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THE STUDY OF THE SLOPE MOVEMENT OF A FOUR-WHEELED TRACTOR

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Abstract—The article describes the features of the slope movement of a four-wheeled tractor. The reaction of the tractor in relation to the ground, taking into account the masses that fall on the front and rear wheels of the tractor, the weight and strength of the resistance were calculated, as well as the crushing of the wheel when moving along the slope were analyzed.

Keywords— four-wheel tractor, slope, deformation, wheel motion, elastic wheel, reactive moment, wheel crushing, unstabilized wheel, wheel rolling on a slope.

I INTRODUCTION

When a wheel (rigid or elastic) is rolling on a slope (on a deformable or non-deformable surface), the unstabilized and stabilized wheels are rolling. An example of rolling of an unstable wheel can be the rolling of the wheels of a conventional flat or low-gradient tractor, when the longitudinal plane of the wheel is located normally to the surface and under an angle of 90° - α to the horizontal plane (Figure 1a).

Where:
a - rolling of a wheel located normal to the surface and at an angle 90° - α to the horizontal plane
b- movement of the wheel in a vertical position relative to the horizontal plane
$M_{skeleton}$ -reactive moment from the weight of the tractor frame
b - wheel width
b_α -when a stabilized wheel rolls on a slope, the surface of the contact patch is not only distorted in shape, but also decreases in width by an amount
r_{da} - dynamic radius of an unstabilized wheel when rolling on a slope
$R_z = G_z$ - the constituent reaction of the soil prevents the wheel from sliding under the influence of the constituent load
$R_y = G_y$ - the component of the soil reaction normal to the surface perceives the load
e -the point of application of the resultant soil reactions is shifted by an amount from the longitudinal plane of symmetry of the wheel
α - in this case, the longitudinal plane of the wheel is always perpendicular to the horizontal within certain limits of the slope angle and forms an angle with the surface.

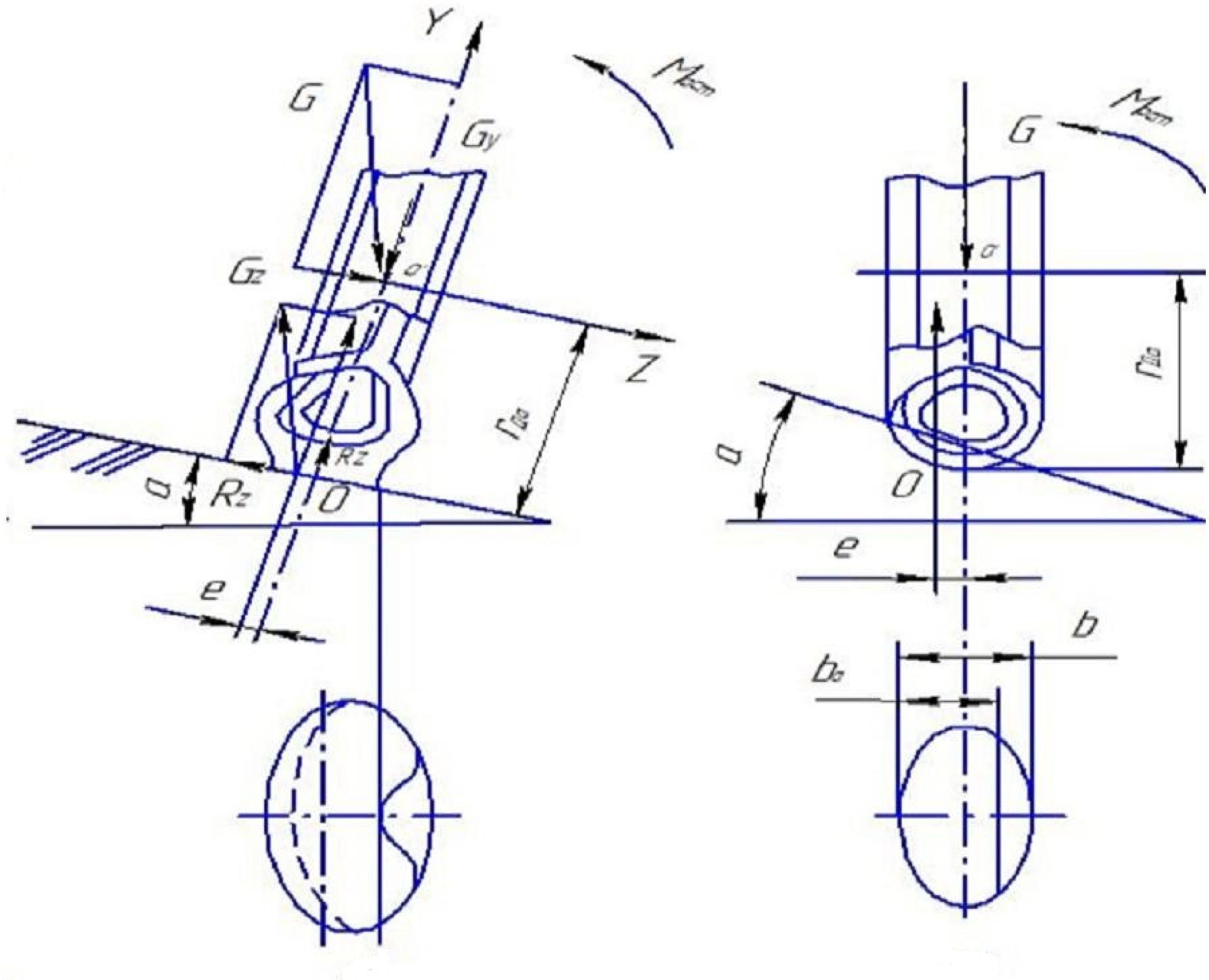
Stabilization of the wheel on the slope is understood as moving it in the transverse plane until the tractor frame is installed in a vertical position relative to the horizontal plane (Figure 1b). This includes rolling the wheels of a special steeply sloping tractor. In this case, the longitudinal plane of the wheel within certain limits of the slope angle is always perpendicular to the horizontal one and forms an angle of 90° - α with the surface. Wheel rolling in the stabilised mode is achieved by means of special stabilising devices installed on a steeply sloping tractor [1].

The performance of tractors can be divided into three main groups:

- characteristics of the tractor's adaptability to meet the technological requirements arising from the working conditions, or technological (agrotechnical);
- determining the productivity and efficiency of the unit, or technical and economic;
- ensuring the driver's comfort and safety, or General technical.

It should also be noted that due to the displacement of the resultant reaction of the soil *R* from the plane of symmetry of the wheel by the value *e* in addition to the tipping moment, there is a moment of withdrawal of the wheel $M_{withdrawal=X_e}$ acting in the plane XOZ' This moment, as well as the tipping moment, is balanced by the reactive moment from the weight of the tractor frame $M_{skeleton}$. The pullback moment causes the wheel to move sideways down the slope.

Since the value of soil reactions over the wheel width is not constant,



a) b)

Fig. 1: The generalized structure of a multi-coordinate motion module

$$R = \int_0^{\alpha_0} \int_0^{b} \sigma \cdot d\,A \tag{1}$$

where α_0 - angle of coverage of the contact surface of the wheel; it's value is variable for the width of the wheel, b - is the width of the wheels; $dA = r \cdot \; d\alpha \; dx$.

Based on the given values are calculated in the Python program [2, 3]. The radius of the front right and front left, back right and back left wheels, wheel swing relative to the plane of symmetry were considered the same.

II Results and discussion

$$s = 1.015; \alpha_0 = 0.348; \; k = 0.000000011;$$
$$\sigma = k \cdot \; s = 1.1164\text{e} - 08;$$

$$\text{R}_{front\_left} = \int_0^{\alpha_0} \int_0^{b} \sigma \cdot d\,A =$$
$$\int_0^{\alpha_0} \int_0^{b} \sigma \cdot r_{\delta front\_left} dadx =$$
$$\sigma \cdot r_{\delta front\_left} \cdot \alpha_0 \cdot b = 4.2603\text{e} - 10\; m$$

$$R_{front\ right} = 4.2603\text{e}-10\ m$$
$$R_{back\ left} = 7.7776\text{e}-10\ m$$
$$R_{back\ right} = 7.7776\text{e}-10\ m$$

Using the method for determining the resultant soil reactions that occur when a rigid driven wheel rolls over a horizontal deformable surface (rolling of the driven wheel), equation (2) for section I-I can be written as follows [1, 4]:

$$dX = dF_{resistances} = \frac{1}{2}k \cdot h_x^2 \cdot dx \qquad (2)$$

$$h = 0.78m; X = 0.5 \cdot k \cdot h^2 = 4.29\text{e}-9kg \cdot \frac{m}{s^2}$$

k-coefficient of volumetric crumpling of the soil, h_x-depth of the track, mm

$$dY = dG = k \cdot h_x \cdot \sqrt{2 \cdot r \cdot h_x} dx \qquad (3)$$

$$Y_{front\ right} = k \cdot h^2 \cdot \sqrt{2 \cdot r_{\delta front\_left} \cdot h} =$$
$$= 7.0272\text{e}-09\ kg \cdot \frac{m}{s^2};$$
$$Y_{front\ right} = 7.0272\text{e}-09\ kg \cdot \frac{m}{s^2};$$
$$Y_{back\ left} = 9.4947\text{e}-09\ kg \cdot \frac{m}{s^2};$$
$$Y_{back\ right} = 9.4947\text{e}-09\ kg \cdot \frac{m}{s^2}$$

where h_0=0 m; $x = 1.11\ m$; $\alpha = 20^0$; tgα= 0.363; $h_x = h_0 + x \cdot tg\alpha$; $h_x = 0.40293m$

Substituting the value of h_x in equations (2) and (3), we get $X = F$

$$X = F_{resistances} = \frac{1}{2} \cdot k \cdot \int_0^b (h_0 + x \cdot t\ g\alpha)^2 dx \qquad (4)$$

$$X = F_{resistances} = 2.2769\text{e}-10\ kg \cdot \frac{m}{s^2}$$

$$Y = G = k \cdot \int_0^b (h_0 + x \cdot tg\alpha)\sqrt{2 \cdot r_\delta \cdot (h_0 + x \cdot tg\alpha)} dx$$

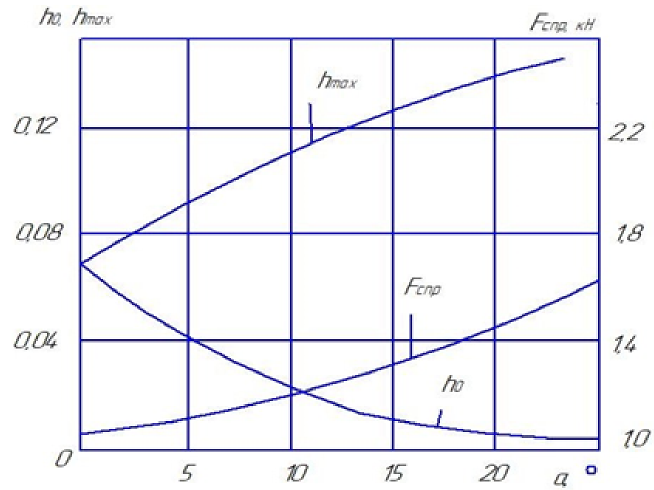


Fig. 2: Dependence of the rolling resistance of a rigid wheel on the slope angle

$$Y_{front\ left} = G_{front\ left} = k \cdot \int_0^b (h_0 + x \cdot tg\alpha)$$
$$\sqrt{2 \cdot r_{front\ left} \cdot (h_0 + x \cdot tg\alpha)} dx = 6.6531\text{e}-10\ kg \cdot \frac{m}{s^2};$$
$$Y_{front\ right} = G_{front\ left} = 6.6531e-10kg \cdot \frac{m}{s^2};$$
$$Y_{back\ left} = G_{back\ left} = 8.9893\text{e}-10\ kg \cdot \frac{m}{s^2};$$
$$Y_{back\ right} = G_{back\ right} = 8.9893\text{e}-10\ kg \cdot \frac{m}{s^2};$$

Solving equations (5) and (6) we find

$$F_{resistances} = \frac{1}{2}k \cdot b \cdot h_0^2 + \frac{1}{2}k \cdot h_0 \cdot b^2 \cdot tg\alpha + \frac{1}{6}k \cdot b^3 \cdot tg^2\alpha \qquad (5)$$

$$F_{resistances} = \frac{1}{2}k \cdot b \cdot h_0^2 + \frac{1}{2}k \cdot h_0 \cdot b^2 \cdot tg\alpha + \frac{1}{6}k \cdot b^3 \cdot tg^2\alpha =$$
$$4.0056\text{e}-12\ kg \cdot \frac{m}{s^2}$$

$$D = 1.57m$$

$$G = \frac{2}{5}\frac{k \cdot \sqrt{D}}{tg\alpha}\left[(h_0 + b \cdot t\ g\alpha)^{\frac{5}{2}} - h_0^{\frac{5}{2}}\right] \qquad (6)$$

$$G = \frac{2}{5}\frac{k \cdot \sqrt{D}}{tg\alpha}\left[(h_0 + b \cdot t\ g\alpha)^{\frac{5}{2}} - h_0^{\frac{5}{2}}\right] = 3.9592\text{e}-11\ kg \cdot \frac{m}{s^2}$$

By solving equations (6) and (7) together, it is possible to determine the rolling resistance force of the wheel $F_{resistances}$ on the slope due to the formation of a track, as well as the depth of the track h_0 and $h_{max}(h_{max} = h_0 + b \cdot tg\alpha_= 0.0925m$.

As can be seen from equations (6) and (7), the strength of the rolling resistance of a rigid wheel on a deformable slope surface depends, among other factors, on the angle of the slope. Figure 2 shows the dependence of the rolling resistance force of the wheel $F_{resistances}(D = 1.57m)$, due to the formation of a track, as well as the depth of the track h_0 and h_{max} on the angle of the slope when driving on a stubble loam, $k = 0.1 \cdot 10^7 \ \frac{kg}{s^2 \cdot m^2}$ by $G = const = 10000\ kg \cdot \frac{m}{s^2}$.

Figure 2 shows that at $\alpha = 0$ the track depth is 0.076 m, which corresponds to the horizontal rolling of this wheel. As the slope angle increases, the wheel's rolling resistance increases, and the maximum track depth also increases, while h_0 decreases. For $h_0 = 0$ and $b_\alpha = b$ formulas (6) and (7) have the following form:

$$F_{resistances} = \frac{1}{6}\frac{k}{tg\alpha} \cdot h_{max}^3 \tag{7}$$

$$F_{resistances} = \frac{1}{6}\frac{k}{tg\alpha} \cdot h_{max}^3 = 719.6344\frac{m}{s^2}$$

$$G = \frac{2}{5}\frac{k \cdot \sqrt{D}}{tg\alpha} \cdot h_{max}^{\frac{5}{2}} = 6349.5756 \ \frac{m}{s^2}$$

$$h_{max} = \sqrt[5]{(\frac{5}{2}\frac{G \cdot tg\alpha}{k \cdot \sqrt{D}})^2} \tag{8}$$

$$h_{max} = \sqrt[5]{(\frac{5}{2}\frac{G \cdot tg\alpha}{k \cdot \sqrt{D}})^2} = 0.1161\text{m}$$

Substituting the h_{max} values from formula (4) into formula (8), we get

$$F_{resistances} = \frac{1}{6}k \cdot \ b_\alpha \cdot (\frac{5}{2}\frac{G \cdot t\ g\alpha}{k \cdot \sqrt{D}})^{\frac{4}{5}} = 719.6344\ kg \cdot \frac{m}{s^2};$$

$$F_{resistances} = \frac{5}{12} \cdot \sqrt[5]{\frac{5}{2}\frac{G^6 \cdot tg\alpha}{k \cdot D^3}} = 445485.3202\ kg \cdot \frac{m}{s^2};$$

Because $b_\alpha = \frac{h_{max}}{tg\alpha} = 0.3199$.

When rolling the driven elastic stabilized wheel on the deformable surface of the slope, other than the rolling resistance forces due to the formation of a track, it is necessary to take into account the loss of energy for normal and tangential deformation of the tire. Therefore, the formulas for determining the rolling resistance of an elastic wheel on a slope in the driven mode have the form [5, 6]: by $b_\alpha = b$, $B = 7$:

$$F_{resistances} = \frac{1}{2}k \cdot \ b \cdot \ h_0^2 + \frac{1}{2}k \cdot h_0 \cdot b^2 \cdot \ tg\alpha + \frac{1}{6}k \cdot b^3 \cdot \ tg^2\alpha + B \cdot \sqrt[3]{\frac{G^4}{\rho \cdot D_{np}^2}} \tag{9}$$

$$F_{resistances} = \frac{1}{2}k \cdot \ b \cdot \ h_0^2 + \frac{1}{2}k \cdot h_0 \cdot b^2 \cdot \ tg\alpha + \frac{1}{6}k \cdot b^3 \cdot \ tg^2\alpha + \\ + B \cdot \sqrt[3]{\frac{G^4}{\rho \cdot D_{np}^2}} = 129805.6835kg \cdot \frac{m}{S^2};$$

$$G = \frac{2}{5}\frac{k \cdot \sqrt{D}}{tg\alpha}\left[(h_0 + b \cdot t\ g\alpha)^{\frac{5}{2}} + h_0^{\frac{5}{2}}\right] = 6349.5756kg \cdot \frac{m}{s^2}$$

by $b_\alpha \prec b$ and $h_0 = 0$

$$F_{resistance} = \frac{5}{12}\sqrt[5]{\frac{5}{2}\frac{G^6 \cdot tg\alpha}{k \cdot D_{np}^2}} + B \cdot \sqrt[3]{\frac{G^4}{\rho \cdot D^2}} \tag{10}$$

$$F_{resistance} = \frac{5}{12}\sqrt[5]{\frac{5}{2}\frac{G^6 \cdot tg\alpha}{k \cdot D_{np}^2}} + B \cdot \sqrt[3]{\frac{G^4}{\rho \cdot D^2}} = 129831.7123kg\frac{m}{s^2}$$

$$h_{max} = \sqrt[5]{\frac{25}{4}\frac{G^2 \cdot tg^2\alpha}{k^2 \cdot D_{np}}} = 0.1161m$$

where D_{np}-is the diameter reduced to the rigid diameter of the elastic wheel.

III Conclusion

The movement of the tractor on the slope is indicated and calculated based on the data provided in the Python program. The resistance forces of the general form of tractor through the mass and radius falling on the wheel, through the mass falling on each wheel, are calculated in the Python program. The second figure shows a graph of the dependence of the rolling resistance of the hard wheel on the slope.

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