Determination of the moment of resistance to turning of a forestry articulated machine

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Abstract. This article considers the calculation of the moment of resistance to turn off a wood articulated machine. The total moment is determined from the sum of the moment of resistance to turning the tire in place, the moment that occurs when the ground is cut off by the side surface of the tire, the moment of resistance to rolling the wheel.

1. Introduction

The initial parameter for calculating the articulated frame is the moment of resistance to mutual turn of the links. For the calculation, it is necessary to consider the turn from a static position, since in this case resistance to turn is maximum. The calculation scheme is shown in figure 1.

Figure 1. Calculation scheme for determining the moment of resistance to rotation.
In Figure 1: \( B \) – track of the designed machine, m; \( L_{q} \) – distance between the wheels of the balancing cart, m; \( a, b \) – respectively, the longitudinal and transverse axis of the tire contact patch, reduced to an equal rectangle, m; \( l_{1}, l_{2} \) – distances, respectively, of the first and second links from the axis of the vertical hinge of the articulated module assembly to the axis of the tandem bridge.

Moment for the implementation of the relative turn of the links, \( N \cdot m \) [1-4]:

\[
T_{\text{comp} \Sigma} = T_{\text{comp} 1} + \frac{\left(T_{\text{comp} 2} - T_{\text{comp} 1}\right) \cdot l_{1}}{l_{1} + l_{2}}
\]

where \( T_{\text{comp} 1}, T_{\text{comp} 2} \) – moments of resistance to turn of the first and second modules, respectively, \( N \cdot m \).

When the module is turned, the wheel performs a complex movement, which can be represented as the sum of two movements: turning the wheel in place and rolling the wheel. Thus, the moment of resistance to turn of the \( n \)-module is equal to, \( N \cdot m \):

\[
T_{\text{comp} n} = M_{\text{tr} n} + M_{\text{cp} n} + M_{k n}
\]

where \( M_{\text{tr}} \) – is the moment of resistance to turn the tire in place, \( N \cdot m \); \( M_{\text{cp}} \) – the moment arising when cutting off the soil by the side surface of the tire, if the module is in the track, \( N \cdot m \); \( M_{k} \) – is the moment of resistance to wheel rolling, \( N \cdot m \).

To determine the moment of resistance to turning the tire on the spot, let us assume that the coefficient of adhesion \( \varphi \) and specific pressures at each point of the tire print with the supporting surface are the same. We will take into account that the wheel axis is located parallel to the reference surface perpendicular to the longitudinal axis of the module.

2. The moment of resistance to turn the tire in place
The car is equipped with diagonal low-profile tires, so the contact spot of the tire with the support surface will have the shape of a rectangle. To determine the size of the contact spot, we use the calculation scheme (Figure 2).

![Figure 2](image)  
**Figure 2.** Calculation scheme for determining the tire contact spot

Figure 2 shows: \( b_{w} = b \) – width of the tire profile; \( r \) – radius of the tire; \( G_{k} \) – weight per wheel of the module; \( h_{z} \) – deflection of the tire. The deflection of the \( n \)-module tire is determined by the formula, m:
where \( K \) – is the empirical coefficient; \( p_w \) – is the tire pressure, kPa.

We determine the value of the coefficient \( K \), knowing the load carrying capacity \( G_w \) and the radius under static load \( r_0 \):

\[
K = \frac{(r_{cr} - r_0) \cdot (1 + p_w)}{G^{3/4}_w}
\]

Calculation of the length of the longitudinal axis of the contact patch of the n-module tire, m:

\[
a_n = 2 \cdot \sqrt{r^2 - (r - h_{xn})^2}.
\]

Let’s determine the pole of the tire turn. Let’s select an elementary area with sides \( dx \) and \( dy \) on the contact spot ab (Fig. 3).

\[
dF_{mpy} = dF_{yp} = \frac{G_k \cdot \varphi}{a_n \cdot b_n} \ dx \ dy.
\]

The projection of the elementary frictional force on the AX axis is equal to:

\[
dF_{mpx} = \frac{G_k \cdot \cos \beta}{a_n \cdot b_n} \ dx \ dy; \ \cos \beta = \frac{y}{\sqrt{y^2 + x^2}}.
\]
The projection of the elementary friction force on the axis will take the form AX:

\[ dF_{\text{trp}} = g_{k,n} \cdot \varphi \cdot \frac{g_1}{\sqrt{y^2 + x^2}} \ dx \ dy. \]

\( dF_{\text{trp}} \) will tend to rotate the wheel about its axis. Thus, when turning the wheel in place, the turning pole will be at the intersection of the projection of the wheel axis on the support surface and the direction of action of the projection of the resultant friction force in the contact spot when turning the tandem bridge. Formula for determining the Y turn pole coordinate:

\[ Y = \int \int y \ dF_{\text{trp}} = \int y \ \int x \ \frac{y^2}{\sqrt{y^2 + x^2}} \ dx \ dy \]

The center of the tire contact spot is determined by the coordinates \((L_a/2; B/2)\). As a consequence, the limits of integration of \(y_1, y_2, x_1, x_2\) can be represented as:

\[ x_1 = \frac{L_a - a_n}{2}; \ x_2 = \frac{L_a + a_n}{2}; \ y_1 = \frac{B - b_n}{2}; \ y_2 = \frac{B - b_n}{2} \]

Let's determine the moment of resistance to turning the tire in place. The calculation scheme is shown in (Fig. 4), where O is the pole of turning the tire in place.

![Figure 4](image)

**Figure 4.** Calculation scheme for determining the moment of resistance to turning the tire in place

Contact tire boundary coordinates \(u_1, u_2, v_1, v_2\) are defined as:

\[ u_1 = \frac{-a_n}{2}; \ u_2 = \frac{a_n}{2}; \ v_1 = \frac{B + b}{2} - Y; \ v_2 = \frac{B - b}{2} - Y. \]

Resistance to turning the tire in place: \(dM_{\text{trp}} = dF_{\text{trp}} \cdot w;\)

\[ dF_{\text{trp}} = dG_{k,n} \cdot \varphi = \frac{G_{k,n} \cdot \varphi}{a_n \cdot b_n} \ du \ dv. \]
Arm of the moment: $w = \sqrt{u^2 + v^2}$. Substitution:

$$dM_{tr n} = G_{k n} \frac{\varphi}{a_n \cdot b_n} \cdot \sqrt{u^2 + v^2} du dv.$$

Module frictional moment:

$$M_{tr n} = 4 \cdot \int_{v_1}^{v_2} \int_{u_1}^{u_2} G_{k n} \frac{\varphi}{a_n \cdot b_n} \cdot \sqrt{u^2 + v^2} du dv.$$

Let’s determine the moment that occurs when the soil is cut by the side surface of the tire (Fig. 5).

The depth on the drag can be equal to the clearance. However, on the drag, the turn is made in motion. Turning in place occurs when loading assortments, where the track size is determined by the deformation of the soil under the tire of the machine during a single pass and depends on the tire pressure on the soil and the strength properties of the soil. On drained soils with a single pass, the depth of the track does not exceed 5 cm [4-8].

The depth of the formed track, m: $h_{\text{колеи}} = 2,2 \cdot \frac{1 - \mu_{n.p}^2 \cdot \sigma_s}{E} \mu_{n.p}$, where $\mu_{n.p}$ – is the modulus of longitudinal expansion of the soil; $E$ – is the modulus of soil deformation, Pa.

Contact area of the tire with the track, m$^2$: $S_{k} = \frac{r^2}{2} \left( \left( \frac{\pi \cdot j}{180} - \sin j \right) - \left( \frac{\pi \cdot e}{180} - \sin e \right) \right)$,

where $j = 2 \cdot \arccos \frac{r - h_{\text{колои}} - h_{k,n}}{r}$; $e = 2 \cdot \arccos \frac{r - h_{k,n}}{r}$.

The moment that occurs when the ground is cut off by the side surface of the tire, $N \cdot m$:

$$M_{cp n} = T_{\text{сопр}} \cdot \mu_\theta \cdot \tan \lambda + C_0 \cdot \lambda \cdot \mu_\theta \cdot 4 \cdot S_{k,n},$$

where $\mu_\theta = 0,4 ... 0,9$ – depends on the type of surface [8-10]; $C_0, \lambda$ – strength parameters of the deformable surface, depending on the soil consistency index.

Wheel rolling resistance moment, $N \cdot m$:

$$M_{k n} = 2 \cdot G_{k n} \cdot f \cdot B$$

where $f$ – is the rolling resistance coefficient.

Figure 5. Calculation scheme for determining the track
As a result, we obtain a system of two equations:

\[
\begin{align*}
M_{cp,n} &= T_{comp_n} \cdot \mu_0 \cdot \tan \lambda + C_0 \cdot l_n \cdot \mu_0 \cdot 4 \cdot S_{kn}; \\
T_{comp_n} &= M_{tr,n} + M_{cp,n} + M_{kn}.
\end{align*}
\]

Let's determine the end formula:

\[
T_{comp_n} = \frac{M_{tr,n} + M_{kn} + 4 \cdot C_0 \cdot l_n \cdot \mu_0 \cdot S_{kn}}{1 - \mu_0 \cdot \tan \lambda}.
\]

3. Conclusion

A formula for determining the moment of resistance to turn of the module is derived and calculation schemes and formulas for determining the depth of the track depending on the type of surface are proposed.

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