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THE STUDY OF BRAKING DYNAMICS ON TRACTORS WITH WHEELS AND INFLUENCE OF THE FORCES WHICH APPEAR AT MOVEMENT ON BRAKING CAPABILITY

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Abstract: The means of transport in agriculture are used to transport agricultural products into and out of agricultural farms, agricultural transport representing all work and operations that ensure flow of materials and products from field to farms, respectively from the farms to the various sectors of processing. In this work is carried out an analysis of braking dynamics on tractors with wheels and influence of the forces which appear when driving straight on a slope regarding braking efficiency.
Keywords: aggregate, braking, space, rectilinear

1. INTRODUCTION

In agriculture are transported significant quantities of products and materials. Thus, before preparing the ground for sowing, are transported large quantities of fertilizers, and during works of seeding and planting, are transported in field the seeds and planting material, necessary for the execution of these works. During harvest and gathering the harvest is performed a high volume of transport, therefore, the correct organization of work transport of the harvest and other secondary materials increases productivity and reduces crop losses.

Also, for technical and technological service of tractors and agricultural machinery, in the course of agricultural operations, is transported, into field, large quantities of technological materials (fertilizers, planting material, pest control substances, etc.) and fuels [2], [6].

In some of the agricultural production processes, the transport is an integrated part of field work technology. Thus, with the expansion of animal husbandry complexes and agricultural development of various industrial units, agricultural transport has become more complex, characterized by the existence of the loading, transshipment and unloading operations of materials (sometimes, together with unloading is done and the dosing of materials).

Normal approach to all transport agricultural mechanization issues, must be made by knowing the factors that differentiate it from other transport activities.

The operation of agricultural transport is an important part of the process of production in agriculture, the aim being to move materials and agricultural products without damage them (without modify the physic-mechanical properties).

Agricultural transport presents a number of particularities towards transports made in other activity fields of economy, in special, determined by the character of agricultural production and the special conditions under which agricultural work is carried out.

Given to the work that running in agriculture, different amounts of products and materials is transported as follows:

- fertilizer transport to prepare the ground for sowing and planting;
- transport of seeds and planting material in the field for seeding and planting;
- transport of water, herbicides and insecticides for pest and disease control, crop maintenance;
- fuels and lubricants transportation for technological service operations in agriculture, etc...

- primary and secondary agricultural products transport resulting from harvesting crops with a view to recovery and storage;

The transport has a special importance in zoo-technical complexes: animal husbandry unit as well as in industrial unit for finite and primary processing of agricultural products [7], [8], [9].

The transport is a link in a production process and not a stand-alone work, so that it is related to other operations such as loading and unloading, the groups of transport causing in most cases the type of means of transport with which it must be carried out [5].

Agricultural transport [10, 12, 12] presents some particularities caused by the production and the specific conditions under which agricultural work is performed, the factors that influence directly the equipment used are: transport season, volume of transport, dispersion, distance of transport, road conditions and climatic conditions [4].

In agriculture, the basic means of transport is composed of tractor and trailer which according to destination can be for transport technology, current transport and special transport. On the basis of the particular characteristics of the driving system, the unit tractor-trailer [3] can be biaxial, commonly referred to as trailers with two axis or mono axis, commonly known as semi-trailers.

It should be noted that due to the development of agricultural and zoo-technical units of industrial type, which can provide a continuous and rhythmic flow transport, independently of the season, and the existence of paved roads, the use of means of transport propelled (auto trucks, trucks, trans-container, chassis propelled, etc.,) are justified in the transport process.

In the actual condition, in which technological transport takes place, basic, is used the tractor-trailer aggregate biaxial, mono axis or the unit in tandem.

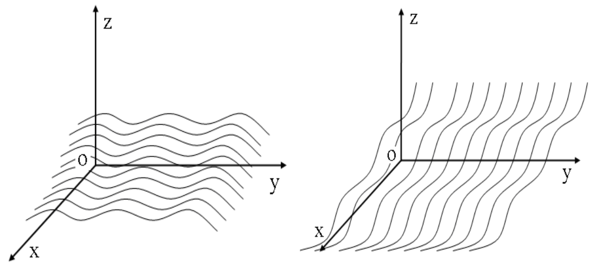

Fig. 1 - Types of uneven paths [2]. a) road with unevenness in the longitudinal plan , b) road with unevenness in the transversal plane

2. MATERIAL AND METHOD

Theoretical studies have been carried out on a tractor-semi-trailer unit (trailer mono axis) used in transport, in uniform working regime and in accelerated and decelerated working regime, following the roadway conditions with various geometric aspects, as it is in reality [13].

In terms of the roadway (the road), it can be:

- ✓ Smooth roadway;
- ✓ Uneven roadway in the longitudinal plane (fig. 1a);
- ✓ Uneven roadway in the transverse plane (fig. 1b);
- ✓ Uneven roadway in the transverse and longitudinal plane.

In figure 1 is presented the unevenness of uneven runways in the longitudinal, respectively tangential, including vertical unevenness. In figure 2 is presented the appearance of a smooth road - stubble (fig. 2 A), respectively of an uneven road (fig. 2 b).


Fig. 2 – Aspects of the roadway. a) smooth road; b) uneven road

3. RESULTS AND DISCUSSIONS

Dynamic braking of wheel tractors / General equation of rectilinear motion of braked tractor

It's considered the case of a tractor that moves with variable-speed on a road with α_p inclination from horizontal location (fig. 3), where: R_a – global resistence force acting on tractor; F_{az} – air resistence; C_a - frontal pressure centre (metacentre); G_t – tractor's weight in its load centre; $G_t \sin a$ - component parallel to road inclined plan; $G_t \cos a$ – commun component to road inclined plan; C_{gt} – tractor gravity centre; R_{dt} – inertia force of tractor mass in translation movement; F_{fr2} – braking force at rear wheel; R_{rul2} – rear wheel resistence force to running; Z_2 – reaction of rolling track on tractor's rear wheel; R_{i2} – tangential reaction on tractor's rear wheel; F_{fr1} – braking force at frontal wheel; R_{rul1} – frontal wheel resistence force to running; Z_1 – rolling track reaction on tractor frontal wheel; R_{i1} – tangential reaction on tractor frontal wheel; a_t – distance between the steering axle (front)and the load centre;

b_t – distance between the rear axle shaft and the load centre; L_t – tractor's axle base; h_a – distance on vertical from the front pressure centre to soil; h_g – distance on vertical from load centre to soil; v – displacement speed; α_p – field slope angle (slope);

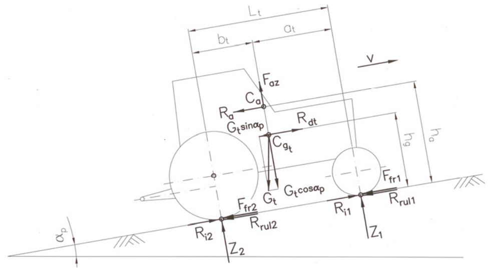

Fig. 3 - Braked tractor into the rectilinear movement

In this case, the acceleration is negative, so the force of inertia of the mass of the translational movement of the vehicle is directed in the running direction. Also, the direction of torques generated by the inertia of the rotating parts is the same with that of rotation of the wheel.

The equation of equilibrium of forces in the direction movement of the tractor is:

$$R_{dt} + R_{i1} + R_{i2} - F_{fr1} - F_{fr2} - R_{rul1} - R_{rul2} - R_p - R_a = 0 \tag{1}$$

It can be written in the form:

$$R_{dt} + R_{i1} + R_{i2} = (F_{fr1} + F_{fr2} + R_{rul1} + R_{rul2} + R_p + R_a) = 0 \tag{2}$$

Noting

$$R_{dt} + R_{i1} + R_{i2} = R_d = \delta \frac{G_t}{g} \cdot \frac{d\nu}{dt} \tag{3}$$

$$F_{fr1} + F_{fr2} = R_{fr} \tag{4}$$

$$R_{rul1} + R_{rul2} = R_{rul} = f \cdot G_t \cdot \cos\alpha_p \tag{5}$$

Result:

$$R_d = (F_{fr} + R_{rul} + R_p + R_a) \tag{6}$$

or

$$\delta \frac{G_t}{g} \cdot \frac{d\nu}{dt} = \left(F_{fr} + f \cdot G_t \cdot \cos\alpha_p + G_t \cdot \sin\alpha_p + \frac{k \cdot A}{13} \cdot V^2 \right) \tag{7}$$

Dividing with G_t, result:

$$\delta \frac{G_t}{g} \cdot \frac{d\nu}{dt} = \left(\frac{F_{fr}}{G_t} + f \cdot G_t \cdot \cos\alpha_p + \sin\alpha_p + \frac{k \cdot A}{13G_t} \cdot V^2 \right) \tag{8}$$

or $\frac{\delta}{g} \cdot \frac{d\nu}{dt} = -\left(\gamma_{fr} + \psi + \frac{k \cdot A}{13 \cdot G_t} \cdot V^2 \right), \frac{d\nu}{dt}$ is deceleration.

where:

$$\gamma_{fr} = \frac{F_{fr}}{G_t} \tag{9}$$

represents the specific braking force of the tractor.

Equation (8) represents the general equation of motion of the tractor regime braking.

Determining braking capability

The parameters which characterize maximum braking possibilities of tractors are: maximum deceleration, minimum amount of braking and minimum time for braking.

Analytical determination of maximum deceleration [1]

From the general equation of motion of the tractor braking regime (8) result:

$$\left| \frac{d\nu}{dt} \right|_{\max} = \frac{g}{\delta} \cdot \left(\gamma_{fr} + \psi + \frac{k \cdot A}{13G_t} \cdot V^2 \right) \tag{10}$$

In this case, because δ is the coefficient which takes into account the influence of rotating parts of the whole cinematic chain from the wheels up to the engine, including, the relation is valid for the case where braking is carried out with the engine switched on with the transmission. When the engine is switched off, the coefficient δ will become:

$$\delta_0 = 1 + \delta_r \cong 1{,}02 \div 1{,}04$$

representing the influence of rotating masses connected to the wheels, except those belonging to the engine. Equation (9) becomes:

$$\left| \frac{d\nu}{dt} \right|_{\max 0} = \frac{g}{\delta_0} \cdot \left(\gamma_{fr0} + \psi + \frac{k \cdot A}{13G_t} \cdot V^2 \right) \tag{11}$$

Maximum deceleration depends, apart from braking forces developed at the wheel, on the specific resistance of the road, ψ, and on the speed and aerodynamics of tractor, *k*. At relatively low speeds, up to 70 ÷ 80 km/h, the effect of air resistance can be neglected.

Maximum deceleration is limited by adherence which limits the maximum value of longitudinal and tangential forces of contact patch when braking. These forces are: rolling resistance, the braking force and the resistance due to the inertia of the rotating wheels and cinematic parts related to them:

$$\left.\begin{aligned} X_{f1} &= R_{rul1} + F_{fr1} + R_{i1} \\ X_{f2} &= R_{rul2} + F_{fr2} + R_{i2} \end{aligned}\right\} \tag{12}$$

where: $R_{i1} = \frac{M_{i1}}{r_r}$ şi $R_{i2} = \frac{M_{i2}}{r_r}$

The equation of equilibrium of the forces acting in the direction of movement is in this case:

$$\frac{G_t}{g} \cdot \frac{dv}{dt} = -\left(X_{f1} + X_{f2} + G_t \sin\alpha_P + \frac{k \cdot A}{13} \cdot V^2 \right) \tag{13}$$

This results in:

$$\left|\frac{dv}{dt}\right| = g \cdot \left(\frac{X_{f1} + X_{f2}}{G_t} + \sin\alpha_p + \frac{k \cdot A}{13 \cdot G_t} \cdot V^2 \right) \tag{14}$$

The limiting conditions by the adherence of the tangential longitudinal forces from contact patch at braking are:

$$\left.\begin{aligned} X_{f1} &\le \varphi_x \cdot Z_{1\varphi} \\ X_{f2} &\le \varphi_x \cdot Z_{2\varphi} \end{aligned}\right\} \tag{15}$$

At the limit, it results:

$$X_{f1} + X_{f2} = \varphi_x \left(Z_{1\varphi} + Z_{2\varphi} \right) = \varphi_x \cdot G_t \cdot \cos\alpha_p \tag{16}$$

Equation (14) becomes:

$$\left|\frac{dv}{dt}\right|_{\max\varphi} = g \cdot \left(\varphi_x \cdot \cos\alpha_p + \sin\alpha_p + \frac{k \cdot A}{13 \cdot G_t} \cdot V^2 \right) \tag{17}$$

When braking on level ground, at small speeds enough for neglecting air resistance (under 70÷80 km/h), the relation (17) becomes:

$$\left|\frac{dv}{dt}\right|_{\max\varphi} = g \cdot \varphi_x \tag{18}$$

In these cases, limited maximum deceleration of adherence can be expressed as a fraction of the acceleration of gravity.

Maximum deceleration is obtained for braking without locking the wheels, because at wheel lock the coefficient of adherence is less than $\varphi_{ax} < \varphi_x$.

Analytical determination of the braking space [1]

For the determination of the braking space, it is considered that $v = \frac{ds}{dt}$, whence $dt = \frac{ds}{v}$, in its turn, the acceleration is $a = \frac{dv}{dt}$. Taking into account the expression of *dt,* result:

$$a = \frac{dv}{dt} = \frac{v \cdot dv}{dS} \tag{19}$$

From this relation results that the space covered in a decelerated motion is:

$$S_{fr} = \int_{v_0}^{v} \frac{1}{a} \cdot v \cdot dv = \frac{1}{13} \int_{V_0}^{V} \frac{1}{a} \cdot V \cdot dV \tag{20}$$

Substituting this relation, acceleration resulting from expression (8) gives:

$$S_{fr} = -\frac{\delta}{13g} \cdot \int_{v_0}^{v} \frac{V \cdot dV}{\gamma_{fr} + \psi + \frac{k \cdot A}{13 \cdot G_t} \cdot V^2} = \frac{\delta}{13g} \cdot \int_{v_0}^{v} \frac{V \cdot dV}{\gamma_{fr} + \psi + \frac{k \cdot A}{13 \cdot G_t} \cdot V^2} \tag{21}$$

where V_0 is the initial speed, and V is the velocity at the end of braking.

However, by carrying out the same operation in equation (14) result:

$$S_{fr} = -\frac{1}{13g} \cdot \int_{v_0}^{v} \frac{V \cdot dV}{\frac{X_{f1} + X_{f2}}{G_t} + \sin\alpha_p + \frac{k \cdot A}{13 \cdot G_t} \cdot V^2} = \frac{1}{13g} \cdot \int_{v_0}^{v} \frac{V \cdot dV}{\frac{X_{f1} + X_{f2}}{G_t} + \sin\alpha_p + \frac{k \cdot A}{13 \cdot G_t} \cdot V^2} \tag{22}$$

Assuming that during braking, the braking forces are constant, meaning $\gamma fr = const.$, Then equation (21) becomes, after solving the integral:

$$S_{fr} = \frac{\delta}{2g}\cdot\frac{G_t}{k\cdot A}\cdot\ln\frac{\gamma_{fr}+\psi+\frac{k\cdot A}{13\cdot G_t}\cdot V_0^2}{\gamma_{fr}+\psi+\frac{k\cdot A}{13\cdot G_t}V^2} = \frac{\delta}{2g}\cdot\frac{G_t}{k\cdot A}\cdot\ln\left[1+\frac{\frac{k\cdot A}{13\cdot G_t}\left(V_0^2-V^2\right)}{\gamma_{fr}+\psi+\frac{k\cdot A}{13\cdot G_t}V^2}\right] \quad (23)$$

Considering that $\frac{k\cdot A}{13\cdot G_t}V^2 << \gamma_{fr}$ (the air resistance is much smaller than the brake force) and that *ln(1+x)* ≅ *x*, results in a simplified form of the relation (23):

$$S_{fr} \cong \frac{\delta}{2g}\cdot\frac{G_t}{k\cdot A}\cdot\frac{\frac{k\cdot A}{13\cdot G_t}\left(V_0^2-V^2\right)}{\gamma_{fr}+\psi} = \frac{\delta}{26g}\cdot\frac{V_0^2-V^2}{\gamma_{fr}+\psi} \quad (24)$$

The minimum space of the braking limited by the adherence is obtained by integrating the relation (22), in which:

$$\frac{X_{f1}+X_{f2}}{G_t} = \frac{\varphi_x\cdot G_t\cdot\cos\alpha_p}{G_t} = \varphi_x\cdot\cos\alpha_p \qquad S_{fr\min\varphi} = \frac{1}{2g}\cdot\frac{G_t}{k\cdot A}\cdot\ln\frac{\varphi_x\cdot\cos\alpha_p+\sin\alpha_p+\frac{k\cdot A}{13\cdot G_t}\cdot V_0^2}{\varphi_x\cdot\cos\alpha_p+\sin\alpha_p+\frac{k\cdot A}{13\cdot G_t}\cdot V^2} \quad (25)$$

Simplified expression, following the same approximations as in the previous case, is:

$$S_{fr\min\varphi} \cong \frac{1}{26\cdot g}\cdot\frac{V_0^2-V^2}{\varphi_x\cdot\cos\alpha_p+\sin\alpha_p} \quad (26)$$

If braking is to be carried out on level ground, until it stops, then:

$$S_{fr\min\varphi} \cong \frac{V_0^2}{26\cdot g\cdot\varphi_x} \quad (27)$$

Analytical determination of the braking time [1]

From the expression (8):

$$\frac{\delta}{g}\cdot\frac{dv}{dt} = -\left(\gamma_{fr}+\psi+\frac{k\cdot A}{13\cdot G_t}\cdot V^2\right)$$

resulting the formula for calculating braking time:

$$dt = -\frac{\delta}{g}\cdot\frac{dv}{\left(\gamma_{fr}+\psi+\frac{k\cdot A}{13\cdot G_t}\cdot V^2\right)};\quad t_{fr} = -\frac{\delta}{g}\cdot\int_{v_0}^{v}\frac{dv}{\left(\gamma_{fr}+\psi+\frac{k\cdot A}{13\cdot G_t}\cdot V^2\right)} = \frac{\delta}{3{,}6g}\int_{v_0}^{v}\frac{dv}{\left(\gamma_{fr}+\psi+\frac{k\cdot A}{13\cdot G_t}\cdot V^2\right)} \quad (28)$$

If during braking the braking forces are constant, meaning *γfr = const.*, and if the air resistance is neglected, then the equation (28) becomes, after solving the integral:

$$t_{fr} = -\frac{\delta}{3{,}6g}\cdot\frac{1}{\gamma_{fr}+\psi}\cdot\sqrt{\frac{13\ (\gamma_{fr}+\psi)\cdot G_t}{k\cdot A}}\cdot arctg\sqrt{\frac{k\cdot A}{13(\gamma_{fr}+\psi)\cdot G_t}}\cdot V\Big|_V^{V_0} = \quad (29)$$

$$= \frac{\delta}{g}\cdot\sqrt{\frac{G_t}{(\gamma_{fr}+\psi)\cdot k\cdot A}}\cdot\left[arctg\sqrt{\frac{k\cdot A}{13(\gamma_{fr}+\psi)\cdot G_t}}\cdot V_0 - arctg\sqrt{\frac{k\cdot A}{13(\gamma_{fr}+\psi)\cdot G_t}}\cdot V\right]$$

Minimum time braking at adherence limit result when tangential reactions (X_1 + X_2) correspond to the adherence limit, in accordance with his relation (14):

$$t_{fr\min\varphi} = \frac{1}{3{,}6g}\cdot\int_{v}^{v_0}\frac{dV}{\varphi_x\cdot\cos\alpha_p+\sin\alpha_p+\frac{k\cdot A}{13\cdot G_t}\cdot V^2} \quad (30)$$

Its solution leads to the expression:

$$t_{fr\min\varphi} = \frac{1}{g}\cdot\sqrt{\frac{G_t}{(\varphi_x\cdot\cos\alpha_p+\sin\alpha_p)\cdot k\cdot A}}\cdot\left[arctg\sqrt{\frac{k\cdot A}{13(\varphi_x\cdot\cos\alpha_p+\sin\alpha_p)\cdot G_t}}\cdot V_0 - arctg\sqrt{\frac{k\cdot A}{13(\varphi_x\cdot\cos\alpha_p+\sin\alpha_p)\cdot G_t}}\cdot V\right] \quad (31)$$

Minimum time necessary to stop the tractor is obtained for *V = 0*, so:

$$t_{fr\min\varphi_0} = \frac{1}{g}\cdot\sqrt{\frac{G_t}{(\varphi_x\cdot\cos\alpha_p+\sin\alpha_p)\cdot k\cdot A}}\cdot arctg\sqrt{\frac{k\cdot A}{13(\varphi_x\cdot\cos\alpha_p+\sin\alpha_p)\cdot G_t}}\cdot V_0 \quad (32)$$

Considering that: arctg $x \cong x$, result:

$$t_{fr\min\varphi_0} = \frac{1}{3{,}6\cdot g}\cdot\frac{V_0}{\varphi_x\cdot\cos\alpha_p+\sin\alpha_p} \quad (33)$$

If the tractor is moving on level ground,

$$t_{fr\min\varphi_0} = \frac{1}{3{,}6\cdot g}\cdot\frac{V_0}{\varphi_x} \quad (34)$$

4. CONCLUSIONS

The unit of transport, tractor-trailer/semi-trailer, in various constructive versions is used for the transport of certain materials intended to different states: solid, liquid, gaseous or in bulk, characterized by various physical and mechanical properties, the studies and research regarding the units of transport, pointing the most common use of means of transport unit consisting of tractor-semitrailer aggregate.

Theoretical research on tractor-semitrailer aggregate must satisfy the technical requirements of European and international rules and regulations that take into account the mechanical conditions of the unit aggregate, according to the regime of movement: constant speed, movement under the braking, movement under the braking on the rear wheels and braking on rear and front wheels, movement on the horizontal and inclined road.

In terms of static and dynamic forces that act on unit tractor-semi-trailer, the analysis has been carried out under conditions of smooth road and uneven surfaces in the longitudinally and transversely plan.

From the theoretical study conducted on the dynamics of tractor-semitrailer unit result:

- the conditions under which this study was conducted have character of generality and can be customized in conditions when the unit is on an incline on the roadway;
- the study was conducted under climbing conditions of the unit on a road inclined with α angle, with full braking (braking on the front wheels and rear wheels), the road been considered as smooth and uneven in the plan longitudinally and transversely.

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