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Engineering

Determination of the Normal Reaction of the Soil to the Wheels of Adaptive Self-Propelled Chassis

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ABSTRACT. The article considers the methods to define the normal reaction of the wheels of adapted self-propelled chassis in the case of balance suspension of the driving tandem wheels. The calculation formulae for the normal reactions of the front guide and rear driving wheels are deduced. It is established that the total normal reaction to the truck is distributed equally between the rear and front tandem wheels, thus having an impact on the traction characteristics of the running system. The normal reactions of the wheels are determined by considering the assembly of the operating equipment allowing to identify the optimal locations of the technological working organs along the girders of the chassis by considering the minimization of the pressure of the wheels on the soil.

Key words: *adaptability, self-propelled chassis, track movers.*

It is known that because of the impact of mobile agricultural machines on the soil, the density of the latter in the plough-layer and subsurface increases, causing significant changes in the soil structure and properties, deterioration of the habitation of the root system and eventually, reduction of crop capacity.

In terms of shifting to intense technologies of agricultural production machines are made more and more complex, their functional capabilities are extended, output is boosted and as a result, the mass, number of passes and speed of their movement along the field are increased. The greater the impact of the track movers of a tractor on the soil, the more the loss in crop productivity. Every pass of a tractor or an agricultural machine along the field forms compacted zones of a significant size in the soil, which are concentrated around the tracks and spread at the distance of 0.8÷1.0 m in both directions from the tracks of the caterpillars and wheels.

In the depth, such zones are spread over the whole topsoil (0÷30 cm), reaching 0.6 m. Besides, the soil density and porous space (the volume of pores and their distribution between the air and water phases) change the most [1]. As the soil compaction increases, the volume of air pores is reduced and the gas exchange is reduced, having a negative effect on the biological processes and consequently, growth and development of plants.

The above-mentioned negative effects are even more aggravated when perennial plantings are concerned, where the tractors repeatedly move along a permanent track. When the density of the root-inhabited soil layer is several times more than the optimal value, the crop yield is significantly reduced and the process of the plant drying is accelerated.

There are different methods to reduce the compacting influence of the track movers of agricultural machines, including those of engineering machines on the soil. Some methods aim at perfecting tractors, agricultural machines and their track movers to eliminate or reduce the adverse impact on soil. To this end, as well as to extend the functional capabilities, has been a running gear of the self-propelled chassis T-16MMT has been designed, which allows exploiting power techniques at farms with both, low- and high-clearances, i.e. assigning adaptive properties to them [2]. The designed running gear consists of two balancers, with four driving wheels at their ends, which receive the rotation movement from the driving axle through the roller chain.

Basic part

In order to determine the normal reactions of the track movers to the soil by considering the possible position of the working equipment, we draw a diagram of the internal forces influencing the chassis, which moves along a horizontal surface and without considering the air resistance and forces of inertia (Fig. 1).

The weight of the self-propelled chassis G_C is applied in the center of gravity of the machine. Fig. 1 schematically shows the possible location of the working equipment on the girders of the chassis. Their weight indicators are denoted by G_C, and their technological resistance is denoted by F_i. The coordinates of the given forces relative to the axles crossing the points of suspension of the balance carriage, are denoted by a_i and h_i.

Normal reactions of the soil to the driving tandem wheels, Y_1, Y_2 and to the steering wheel, Y_d are applied to the points of intersection of the vertical axles of the wheels with the bearing area, and the corresponding moments of rolling resistance for the complete machine are replaced by $M_f = M_{f1} + M_{f2} + M_{fd}$.

The soil reactions, which are parallel to the surface of the track and acting along the direction of movement, i.e. the propelling forces $x_1 = P_{r1} - P_{fr1}$ and $x_2 = P_{r2} - P_{fr2}$ are applied to the axle of the corresponding tandem wheels. They may also be transferred to the common axle of suspension of the balance carriage 0 [3,4].

The traction resistance P_h is applied to the point of trailer located at the height of h_h above the surface. Generally, it is directed at the angle γ_h to the given surface. Angle γ_h is considered positive, when the line of traction resistance is inclined downward, in the direction of the bearing area, and it is negative when it is inclined upward.

If we transfer the force of traction resistance P_h in the direction of its action until it crosses the plane running through the axle of suspension of the balancer, its height above the surface of track will be

$$h'_h = h_h + \ell_h tg\gamma_h,$$

where ℓ_h is the longitudinal direction of the point of trailer up to the axle of the balancer.

From the condition of equilibrium of the system relative to the axles x and y and axle of the balance suspension of the driving wheels, we obtain:

$$\left.\begin{aligned} &(x_1 + x_2) - P_h \cos\gamma_h - P_{fd} - \sum_{i=1}^{5} F_i = 0; \\ &Y_1 + Y_2 + Y_d - P_h \sin\gamma_h - G_c - \sum_{i=1}^{5} G_i = 0; \\ &Y_d L - (Y_1 - Y_2)d \pm P_h \cos\gamma_h \cdot b + M_f + \\ &\quad + \sum_{i=1}^{5} F_i h_i - G_c f_{cg} - \sum_{i=1}^{3} G_i f_i + \sum_{i=4}^{5} G_i f_i = 0, \end{aligned}\right\} \quad (1)$$

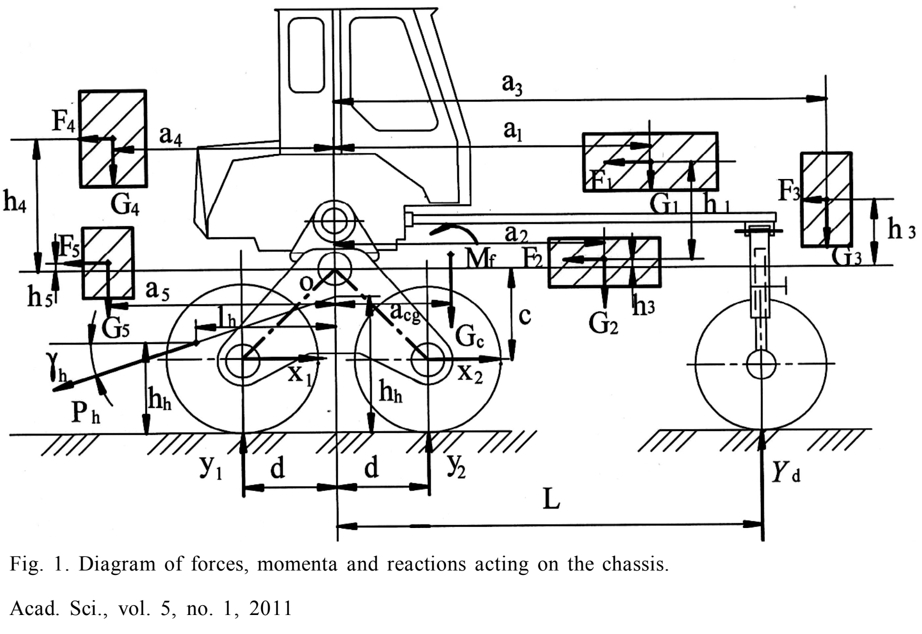

Fig. 1. Diagram of forces, momenta and reactions acting on the chassis.

where $b = C + r_r - h_h'$; $M_f = P_f r_r = fr_r \left(G_c + \sum_{i=1}^{5} G_i \right)$.

If the line of the traction resistance runs below the point 0, the moment of P_h is negative and vice versa.

By considering the value of rolling resistance of the complete machine, the intermediate formula to determine the reaction Y_d in the third equation of system (1) will look as follows:

$$Y_d = \frac{(Y_1 - Y_2)\,d \pm P_h \cos\gamma_h \cdot b - \sum_{i=1}^{5} F_i h_i + G_c f_{cg}}{L} + \frac{\sum_{i=1}^{3} G_i f_i - \sum_{i=4}^{5} G_i f_i - fr_r \left(G_c + \sum_{i=1}^{5} G_i \right)}{L}. \quad (2)$$

Equation (2) means that the value of the reaction Y_d depends on the difference of reactions ($Y_1 - Y_2$). If the reactions Y_1 and Y_1 are equal, formula (2) may be used to determine the vertical reaction of the driving wheels of a two-axle self-propelled chassis. When the value of the reactions difference ($Y_1 - Y_2$) is positive, reaction Y_d is increased and vice versa, in the case of negative difference between the reactions, the given value is reduced.

In order to determine the difference of reactions ($Y_1 - Y_2$), by considering the design of the balance suspension of the driving wheels of the self-propelled chassis, we use the methodology by Prof. E.A. Chudakov [4].

Fig. 2 shows the carriage of a balance suspension and forces, moments and reactions, acting on both driving axles. Reaction S of the propelling force, transferred from the driving wheels to the chassis frame equals the total propulsive force x or the sum of forces ($x_1 + x_2$), i.e.

$$S = x = x_1 + x_2.$$

Let us consider the equilibrium of the carriage in respect to point 0. In the case of the design, shown in the diagram in Fig. 2, resultant of all forces acting on both axles of the chassis, it must cross the axle 0, relative to which the carriage can pivot, i.e. the moment of all forces relative to the given axle must equal 0. Thus, we have:

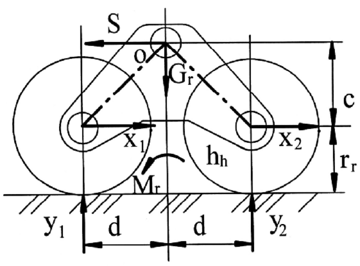

Fig. 2. Diagram of forces, momenta and reactions acting on the driving axle of the chassis.

$$(Y_1 - Y_2)\,d - (x_1 + x_2)C - M_{fr} = 0, \quad (3)$$

where

$$M_{fr} = M_{f1} + M_{f2} = G_r f \cdot r_r = \left(G_c + \sum_{i=1}^{5} G_i \right) f \cdot r_r - Y_d f \cdot r_r.$$

From the first equation of system (1), we determine:

$$x_1 + x_2 = P_h \cos\gamma_h + Y_d f + \sum_{i=1}^{5} F_i. \quad (4)$$

By duly transforming equation (3), we get:

$$(Y_1 - Y_2)\,d = (x_1 + x_2)C + M_{fr} = P_h \cos g_h \times C + \left(G_c + \sum_{i=1}^{5} G_i \right) f \times r_r + \sum_{i=1}^{5} F_i \times C + Y_d f\,(C - r_r). \quad (5)$$

By substituting the derived expression for the difference of reactions ($Y_1 - Y_2$) in equation (2) and solving it relative to the reaction Y_d, we determine the final expression for the given reaction:

$$Y_d = \left[P_h \cos\gamma_h (C \pm b) + G_c \cdot a_{cg} + \sum_{i=1}^{3} G_i a_i - \sum_{i=4}^{5} G_i a_i - \sum_{i=1}^{5} F_i (h_i - C) \right] \Big/ L - f\,(C - r_r). \quad (6)$$

The calculation formula Y_d can be used to determine the difference of reactions quite easily:

$$Y_1 - Y_2 = \frac{P_h \cos\gamma_h \cdot C + \left(G_c + \sum_{i=1}^{5} G_i \right) f \cdot r_r + \sum_{i=1}^{5} F_i C}{d} + \frac{f\,(C - r_r)}{d} \cdot Y_d. \quad (7)$$

The reactions to the driving wheels of the balancer are determined by the expression:

$$y_1 = \frac{G_r + P_h \sin\gamma_h}{2} + \frac{Y_1 - Y_2}{2}; \quad (8)$$

$$y_2 = \frac{G_r + P_h \sin\gamma_h}{2} - \frac{Y_1 - Y_2}{2}. \quad (9)$$

By substituting the values G_r and $Y_1 - Y_2$ in the given expression, we gain:

$$Y_1 = \frac{G_c + \sum_{i=1}^{5} G_i + P_h \sin\gamma_h}{2} - \frac{Y_d}{2} + \frac{P_h \cos\gamma_h \cdot C + \left(G_c + \sum_{i=1}^{5} G_i \right) f \cdot r_r + \sum_{i=1}^{5} F_i C}{2d} + \frac{f\,(C - r_r)}{2d} \cdot Y_d.$$

Thus,

$$Y_1 = \frac{G_c + \sum_{i=1}^{5} G_i + P_h \sin\gamma_h}{2} +$$

$$+ \frac{P_h \cos\gamma_h \cdot C + \left(G_c + \sum_{i=1}^{5} G_i\right) f \cdot r_r + \sum_{i=1}^{5} F_i C}{2d} -$$

$$- \left[1 - \frac{f(C-r_r)}{d}\right] \cdot \frac{Y_d}{2}. \quad (10)$$

Similar transformations for Y_2 produce the following expression:

$$Y_2 = \frac{G_c + \sum_{i=1}^{5} G_i + P_h \sin\gamma_h}{2} -$$

$$- \frac{P_h \cos\gamma_h \cdot C + \left(G_c + \sum_{i=1}^{5} G_i\right) f \cdot r_r + \sum_{i=1}^{5} F_i C}{2d} -$$

$$- \left[1 + \frac{f(C-r_r)}{d}\right] \cdot \frac{Y_d}{2}. \quad (11)$$

Let us analyze expressions (6) … (11).

In the case of operation of the self-propelled chassis driven by the takeoff mode P_h=0, we get:

$$Y_d = \frac{G_c a_{cg} + \sum_{i=1}^{3} G_i a_i - \sum_{i=4}^{5} G_i a_i - \sum_{i=1}^{5} F_i (h_i - C)}{L - f(C-r_r)}; \quad (12)$$

$$Y_1 - Y_2 = \frac{\left(G_c + \sum_{i=1}^{5} G_i\right) f \cdot r_r + \sum_{i=1}^{5} F_i C}{d} + \frac{f(C-r_r)}{d} \cdot Y_d; \quad (13)$$

$$Y_1 = \frac{G_c + \sum_{i=1}^{5} G_i}{2} + \frac{\left(G_c + \sum_{i=1}^{5} G_i\right) f \cdot r_r + \sum_{i=1}^{5} F_i C}{2d} -$$

$$- \left[1 - \frac{f(C-r_r)}{d}\right] \cdot \frac{Y_d}{2}; \quad (14)$$

$$Y_2 = \frac{G_c + \sum_{i=1}^{5} G_i}{2} - \frac{\left(G_c + \sum_{i=1}^{5} G_i\right) f \cdot r_r + \sum_{i=1}^{5} F_i C}{2d} -$$

$$- \left[1 + \frac{f(C-r_r)}{d}\right] \cdot \frac{Y_d}{2}. \quad (15)$$

If the number of the equipment suspended on girders is $i = 1$, we obtain:

$$Y_d = \frac{G_c a_{cg} + G_i a_i - F(h-C)}{L - f(c-r_r)}; \quad (16)$$

$$Y_1 - Y_2 = \frac{(G_c + G_1) f \cdot r_r + F_1 C}{d} + \frac{f(C-r_r)}{d} \cdot Y_d; \quad (17)$$

$$Y_1 = \frac{G_c + G_1}{2} + \frac{(G_c + G_1) f \cdot r_r + F_1 C}{2d} -$$

$$- \left[1 - \frac{f(C-r_r)}{d}\right] \cdot \frac{Y_d}{2}; \quad (18)$$

$$Y_2 = \frac{G_c + G_1}{2} - \frac{(G_c + G_1) f \cdot r_r + F_1 C}{2d} -$$

$$- \left[1 + \frac{f(C-r_r)}{d}\right] \cdot \frac{Y_d}{2}. \quad (19)$$

If the suspended equipment (for example, the working body for applying fertilizers, sprinklers, etc.) operates in the gravitational mode, $F_i = 0$ in the given expressions.

In static (immovable) state of the chassis over a horizontal section without any technical equipment the normal reactions $(P_h = 0;\ G_i = 0;\ F_i = 0;\ M_f = 0)$, which in the given case are called static:

$$Y_d = \frac{G_c a_{cg}}{L};\ Y_1 - Y_2 = 0;\ Y_1 = \frac{G_c}{2} - \frac{G_c a_{cg}}{2L};$$

$$Y_2 = \frac{G_c}{2} - \frac{G_c a_{cg}}{2L}. \quad (20)$$

The obtained results allow judging about the influence of assembling the self-propelled chassis to the value of reactions Y_d, Y_1 and Y_2 acting on steering and driving tandem wheels. These reactions are much influenced by the vertical coordinate of the suspension point of a balance carriage. The higher the suspension point is (i.e. the greater the size C), the greater the load of the front steering wheels and the greater the unload of the rear wheels. At the same time, the difference of reactions between the rear and front wheels increases. If the line of action of the hook resistance runs below the suspension point 0, the steering wheels get loaded and the rear wheels get unloaded and vice versa, when the line runs above the given point. During the exploitation, the change of load on hook *cc* is of an accidental nature in time and therefore the values Y_d, Y_1 and Y_2 will change, similar to the load P_h.

The more the unloading of the front axle of the balancer and loading of the rear axle, the higher is the point of the balancer suspension.

An adaptive self-propelled chassis is first of all designed to work with tall-stalked crops and therefore, reduction of the height C to 0 is impossible. However, when $C=r_r$ the difference of reactions reduces correspondingly and from equation (13), we get:

$$Y_1 - Y_2 = \frac{\left(G_c + \sum_{i=1}^{5} G_i\right) f \cdot r_r + \sum_{i=1}^{5} F_i C}{d}. \qquad (21)$$

In the case of assembling the chassis with one technological equipment operating in a gravitational mode, we will get:

$$Y_1 - Y_2 = \frac{(G_c + G_i) f \cdot r_r}{d}. \qquad (22)$$

For instance, at $G_c + G_1 = 20kN$; $f=0.06$; $r_r/d = 0.8$; $Y_1 - Y_2 = 0.96kN$ ..

The working equipment, located on the girders in front of the suspension point of the balancer load the steering wheels, and the ones on the opposite side unload them. Accordingly, in order to reduce the reaction difference ($Y_1 - Y_2$), for structural or technological expediency, it is beneficial to assemble some working equipment from the rear side of chassis. A positive effect for this purpose can also be gained by using removable loads (ballasts).

By using the derived calculation formulae, a constructor can calculate the optimal location of the working equipment on the girders of the chassis to gain optimal loads on the wheels. Here is a practical example. Let us assume that it is necessary to assemble the technological equipment operating under a gravitational mode (sprinkler, fumigator, fertilizer applying machine, etc.), with the weight of $G_1=3000N$, on the girders of the chassis so that the load on the steering wheels should be within the admissible limits $Y_d \geq 0.2(G_c + G_1)$. The other parameters of calculation have the following values:

$$G_c = 20100N;\ f_{cg} = 0.466m;\ L = 2.55m;\ r_r = 0.45m;$$

$$C = 0.55m;\ f = 0.01;\ r_r/d = 0.546m.$$

From the calculation formula of normal load of the steering wheel (12), we shall get:

$$a_1 = \frac{Y_d\left[L - f(C - r_r)\right] - G_c a_{cg}}{G_i}. \qquad (23)$$

The numerical value $Y_d \geq 0.2(20100 + 3000) \geq 4620N$.

Let us assume $Y_d = 4700N$. By substituting the numerical values of the parameters in (23), we obtain $a_1 = 0.855m$. The load on the axle of a balancer $G_r = G_c + G_1 - Y_d = 18400N = 18.4kN$. The load on the rear driving wheels of the balancer is defined from expression (14), by considering the peculiarities of the equipment in question:

$$Y_1 = \frac{G_c + G_1}{2} + \frac{(G_c + G_1) f \cdot r_r}{2d} - \left[1 - \frac{f(C - r_r)}{d}\right] \cdot \frac{Y_d}{2} = 9858N = 9.858kN.$$

Similarly, for the front driving wheels of the balancer we shall have:

$$Y_2 = \frac{G_c + G_1}{2} - \frac{(G_c + G_1) f \cdot r_r}{2d} - \left[1 + \frac{f(C - r_r)}{d}\right] \cdot \frac{Y_d}{2} = 8542N = 8.542kN.$$

The difference of reactions is $Y_1 - Y_2 = 1316N = 1.316kN$.

Mean pressure on the bearing area is:

$$q_m = \frac{G_c + G_1}{2F_d + 4F_b}.$$

In accordance with [1], the bearing area of front wheels of the self-propelled chassis T-16 MMT is $2F_d = 0.041m^2$, and that of the driving wheels is - $2F_b = 0.087m^2$. In the case of using the same wheels for the balance carriage $4F_b = 2 \cdot 0.087 = 0.174m^2$. Then, we shall have:

$$q_m = \frac{23100}{0.041 + 0.174} = 107441.9\frac{N}{m^2} \approx 0{,}107MPa$$

Mean pressure of the adapted self-propelled chassis is almost equally distributed between the axles. Thus, we get:

$$q_{md} = \frac{4700}{0.041} = 114634.2\frac{N}{m^2} \approx 0.115\text{MPa};$$

$$q_{mb} = \frac{18400}{0.174} = 105747.1\frac{N}{m^2} \approx 0.106\text{MPa}.$$

In accordance with GOST 24096-80, the running systems must ensure the maximum mean pressure of the girders on the soil of no more than $0.080 \div 0.11$ MPa [3].

For the self-propelled chassis T-16 MMT the pressure is 0.157 MPa.

Therefore, the modification of the self-propelled chassis designed by using the principles of adaptability, generally meets all technical and technological requirements of a power unit designed to work on small farms.

Conclusions

Methods have been developed for determining the normal reactions to the wheels of the adapted self-propelled chassis. Adaptability, i.e. the ability to adapt the power units to the sizes of plants by considering their growing conditions, is ensured by means of a balance suspension of driving tandem wheels. The developed methods consider the specifics of such a suspension. The summary normal reaction to the carriage has been found distributed unequally between the rear and front driving wheels. Such inequality can partially be eliminated by employing a rational assembly of the working equipment on the girders of the chassis. In addition, methods to calculate the parameters of assembling the equipment and technological evaluation of the impact of the given assembly on the equality and value of the specific pressure of the wheels on the soil have been developed.

საინჟინრო მეცნიერებანი

ადაპტური თვითმავალი შასის თვლებზე ნიადაგის ნორმალური რეაქციების განსაზღვრა

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გადმოცემულია ადაპტური თვითმავალი შასის თვლებზე ნორმალური რეაქციების განსაზღვრის მეთოდიკა წამყვანი ტანდემ-თვლების ბალანსური დაკიდების დროს. გამოყვანილია ნორმალური რეაქციების საანგარიშო ფორმულები წინა მიმმართველი და უკანა წამყვან ტანდემ-თვლებზე შასიზე ტექნოლოგიური მოწყობილობების განლაგების გათვალისწინებით. ეს იძლევა საშუალებას შასის ლანჟერონზე ოპტიმალურად განვალაგოთ მანქანის მუშა ორგანოები ნიადაგზე ნორმალური დაწოლის მინიმალური მნიშვნელობის პირობებში.

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