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# Modeling of the Force Action of the Propelling Device of the Machine-Tractor Aggregate on the Soil in Curvilinear Movement.

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**ABSTRACT**

The results of mathematical modeling of the mechanical impact on the soil of the tractor running system of class 2 as a part of the mounted combined unit are presented. The aim of the study was to determine the rational method of turning a universal tilled tractor on the turning strip. The objects of the study were the trajectories of the universal tractor motion, providing various ways of movement on the turning strip. The classic way of turning the tractor, only with the front driven wheels; Synchronic rotation of the front and rear wheels in different directions, the proposed method of turning the unit with the delay of the inclusion of the rear wheels on the rotating field strip with a simple no-loop rotation have been adopted for the comparison. As a result of the analysis it was revealed that the most rational way of the movement of the unit on the turning strip is the "crab” movement, followed by the transition to turn by the controlled wheels only, providing the lowest unit pressure on the soil, compared with the other methods of movement on the turning strip.
**Keywords**: mathematical modeling, mechanical impact, soil, tractor running system, synchronic rotation

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**INTRODUCTION**

When the tractor enters a turn, the steered wheels turn to make a maneuver. As a result, the wheels of the steer axle will move at an angle to the tractor axis. Depending on whether the steer wheels are driven or driving, different processes will occur while moving to the turn.

In case of the steer wheels on the driven axle the following situation will occur (Fig. 1). When the wheels turn to the angle $\alpha$ relative to the direction of movement of the wheel lateral force $P_б$, starts its action, which together with the force of rolling resistance of the wheels $P_{f\alpha}$ form a resistance force on the wheel $P_{F\alpha}$ the value of which is equal to [2, 6]:

$$P_{f\alpha} = \frac{P_f}{\cos\alpha} \quad (1)$$

An increase in the resistance to the movement of the tractor will lead to its deceleration and, as it was noted earlier, to the change in the axle load. The acceleration of the tractor or its change is caused by the force $\Delta P_f = P_{f\alpha} - P_f$, which is equal to:

$$\Delta P_f = P_f \cdot \left( \frac{1}{\cos\alpha} - 1 \right) \quad (2)$$

The greater the rolling resistance and the stronger the wheel is turned, the greater will be the resistance to the movement of the tractor.

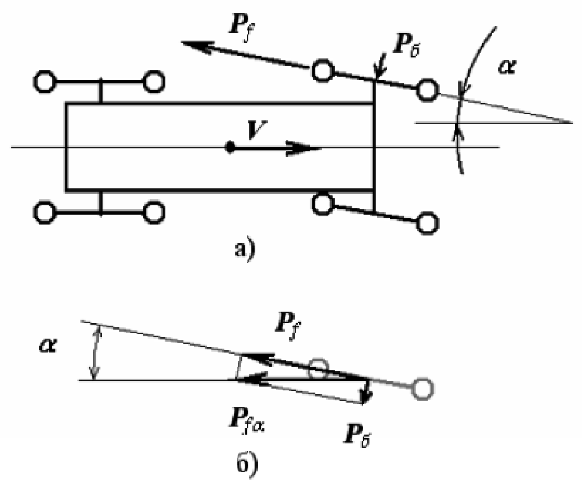


**Fig 1: The scheme of the tractor movement on the turn with the conducted steer wheels (a) and forces acting on the wheel (b).**

For the case of driven wheels on the drive axle the situation will be much different. Because of the wheels movement of the operated bridge at an angle to an axis of a tractor, at preservation of the movement speed of an axis of the operated wheel, speed of movement of the center of masses of a tractor will decrease. Reducing the speed of the center of mass will cause additional acceleration while the machine is moving. To find the magnitude of the occurring acceleration the scheme of the tractor movement with two steered axles on the turn presented on figure 2 should be considered [2].

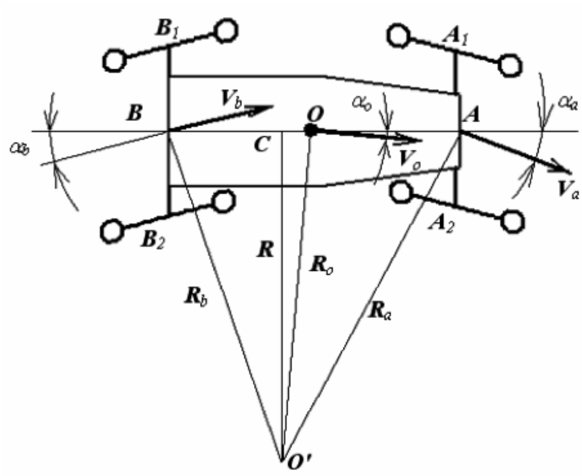


**Fig 2: The scheme of the tractor movement on the turn.**

While turning the tractor without removing the driven wheels, it will move relative to the instantaneous center of rotation of the *O′*. The center of the front axle moves along the radius $R_a$ at the speed $V_a$and the rear radius $R_b$at the speed $V_b$, and the center of mass on the radius $R_o$ at the speed $V_o$. In this case, the ratio $V_a /R_a = V_b /R_b= V_o/R_o$ is true. The relationship between the speed of the bridge and the center of mass is determined by the dependence of:

$$V_o = \frac{R_o}{R_a} \cdot V_a . \qquad (3)$$

The tangential acceleration of the center of mass will be equal to the derivative of the velocity Vo by time t determined from the expression:

$$\frac{dV_o}{dt} = V_a \cdot \frac{d\rho}{dt} + \rho \cdot \frac{dV_a}{dt} . \qquad (4)$$

The obtained dependence shows that when the tractor turns, its acceleration consists of two components: 1 – considering the change in the ratio of the radii of rotation of the center of mass and the front axis; 2 – considering the change in the module of the front axis speed.

Based on the above algorithm, the force action of the wheels of the tractor on the soil at the turn the calculation of forces for universal tractors of drawbar category 2 with all driving and driven wheels was made [2, 3].

Three variants of the unit movement at the turn: only with the front driven wheels, the front and rear wheels rotated in different directions and the trajectory of the unit at the "crab” turn without delay of switching on the rear driven wheels have been analyzed.

The calculations were carried out for the conditions of constant speed of the front axle drive wheels, if the tractor is moving without braking when turning. Different laws of changing the angle of rotation of the wheels of the front and rear axles were set. The process of turning the tractor by 90 degrees was considered, since while turning by 180 degrees, the conditions of the force effect while maintaining the rotation modes are similar.

In the first case, when the rotation was carried out only by the front controlled wheels, the law of changing the angles of rotation of the controlled wheels $\alpha$a and $\alpha$b for the first embodiment of rotation is shown in figure 3. It shows the variation of the angle between the axis of the tractor and the direction of motion of the center of mass $\alpha$o. In the first embodiment, the rotation is only due to the rotation of the wheels of the front axle to the corner, providing the radius of 4.5 m and back for the exit of the turn [1, 2, 4].

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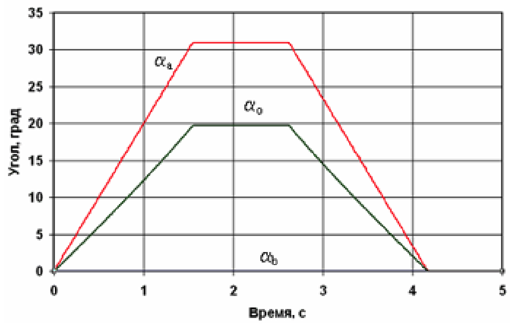


**Fig 3: The law of the turn angles variation of the driven wheels αa and αb for the first option of turning.**

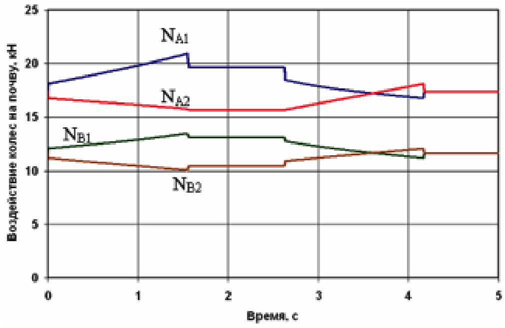


**Fig 4: The nature of changes in the forces of action of the wheels on the soil for the first option of turning.**

In the first option of the turn for the conditions of a constant speed of the first bridge of 2.78 m/s, the force interaction of the wheels with the soil is shown in figure 4.

Before the turn, the reaction of each front axle wheel is 17.4 kN and that of the rear axle being 11.6 kN. At the beginning of the turn, under the action of the PON force, the forces NA1 and NB1 increase by 0.7 and 0.4 kN, respectively, on the outer wheels, and the forces NA2 and NB2 decrease by 0.7 and 0.4 kN, respectively, on the wheels of the inner section of the turn.

In the first section of the turn to 1.55 s after the start while increasing the angle of rotation of the wheels to 31 degrees. the forces of NA1 and NB1 increased to 20.9 and 13.5 kN, respectively, on the outer wheels and decreased on the inner NA2 to 15.8 kN and NB2 to 10,0 kN. The change in forces is due to the growth of the forces of the RC and RR with a certain decrease in the strength of the PON.

In the second section of the rotation from 1.55 s to 2.62 s after the start, the movement occurs at a constant angle of rotation of the wheels-31 degrees. The tractor drives in a circle with a radius of 4.5 m. The difference in forces between the external and internal wheels is due to the centrifugal force of the RC. The force jump at the beginning of the site is associated with the termination of the forces of PON and PR. At the end of the site it is associated with their appearance in the third site.

The third site of the turn starts at 2.62 s with and ends by 4.17 s. It has the same force as on the first site, but the forces of the PON and PR change the sign to the opposite. NA1 and NB1 forces are reduced by 1.7 and 1.6 kN, respectively, on the outer wheels and the NA2 and NB2 forces are increased by 2.4 and 1.2 kN, respectively, on the wheels of the inner turning section. At the end of the site the force jump is associated with the termination of the force of the PON. As a result, there is an increase in the forces of NA1 and NB1 by 0.6 and 0.4 kN, respectively, and a decrease in the forces of NA2 and NB2 by 0.7 and 0.5 kN, respectively.

The analysis of the change of forces shows that at the beginning of the turn there is an increase in the forces on the wheels of the outer radius of turning and a decrease in the forces of the inner radius. At the last turn, their changes are reversed. The maximum value is the force NA1 on the front outer wheel and its value reaches 20.9 kN, which is 20% higher than the value of the force in the rectilinear motion. Various options for the movement of the tractor: with front steering wheels, the front and rear wheels rotating in different directions and the third way, when the rotation was carried out by the "crab" were further considered [5].

While moving from one section of the turn to the other, there was a force jump, which can be associated with the sudden changes in the conditions of the tractor at turning. To confirm this assumption, the calculation of the tractor turning under smooth change of the steering wheel angles according to the harmonic law was realized, as shown in figure 5 The speed of the front axle was 2.78 m / s, and the maximum steering angles of both axles were chosen so that the turn duration was 4.18 s, as for the first version of the turn.

In the case of rotation with a harmonic law of changing the angles of the controlled wheels αa and αb at a speed of 2.78 m/s, the force interaction of the wheels with the soil is shown in figure 6.

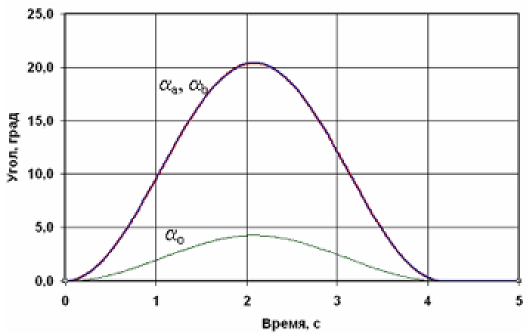


**Fig 5: The harmonic law of change of the turning angles of the driving wheels αa and αb at a speed of 2.78 m / s.**

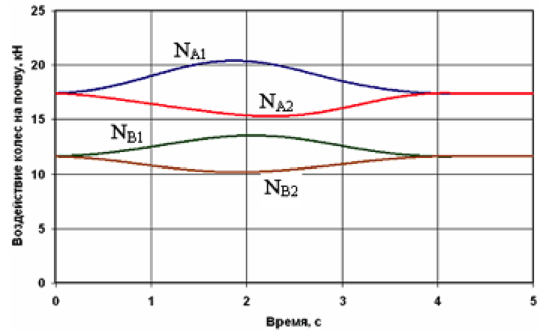


**Fig 6: The nature of changes of the wheels action forces on the soil for the third option of turning at a speed of 2.78 m / s.**

As can be seen from the results presented in figure 6, when ensuring a smooth change in the angles of rotation of the driven wheels, there are no jumps in forces and their smooth change is observed in all areas of turning.

Based on the results of the calculation, the following conclusions can be drawn:

1. The turning conditions of the tractor have an impact on the value of the propelling devices on the soil, and this impact can exceed the value of the rectilinear motion by 20% more, and this leads to an increase in soil compaction.
2. The greatest loads occur on the front steering wheel of the outer radius of turning and different rotation options can be estimated by the magnitude of its impact.
3. At the same speed and turning radius the tractor with two controlled axles creates less load on the soil than with one front axle. Thus, at a speed of 2.78 m/s and a turning radius of 4.5 m, the maximum impact of the driving wheels of a tractor with two controlled axles, the maximum force on the front outer wheel is 0.5 kN or 2.5% lower than when turning with one front controlled motor.
4. The proposed version of the tractor rotation, with the use of the "crab" rotation movement and the use of the harmonic law of motion, allows to reduce the maximum force value on the front outer wheel by 2.4 kN or 9% lower at the speed of 2.78 m/s than at the tractor with the front driven wheels.
5. The decrease in the speed of movement when turning from 2.78 m/s to 1.7 m/s will reduce the maximum load on the soil from 3% to 10% depending on the selected rotation option. The greater the change of force effect at turn, the more influential is the speed at turning.
6. For each case of turning the rotation mode, providing minimum load change on the soil can be chosen. The mode can only be achieved with a computer managing of the movement direction.

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