European Scholar Journal (ESJ)
Available Online at: https://www.scholarzest.com
Vol. 4 No.04, April 2023
ISSN: 2660-5562

TRANSVERSAL STABILITY OF A SPECIALIZED PORTAL TRACTOR UNDER CURVED LINEAR MOVEMENT

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Article history:

Received: 1st February 2023
Accepted: 1st March 2023
Published: 3rd March 2023

Abstract:

The article provides an analysis of the work on the study of the criteria for assessing the safety of portal high-clearance tractors. Studied static and dynamic agility high clearance tractor. An assessment of the safety of the operation of a tractor for horticulture and viticulture is given in terms of the limiting angles of longitudinal and transverse stability, and in terms of critical speeds during curvilinear motion.

Keywords: stability, high-traction tractor, lifting, incline, clearance, sliding.

INTRODUCTION

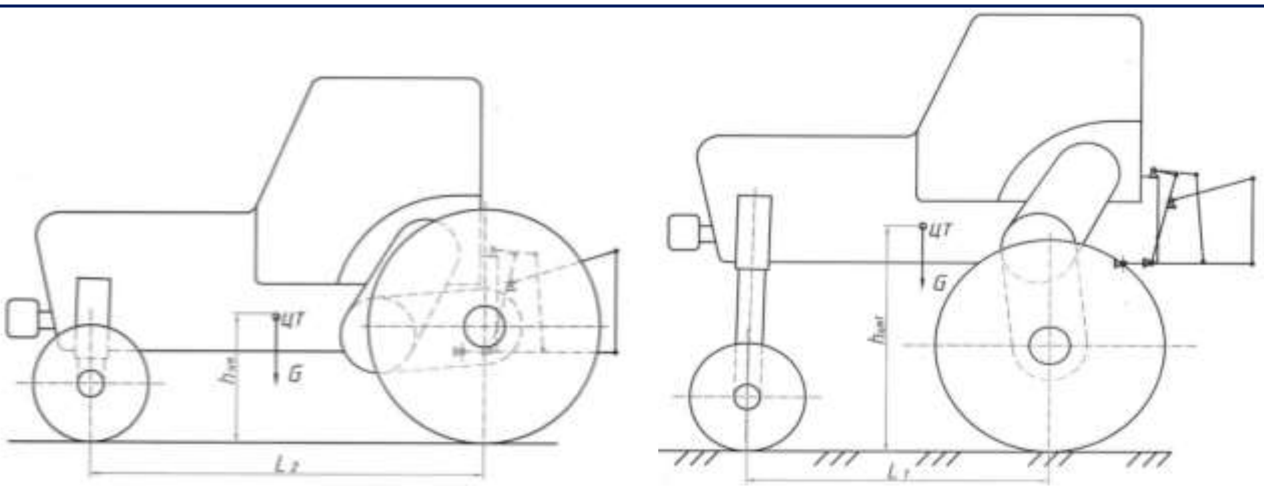
Uzbekistan is a major exporter of food, primarily fruits and vegetables, and over the past three years, the volume of exported agricultural products has increased by more than 3 times. This is largely facilitated by the fact that the area for orchards and vineyards in the country is expanding every year. However, without proper mechanization of fruit and grape cultivation, it is impossible to obtain high productivity, quality, and labor efficiency [1]. Traditional soil cultivation for orchards and vineyards often does not give the desired result, since with repeated passes the soil is not only loosened, but also compacted, its structure is destroyed. In such a situation, a specialized tractor for horticulture and viticulture, adapted to local conditions, which makes it possible to increase the level of mechanization in orchards and vineyards, which makes it possible to increase labor productivity in these industries. Substantiation and calculation of the parameters of the domestic horticultural and vineyard tractor and its creation is one of the urgent tasks in the process of complex mechanization of growing fruits and grapes [2] (Fig. 1).

Studies show that 75-85% of tractor rollovers occur sideways. As you know, a high-clearance tractor has a high center of gravity, with sharp turns and high loads, as well as at relatively high speed, it can tip over quite easily. Field of directions, tractor speed, turning radius, rear torque per axle, center of gravity are interrelated factors that determine the potential for tractor turnover (MyersM . L ., 2006) [3] .

To describe the dynamic behavior of the tractor rollover process, work [11] proposes active steering, which is widely used to prevent skidding and lane departure. An energy indicator of tractor stability has been obtained, which is used to determine the angle of rotation of the steering wheel to maintain stability. Studies have shown that active steering is effective when the tractor is moving on a medium class road surface, and the inclination angle of 15 ° and the speed of movement of 6 m/slowed down the stability limit of the tractor when active steering is on at an angle of inclination >15 ° active steering is not reliable enough to prevent the tractor from tipping over .

Thus, a review of the literature showed [3-1 1] what to the design of high-clearance agricultural tractors the following basic requirements are imposed: high stability in the transverse direction; stability when turning; resistance to sliding in the transverse direction of the slope; high permeability. It is also important to justify the speed and angle of the tractor, which significantly affect rollovers, as well as the coefficient of maximum adhesion, which is the main factor contributing to the slip of the tractor.

The Design and Technology Center for Agricultural Engineering has proposed the design of a portal high-clearance tractor. A distinctive feature of the projected portal tractor is the possibility of its readjustment for various operating conditions (Figures 1 *a*) and *b*) [1 2].



a) *b*)

a) low clearance option; *b*) high clearance option.

Figure 1 - General view of the concept diagram of the projected gantry tractor

METHODS

Stability can be compromised by tipping and sliding. Indicators of the transverse stability of the tractor are the maximum possible speeds around the circumference and the angles of the transverse slope of the road. Both indicators can be determined from the conditions of cross-slip of wheels (skidding) and overturning of the tractor [13] .

When analyzing the factors affecting stability, it is necessary to know the lateral force that causes the tractor to skid or tip over. When turning the tractor, this force is centrifugal force. To determine the centrifugal force, consider the diagram shown in Figure 2. Assume that the tractor is moving along a horizontal road, and the tires are not deformed in the transverse direction.

With uniform motion along an arc of constant radius, the centrifugal force

$$P_ц = m\omega^2 R_{ц.т} \qquad (1)$$

where $m$is the mass of the tractor, *kg* ; ω- angular velocity of rotation around the center of rotation, *rad/s* ; $R_{ц.т}$- turning radius to the center of gravity of the tractor, *m* .

$$\omega = \frac{v}{R}\ , \quad R_{ц.т} = \frac{R}{\cos\gamma}\ , \quad R = \frac{L}{tg\alpha} \approx \frac{L}{C}\ , \qquad (2)$$

where $R$is the turning radius of the tractor; γ- the angle between the radius $R_{ц.т}$and the continuation of the axis of the rear axle; α- the angle between the longitudinal axis of the tractor and the speed vector of the middle of the front axle when turning. This angle is equal to half the sum of the angles of rotation of the steered wheels. The loss of stability of the tractor is dangerous at high speed, when its movement is close to a straight line, while we can assume that $tg\alpha$.

Thus, the centrifugal force acting on the center of gravity of the tractor during its uniform movement along the arc of a circle$(R = const)$ has the form

$$P_ц = \frac{m\omega^2 \cdot R}{cos\gamma} = m\frac{v^2 C}{Lcos\gamma} \qquad (3)$$

Transverse component of centrifugal force

$$P_y = P_ц cos\gamma = \frac{mv^2\theta}{L} \qquad (4)$$

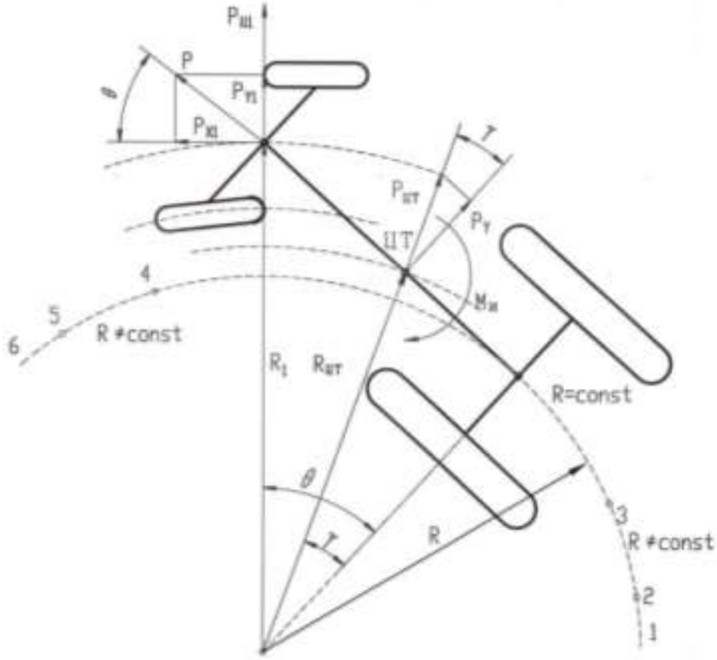


Figure 2 - Curvilinear movement of the tractor

When the tractor enters a turn, in addition to centrifugal force, other inertial forces also arise, since the transition from rectilinear motion to a steady curvilinear motion with a constant radius of curvature is accompanied by a continuous change in the position of the turning center, a decrease in the turning radius and a corresponding increase in the angular velocity of the tractor turn ω_n. For lateral stability, the circumstance is important that when entering a turn, the center of gravity of the machine rotates relative to the middle of the rear axle $O_2$with tangential acceleration dv/dt. As a result of this, a tangential force of inertia arises, $P_t$acting horizontally towards the center of gravity in the same direction as the central force$P'_ц$

$$P_t = m\frac{dv}{dt} = \left({}^{G}/_{g}\right)a\,d\omega_n/dt \ ,$$

where $a$is the longitudinal coordinate of the center of gravity (radius of relative rotation), $d\omega_n/dt$is the change in the angular velocity of the turn ω_n(in Figure 3 it is shown by a dashed line).
The tangential force of inertia depends, ceteris paribus, on the angular acceleration $d\omega_n/dt$, i.e. from a sharp turn, a sharp turn, especially at high speed, can lead to a significant increase in the total lateral force

$$P'_ц + P_t = \left({}^{G}/_{g}\right)\left({}^{v^2}/_{R}\right) + \left({}^{G}/_{g}\right)a\,d\omega_n/dt \ ,$$

tending to break the stability of the machine. When exiting the turn, the radius gradually increases, as a result of which the direction of acceleration $d\omega_n/dt$is opposite, and the tangential force of inertia$(G/g)a\,d\omega_n/dt$ must be subtracted from$P'_ц$.

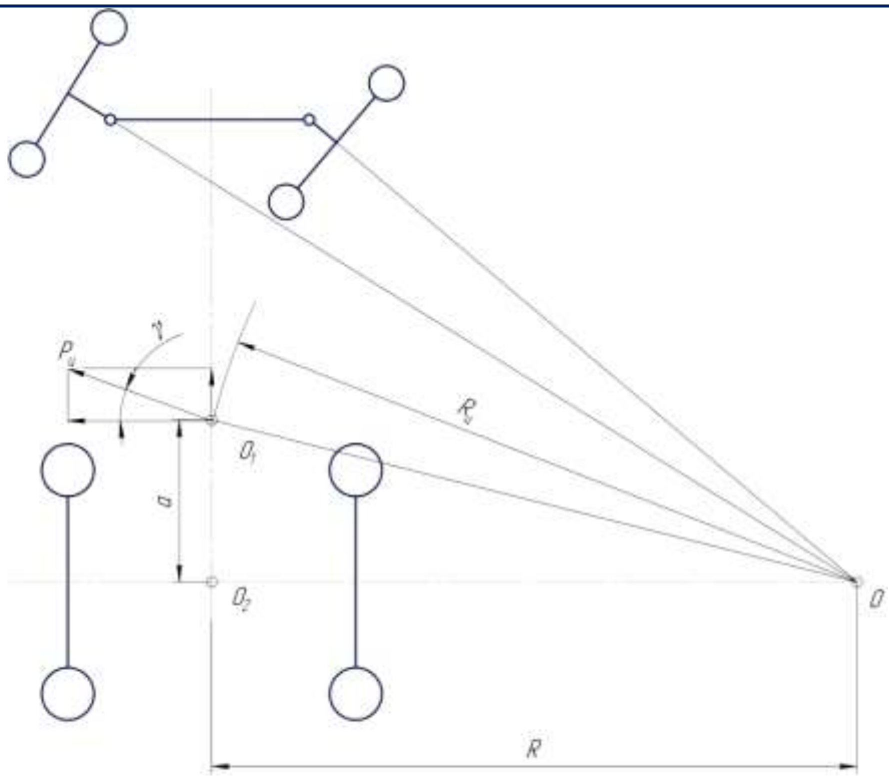


Figure 3 - Turning the tractor

As a result of turning the tractor around the center of gravity, an inertial moment arises$M_и$, proportional to the angular acceleration and moment of inertia of the tractor [14]

$$M_и = J_{тр} \cdot \frac{d\omega_n}{dt} .$$

Under the action of the moment, $M_и$the transverse reactions of the road are redistributed between the axles of the tractor, but usually the influence of this moment on the stability of the tractor is neglected due to its comparative smallness.

Let us determine the critical speeds of the tractor according to the conditions of overturning and skidding. Under the action of centrifugal force, $P_у$the tractor, when moving along a constant curve, Kcan tip over relative to the axis passing through the centers of contact of the tires of the outer wheels with the road. The equation of the moments of forces about this axis has the form

$$0{,}5GB - P_у h_ц = R_{zB} B , \quad (5)$$

where $R_{zB}$is the sum of the normal reactions of the road acting on the inner wheels of the tractor, *N* .

At the moment the tipping starts, the inner wheels of the tractor come off the road, and the sum $R_{zB} = 0$. Then

$$0{,}5GB = P_у h_ц, \quad (6)$$

Substituting relation (1) into (3), and bearing in mind (2), we obtain an expression for the critical velocity under the overturning conditions (*m/s*)

$$v_0 = \sqrt{BLg/2h_{цC}} = \sqrt{BRg/2h_ц} \quad (7)$$

As a result of forceP_y the tires may start to slide along the road in the transverse direction. Sum of cross reactions$P_{ув}$ and $P_{ун}$the road is equal to the sum of the adhesion forces with the road of all tires of the tractor

$$R_{ув} + R_{ун} \leq G\varphi_y \leq P_y = {mv^2C}/{L}$$

Whereφ_y - the coefficient of transverse grip of tires with the road.
Hence the critical speed according to the slip conditions (м/с)

$$v_{кр} = \sqrt{L\varphi_y g/\theta} = \sqrt{Rg\varphi_y} . \quad (8)$$

With a sharp turn by the driver of the steered wheels, the tractor may also lose stability during rectilinear movement. The resulting centrifugal force can reach the value of the adhesion force of the tires to the road.

Assuming that the driver turns the steered wheels at a constant speed, we determine the time interval during which the centrifugal force increases to a dangerous limit. At the start of the slide

$$m\omega_{у.к}\,(v^2 t + v l_2)/L = G\varphi_{сц}\,.$$

Where is the time (sec)

$$t = \left(\frac{Lg\varphi_{сц}}{v\omega_{у.к}} - l_2\right)/v\,. \qquad (9)$$

If the tractor speed is high, then a sharp turn of the steered wheels will cause the tractor to skid for a short period of time, which is less than the driver's reaction time.

When the tractor is moving along a road with a transverse slope, loss of stability is possible due to the action of the transverse component of the tractor's gravity equal to $G\,sin\,\beta$(in Figure 3) . The equation of the moments of all forces about the axis passing through the centers of contact of the tires of the outer wheels with the road

$$Y_B B + G\,sin\,\beta\,h_ц = 0{,}5BG\,cos\,\beta\,.$$

At the moment of the beginning of the overturning of the tractor, the reaction $Y_B = 0$.

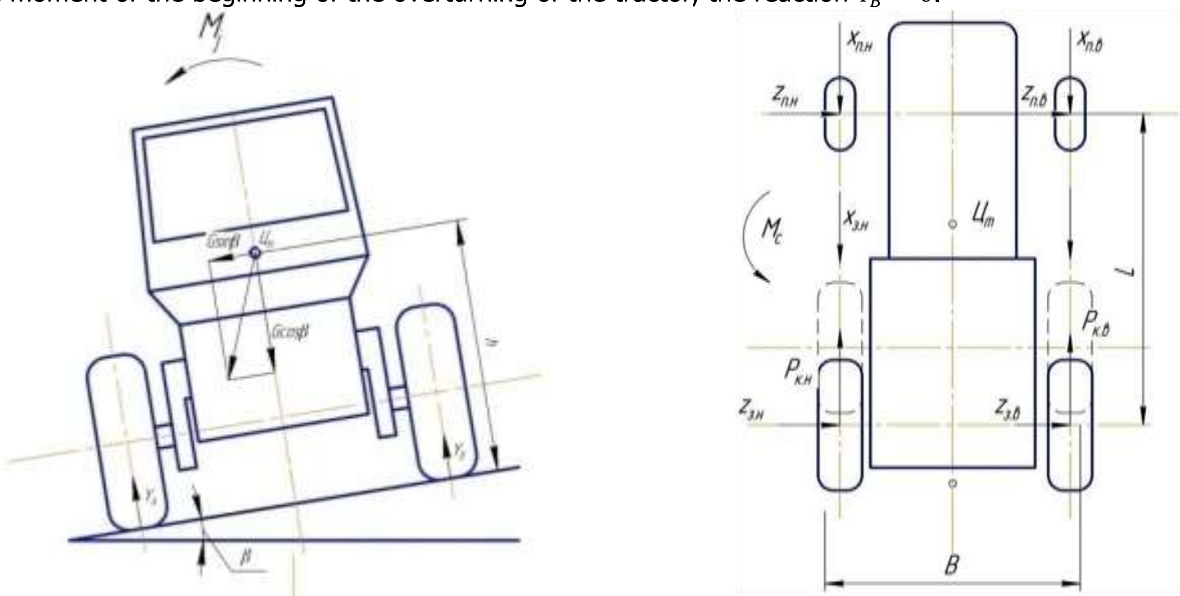


Figure 4. Scheme of forces acting on the tractor when it is working on a transverse slope

From here

$$tg\beta = B/2h_ц.$$

Critical slope angle for rollover conditions

$$\beta_0 = arctg\,(B/2h_ц)\,. \qquad (10)$$

The tractor's ability to resist rollover depends on the roll stability factor $\eta_{поп} = B/2h_ц$. Below are the average values of the coefficient of transverse stability and the corresponding angles $\beta_0$for tractors with various changes in the base and ground clearance.

The critical slope angle according to the skid conditions is determined by projecting all forces onto the road plane

$$G\,sin\,\beta = X_{пв} + X_{пн}\,.$$

According to the conditions of tire grip with the road, the sum of transverse reactions at the time of the start of the skid

$$G\,\sin(\beta_3) = Z_{yb} + Z_{yн} = G\,cos\,\beta_3 \cdot \varphi_{сц}\,.$$

Critical slope angle according to skid conditions

$$\beta_3 = arctg\varphi_{сц}. \qquad (11)$$

RESULTS

According to the proposed formulas, the indicators of transverse stability (maximum) critical speeds of movement of a specialized portal tractor, corresponding to the beginning of sliding and overturning, and critical angles of inclination, corresponding to the beginning of cross-slip of wheels and overturning, are determined; compiled tables 1, 2 and 3 of the average values of the roll coefficient and the corresponding angles β_0 and $\beta_3$for the projected specialized portal tractor TTZ 1033, taking into account changes in the longitudinal base $L$and track$B$ and vertical coordinates $h_{цт}$of the tractor.

Table 1

L(cm)	b(cm)	$h_{цт}$	a(cm)	b(cm)	$\varphi_{сц}$	$v_{кр.о}$(cm/sec)	$v_{кр.ск}$(cm/sec)	R (cm)
302.9 _	300	125.8	152.9	150	0.64	156.76	156.74	357.76
2 2 2.1	300	214.2	136.5	105.6	0.64	134.82	134.82	264.69

Table 2

L(cm)	b(cm)	a(cm)	b(cm)	$h_{цт}$(cm)	$\varphi_{сц}$	$\beta_{0.}$(deg.)	$\beta_{s.}$(deg.)	$\eta_{ном}$
30 2 , 9	300	149.99	152.9	125.8	0.76 _	35°	37°	0.7002
222.1	300	105.61	136.49	214.22	0.76 _	35°	37°	0.7002

Table 3

L(cm)	b(cm)	a(cm)	b(cm)	$h_{цт}$(cm)	$\varphi_{сц}$	$\beta_{0.}$(deg.)	$\beta_{s.}$(deg.)	$\eta_{ном}$
302 , 9	300	99.96	202.94	87.34	0.76 _	51°	37°	1.256
222.1	300	73.29	148.8	119.25	0.76 _	59°	37°	1.717

CONCLUSION

Studies show that 75-85% of rollovers occur sideways. In studies, sustainability assessment is based on three criteria:

a) "side slip criterion";

b) "tipping criterion";

c) general criterion

The critical stability values of the designed tractor are determined according to the criteria of "sliding" and "overturning". Mathematical models of static agility of a portal tractor for low and high clearance versions have been compiled. The values of critical speeds are determined when turning and when moving on a slope.

It has been established that an increase in the longitudinal base of the tractor during curvilinear motion leads to a decrease in lateral stability and the critical speed for overturning, while the critical angle under the conditions of skidding remains unchanged.

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