Analysis of contact parameters of large tires with soil for earthmoving machinery

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Abstract. The article demonstrates the equations for finding the contact width parameters of a large tire with a deformable support surface, such as the radius and angle of the sidewall arc, the sidewall width in the contact area, the track width under the wheel center and at any point of contact. For some large-size tires, the paper discovers graphical dependences of the track width at any point of contact on the internal tire pressure, the vertical wheel load and the tire structure. The authors analyzed the results of these dependencies.

1. Introduction
Earth-moving machines (EMM) separate the soil from the massif and move it. They are equipped not only with a powerful working body, but also with transport running equipment (bulldozers, scrapers, motor graders) [1].

The EMM uses two types of undercarriage equipment: wheeled and crawlers. Wheeled vehicles have several advantages relative to crawlers, namely: high resource; the possibility of developing high transport speeds; significant reduction in metal construction, operating costs, etc. In addition, when relocating, wheeled equipment allows the car to move via public roads.

The parameters of the contact of the wheel propulsion (WP) with the supporting surface determine the main characteristics of the EMM operation such as traction force, rolling resistance, performance and fuel efficiency [2].

Works [3, 4] confirm that the questions of studying the width of a tire profile on the ground are relevant, since EMM during the operation mainly move on soils of different strength. In this regard, the following method was developed to determine the width of the EMM tire profile when driving on the ground [5].

2. The main part
We took the model described in [3, 6, 7] as a basis and made the following assumptions: the wheel moves with constant linear $V_{wp}$ and angular $\omega_K$ speed along a straight-line trajectory; the pneumatic tire is deformed in the radial direction (only those of its elements that are within the contact area $nm$ (Figure 1)); a wheel with a pneumatic tire is represented: outside the contact area, in the form of a cylinder with
a width of \( B_p \) with radius \( r_0 \), in the contact area with associated cylinders with radiuses \( R_1 \) and \( R_2 \) (\( R_2 > R_1 \)), whose centers are located on a vertical axis passing through the center of rotation of the wheel.

**Figure 1.** Diagram of the interaction of the wheel propulsion with a deforming support surface.

Total soil deformation \( h \) can be determined by the formula:

\[
h_{hl} = \frac{a_1^2}{2r_0} \left( \frac{K_1}{C_1 + K_1} \right),
\]

where \( a_1 \) – the length of the loading area of the contact area; \( r_0 \) – the radius of the undeformed tire; \( K_1 \) – the deformation coefficient of the pneumatic tire during compression; \( C_1 \) – the coefficient of complete deformation of the soil.

The amount of soil deformation at any point of contact \( z_p(x) \) is determined from the expression:

\[
z_p(x) = h_{hl} - \frac{x^2}{2R_i},
\]

where \( x \) – the current value of the coordinate of the point \( \xi \); \( R_i \) – is the current value of the radius in the contact area (in the loading zone \( R_i = R_1 \), in the unload zone \( R_i = R_2 \)).

Expressions for determining these values depending on the value of the variable \( x \) in the contact area are presented in the source [5].

Side wall arc angle is:

\[
\alpha_{\xi}(x) = 2 \sqrt{6 \left[ 1 - \frac{2H_{\xi}(x)}{U - B_{\text{tp}}} \right]},
\]

where \( H_{\xi}(x) \) – tire profile height at the point \( \xi \) (Figure 1).

The radius of the side wall is:

\[
r_{\xi}(x) = \frac{U - B_{\text{tp}}}{2\alpha_{\xi}(x)}.
\]
Sidewall width in the contact zone:

\[ b_{h\xi}(x) = r_{h\xi}(x) \left[ 1 - \cos \left( \frac{\alpha_{h\xi}(x)}{2} \right) - \frac{1}{2} \left( \sin \left( \frac{\alpha_{h\xi}(x)}{2} \right) - \frac{z_1(x)}{r_{h\xi}(x)} \right)^2 \right] \]

Track width at any point of contact:

\[ B_{K\xi}(x) = B_{HP} + 2b_{h\xi}(x) \]  

Using this technique, we got graphical dependences of the track width \( B_{K\xi}(x) \) on the value of variable \( x \) for tire of 16.00-24 model YA-140 (static modulus of total deformation of soil \( E_1 = 5 \) MPa, internal tire pressure \( P_\omega = 0.3 \) MPa, vertical load on the wheel \( G_K = 45 \) kN) (Figure 2).

![Figure 2. The dependence of the width of the gauge on the value of the variable \( x \) for tires of 16.00-24 YA-140 model.](image)

When the tire comes into contact with the supporting surface (Figure 2), the track width increases from the value of the tread width to the maximum value under the center of the wheel. Having passed the center, the width of the track begins to decrease to the value at point \( a_3 \), at which the tire comes out of contact with the supporting surface. The difference between the width of the contact \( B_{K\xi}(x) \) and the width of the tread \( B_t \) for tires 16.00-24 on loose soil at \( x = 0 \) is 24.8%, and at \( x = a_3 \) is 13.7%.

According to this method, we received the graphical dependences of the effect of the internal pressure in the tire (Figure 3), the vertical load on the wheel (Figure 4) and the design of the tire (Figure 5) on the gauge width.
Figure 3. The dependence of the internal pressure in the tire 21.00-28 mod. DF-27 on loose soil:
1 – \( P_\omega = 0.4 \) MPa, 2 – \( P_\omega = 0.3 \) MPa, 3 – \( P_\omega = 0.2 \) MPa.

Figure 4. The dependence of the vertical load on the wheel 21.00-28 mod. DF-27:
1 - \( G_K = 15 \) kN, 2 - \( G_K = 50 \) kN, 3 - \( G_K = 85 \) kN.
5

Figure 5. Dependence of the tire design 18.00-25 mod. F-27 on loose soil:
1 - diagonal tire, 2 - radial tire.

After analyzing the presented graphical dependencies, we can draw the following conclusions. A decrease in the internal pressure in the tire \( P_\omega \) from 0.4 to 0.2 MPa (Figure 3) leads to an increase in \( B_\kappa(x) \) at \( x = 0 \) by 7.8%. When the vertical load on the wheel decreases from 85 to 15 kN (Figure 4), the \( B_\kappa(x) \) decreases by 14.4% at \( x = 0 \) and decreases by 12% at \( x = a_3 \). The value of \( B_\kappa(x) \) in the diagonal construction is smaller than the radial one (Figure 5) at \( x = 0 \) by 7.2%, and at \( x = a_3 \) by 2.8%.

3. Conclusion
The parameters of the contact area of a large-sized tire with the soil affect the basic characteristics of the WP EMM, therefore it is necessary to determine and take into account the width of the contact, and it is necessary to conduct experimental studies [8-10] to confirm the dependencies that were obtained analytically.

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