interaction of the tires with the road support surface is significantly different from their interaction with the cylindrical support rollers of the roller tester [3]. Second, in the process of diagnosis there are longitudinal movements of the car [4, 5] which make significant errors in the measurement of traction parameters. In this case, the rolling radii r01 and r02 of wheels change significantly. Third, when the diagnosed vehicle is placed on the tester, there is almost always a non-parallelism of the rotation axes of its wheels and rollers of the tester [4, 5]. Fourth, the tire air pressure pt has an important role in the
process of interaction of the car tire. All these factors affect considerably the value of power and speed losses in the tires of the car driving wheels and cause significant errors in measuring the parameters of the car traction qualities [6, 11, 12].

Based on the aforesaid, it becomes relevant to study the speed losses and the interaction of car tires with the support rollers of roller tester [7, 11].

2. Methods

The experimental study of the wheel rolling radii \( r_{k01} \) and \( r_{k02} \) – wheel rolling radii in the driven mode on each support roller of the tester - was carried out when the normal load \( G_k \), acting on the wheel changed. The displacement \( a \) of the wheel is relative to the plane of symmetry of the support rollers of the tester in the direction of the rear support roller, as well as when varying the tire air pressure \( p_t \).

The change in the value of the wheel displacement \( a \) relative to the rollers simulates the level of disalignment of the tester axes and the car wheels (Figure 1).

The wheels longitudinal displacement of the car diagnosed axis on the rollers of the tester is always in the process of its acceleration under the action of longitudinal reactions. The longitudinal displacement of the wheels may change as a result of insufficient or excessive tire air pressure.

The Kama Euro-236 185/60R15 84H tire was used for the experimental study. The air pressure in the tire was changed discretely from 0.23 MPa to 0.15 MPa in increments of 0.02 MPa. The normal load on the wheel varied from the initial value of 0 N to the maximum value of 4500 N, with a step of 500 N.

Figure 1. The pattern of the car wheel placing on the rollers of the tester with a longitudinal movement: 1 – front support roller; 2 – rear support roller; 3 – car wheel; \( a \) – the value of wheel displacement; \( \omega_p \) – support rollers rotational speed; \( \omega_k \) – wheel rotational speed; \( r_{k01} \) – the rolling radius of the wheels relative to the front support roller; \( r_{k02} \) – rolling radius of the wheel relative to the rear support roller; \( r_f \) – free radius of the wheel; \( G_k \) – wheel load

To identify the functional dependence of the wheel rolling radius \( r_{k01} \) on the front support roller and the wheel radius \( r_{k02} \) on the rear support roller on the value of the normal load \( G_k \) acting on the elastic tire, while varying the displacement of the wheel \( a \) relative to the axis of symmetry of the support rollers and the air pressure in the tire, a special technique and the equipment necessary for its implementation [8] were used. The technique consists in the following: the test wheel is placed on the measuring tester [9, 10], with a certain value of the air pressure in the tire, displacement \( a \) and the normal load \( G_k \), applied to it. After checking the test values, the wheel is rotated. The rotation of the support rollers is carried
out by the rotation of the wheel; however, both support rollers are not connected kinematically to each other. During the rotation of the wheel, the measuring systems of the tester measure the angle of the wheel rotation and both support rollers. The value of this angle is displayed on a special board on the tester control panel in the form of the number of pulses from the $n_1$ wheel position sensors and support rollers $n_1$ and $n_2$.

The wheel rolling radius $r_{k01}$ on the front support roller and the wheel rolling radius $r_{k02}$ on the rear support roller can be calculated as follows:

\[ r_{k01} = \frac{r_p \cdot n_1}{n_k}; \tag{1} \]

\[ r_{k02} = \frac{r_p \cdot n_2}{n_k}; \tag{2} \]

where $r_p$ is the radius of the support roller, m; $n_1$ = number of pulses from the front roller speed sensor; $n_2$ = number of pulses from the rear roller speed sensor; $n_k$ = number of pulses from the wheel speed sensor.

3. Results and discussion

The obtained values of the radii $r_{k01}$ and $r_{k02}$ of the car wheel rolling in the driven mode without displacement $a$ relative to the support rollers with a change in the load on the wheel $G_k$ and varying the tire air pressure $p_t$ are shown in Figure 2.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure2.png}
\caption{Dependence of the wheel rolling radii $r_{k01}$ and $r_{k02}$ in the driven mode on the normal load on the wheel $G_k$ and variation of the tire air pressure $p_t$ without displacement relative to the support rollers of the tester ($a=0$ mm): $\square$ ○ $\times$ $\Delta$ – experimental values; $-\cdots$ – calculated values.}
\end{figure}

The graph shows (Figure 2) that radii $r_{k01}$ and $r_{k02}$ obtained by rolling the wheel without displacement on the two support rollers of the tester do not differ from each other, respectively, in this case, their values will be the same. However, when the tire air pressure $p_t$ reduces, the values of the radii are also reduced.

When the wheel displacement is placed towards the rear support roller at a distance of 15 mm (Figure 1), one can observe a difference in the values of the radii $r_{k01}$ and $r_{k02}$ of wheel rolling in the driven mode relative to the front and rear support rollers (Figure 3 and Figure 4).
Figure 3. Dependence of the wheel rolling radius \( r_{k01} \) in the driven mode on the front roller on the normal load on the wheel \( G_k \) and variation of the tire air pressure \( p_t \) with the wheel displacement relative to the support rollers of the tester in the direction of the rear roller \((a=-15 \text{ mm})\): □○◊×Δ – experimental values; --- – calculated values.

Figure 4. Dependence of the wheel rolling radius \( r_{k02} \) in the driven mode on the rear roller on the normal load on the wheel \( G_k \) and variation of the tire air pressure \( p_t \) with the wheel displacement relative to the support rollers of the tester in the direction of the rear roller \((a=-15 \text{ mm})\): □○◊×Δ – experimental values; --- – calculated values.

4. Analysis

The analysis of figures 3 and 4 shows that when the wheel is displaced towards the rear support roller, the values of the wheel rolling radius \( r_{k01} \) on the front roller increase and the values of the radius \( r_{k02} \) on the rear roller decrease.

Displacement of the wheel towards the front support roller at a distance of 15 mm (Figure 1) increases the values of the radius \( r_{k02} \) rolling wheel on the rear roller and decreases the values of the radius \( r_{k01} \) on the front roller (Figure 5 and Figure 6).

Analysis of dependencies presented in Figures 3, 4, 5 and 6 shows that the wheel rolling radius \( r_{k01} \) on the front roller with the displacement of the wheel in the direction of the front roller \((a = 15 \text{ mm})\) varies with normal load \( G_k \) and the tire air pressure \( p_t \) in much the same way as the \( r_{k02} \) rolling wheels on the rear roller under the same conditions with the displacement of the wheels towards the rear roller \((a = 15 \text{ mm})\). Change of the wheel rolling radius \( r_{k01} \) on the front roller with the displacement of the wheels towards the rear roller \((a = 15 \text{ mm})\) also corresponds to the variation of the wheel rolling radius \( r_{k02} \) on the rear roller with the displacement of the wheel toward the front of the roller tester \((a = 15 \text{ mm})\).
Dependencies (Figures 2–6) of the wheel rolling radii $r_{k01}$ and $r_{k02}$ in the driven mode on the normal load on the wheel $G_k$ and varying the tire air pressure $p_t$, without displacement relative to the support rollers of the tester ($a=0$) was approximated by the formula:

$$r_{k0i} = r_i - G_k^{ag} \cdot \frac{a_p}{p_t} \left(1 - \frac{a}{a_a}\right)$$  \hspace{1cm} (3)

where $r_f$ is the free radius of the wheel, m; $G_k$ = normal wheel load, N; $p_t$ = tire air pressure, MPa; $a$ – the wheel displacement relative to the axis of symmetry of the support rollers, m; $a_G$ – coefficient characterizing the change of the wheel rolling radius $r_{k0}$ when the normal load is $G_k$, $a_G = 0.6$; $a_p$ – coefficient characterizing the change of the wheel rolling radius $r_{k0}$ when the tire air pressure is $p_t$, $a_p = 0.00018$; $a_a$ – coefficient characterizing the change of the wheel rolling radius $r_{k0}$ when the displacement of the wheel relative to the axis of symmetry of the support rollers $a$, $a_a = 110$. 

**Figure 5.** Dependence of the wheel rolling radius $r_{k01}$ in the driven mode on the front roller on the normal load on the wheel $G_k$ and variation of the tire air pressure $p_t$ with the wheel displacement relative to the support rollers of the tester in the direction of the front roller ($a=15$ mm): □○◊×Δ – experimental values; --- – calculated values.

**Figure 6.** Dependence of the wheel rolling radius $r_{k02}$ in the driven mode on the rear roller on the normal load on the wheel $G_k$ and variation of the tire air pressure $p_t$ with the wheel displacement relative to the support rollers of the tester in the direction of the front roller ($a=15$ mm): □○◊×Δ – experimental values; --- – calculated values.
The displacement of wheel \( a \) obtained in equation (3) is taken into account in such a way that when the wheel is displaced towards the front roller, the displacement value is set above zero \((a>0)\). When the wheel is displaced towards the rear roller, the offset value is set below zero \((a<0)\). The calculated values of the rolling radii are also shown in Figures 2-6.

5. Conclusion
From the results obtained, the following conclusions are drawn:

1) Changes of the tire air pressure change of the wheel rolling radii \( r_{k01} \) and \( r_{k02} \) in the driven mode. In this case, the difference between the wheel rolling radii \( r_{k01} \) and \( r_{k02} \) in the driven mode at a pressure of \( p_t = 2.3 \) MPa and \( p_r = 1.5 \) MPa can reach up to 3%.

2) When the wheel is displaced in the longitudinal direction relative to the support rollers of the tester, there is a significant change in the wheel rolling radii \( r_{k01} \) and \( r_{k02} \) in the driven mode. Due to the movement of the wheel the difference between the wheel rolling radii \( r_{k01} \) and \( r_{k02} \) in the driven mode can vary up to 6.5%.

3) The change of the wheel rolling radii \( r_{k01} \) and \( r_{k02} \) in the driven mode may cause the kinematic mismatch forming a wheel slip relative to the front and rear support rollers of the tester in the process of controlling car traction qualities.

4) The coefficients \( a_0 \), \( a_p \) and \( a_s \) obtained as a result of the approximation allow to perform calculations of the wheel rolling radii \( r_{k01} \) and \( r_{k02} \) on two cylindrical bearing surfaces taking into account the displacement of the wheel \( a \) and the tire air pressure \( p_t \).

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