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STUDY OF TRACTOR SHAFT BRAKING FORCES DISTRIBUTION INFLUENCE ON WHEELED TRACTORS BRAKING

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Abstract: Braking forces acting on tractor shaft are influenced by a series of factors such as: deceleration value, braking time, tyres pressure, etc. This paper presents the equations defining the adherence lines, which take into consideration the displacement conditions, the slope angle, the common reactions to soil, the global resistance force, acting on tractor and the air resistance.
Keywords: adherence, braking, axles, reactions, resistence

1. INTRODUCTION

When running on a sloap road, on plane surface, several forces and reactions act upon tractor-semitrailer aggregate and its wheels. During the time,these forces have been studied by numerous researchers [2, 3, 4, 5, 6, 7] who emphasized their influence on tractor braking process, when it runs on a straight-sided trajectory, respectively, when suddenly brakes on a sloped road [4, 5, 6].

2. MATERIAL AND METHOD

If we consider a tractor which runs with a variable speed on a road with α_p inclination towards the horizontal and tractor, then we suddenly brake (fig. 1), 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; $G_t \sin\alpha$ - component parallel to road inclined plan; $G_t \cos\alpha$ – 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).

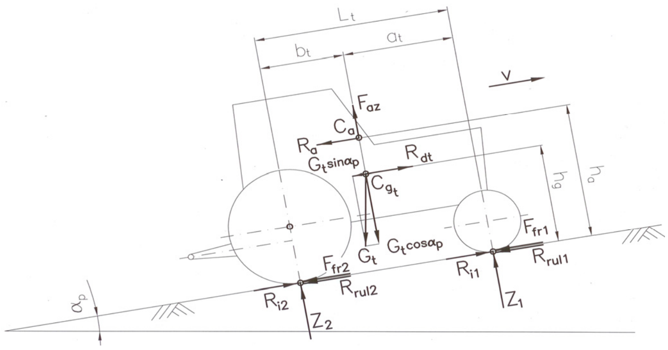

Fig. 1 - Tractor running on a sloped field which suddenly brakes

Then, the values of maximum deceleration limited by adherence are:

$$\left|\frac{dv}{dt}\right|_{\max\varphi} = g\cdot\left(\varphi_x\cdot\cos\alpha_p+\sin\alpha_p+\frac{k\cdot A}{13\cdot G_t}\cdot V^2\right) \tag{1}$$

And minimum time when braking at adherence limit:

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

Are applied when the tractor wheels simulteneously reach the adherence limit, so when tangential longitudinal reactions to braking are distributed depending on normal dynamic loads on tractor wheels.

3. RESULT AND DISCUSSIONS

Adherence limiting conditions of tangential longitudinal forces from tyre contacting part when braking, as we have already shown in relation:

$$\left.\begin{array}{l}X_{f1}\le\varphi_x\cdot Z_{1\varphi}\\ X_{f2}\le\varphi_x\cdot Z_{2\varphi}\end{array}\right\} \tag{3}$$

Normal reactions to soil are precised by relations (4) and (5):

$$Z_1=\frac{b}{L}\cdot G\ \cdot\cos\alpha_p-\frac{h_g}{L}\left(X_1+X_2\right)-\frac{h_a-h_g}{L}\cdot R_a \tag{4}$$

$$Z_2=\frac{a}{L}\cdot G_t\cdot\cos\alpha_p+\frac{h_g}{L}\left(X_1+X_2\right)-\frac{h_a-h_g}{L}\cdot R_a \tag{5}$$

Neglecting the air resistence, they become:

$$Z_1=\frac{b}{L}\cdot G_t\cdot\cos\alpha_p-\frac{h_g}{L}\left(X_{f1}+X_{f2}\right) \tag{6}$$

$$Z_2=\frac{a}{L}\cdot G_t\cdot\cos\alpha_p+\frac{h_g}{L}\left(X_{f1}+X_{f2}\right) \tag{7}$$

We replace $X_1 = - X_{f1}$ şi $X_2 = - X_{f2}$ in (6) and (7), taking into account the fact that in this case X_{f1} and X_{f2} represent reactions to braking process, instead of traction.

We introduce the expressions of normal reactions to soil obtained within inequalities (3), resulting in:

$$X_{f1}\le\varphi_x\cdot\left[\frac{b}{L}\cdot G_t\cdot\cos\alpha_p+\frac{h_g}{L}\left(X_{f1}+X_{f2}\right)\right] \tag{8}$$

$$X_{f1}\le\varphi_x\cdot\left[\frac{b}{L}\cdot G_t\cdot\cos\alpha_p+\frac{h_g}{L}\left(X_{f1}+X_{f2}\right)\right] \tag{9}$$

Limiting, the two relations become equations defining the adherence lines:

$$\left(1-\varphi_x\cdot\frac{h_g}{L}\right)\cdot\frac{X_{f1}}{G_t}-\varphi_x\cdot\frac{h_g}{L}\cdot\frac{X_{f2}}{G_t}=\varphi_x\cdot\frac{b}{L}\cos\alpha_p;(D_1) \tag{10}$$

$$\varphi_x\cdot\frac{h_g}{L}\cdot\frac{X_{f2}}{G_t}+\left(1+\varphi_x\cdot\frac{h_g}{L}\right)\cdot\frac{X_{f2}}{G_t}=\varphi_x\cdot\frac{a}{L}\cos\alpha_p;(D_2) \tag{11}$$

For a tractor loaded with a certain load, which runs on a road a, b, h_g, α_p şi ϕ_x, are known and X_{f1} and X_{f2} depend on force of pressure on braking pedal.

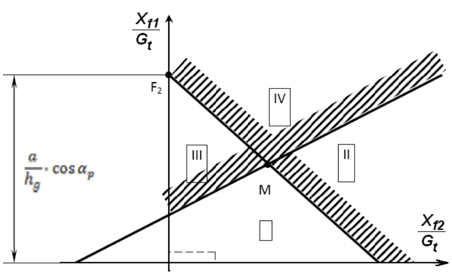

Fig. 2 – Straight lines equations (D_1) and (D_2) in axle system (X_{f1} / G_a; X_{f2} / G_a) [1]

Limiting, the two inequalities form the equations of two lines (D_1) and (D_2) in system of axles (X_{f1} / G_a; X_{f2} / G_a) - figure 2.

Crossing points of these straight lines with axles are:

$$(D_1):\frac{X_{f1}}{G_t}=0\Rightarrow\frac{X_{f2}}{G_t}=-\frac{b}{h_g}\cos\alpha_p; \tag{12}$$

$$(D_2):\frac{X_{f2}}{G_t}=0\Rightarrow\frac{X_{f1}}{G_t}=\frac{a}{h_g}\cos\alpha_p; \tag{13}$$

These points are fixed in case of a tractor, they depending only on gravity centre position (coordinates a, b and h_g) and slope tilting angle αp. When modifying the adherence coefficient, it will result a fascicle of straight lines which pass through respective points.

Points from the diagram located above the straight line (D_1) do not meet the inequality (8) and, therefore the braking force at front shaft axles surpasses the adherence limit, and its wheels block.

Points from the diagram located above the straight line (D_2) do not meet the inequality (9) and therefore thae braking force at rear axle surpasses the adherence limit and its wheels block.

For a certain value of adherence coefficient ϕ_x, the two straight lines cross in point *M* which divides the diagram plan in four domains: I, II, III and IV.

An operating point, "*F*", of the braking system on a ceratin road, defined by α_p and ϕ_x, is characterized by a certain report between parameters $\frac{X_{f1}}{G_t}$ and $\frac{X_{f2}}{G_t}$. Depending on this point position on diagram, the following situations can appear:

- ✓ *F* is situated within domain I, then the both shaft axles braking forces are under the adherence limit (do not block);
- ✓ *F* is situated within domain II, then the rear axle braking forces surpass the adherence limit and rear wheels block, but front wheels do not;
- ✓ *F* is situated within domain III, then the front shaft axles braking forces surpass the adherence limit and front wheels block and rear wheels do not;
- ✓ *F* is situated within domain IV, then the both shaft axles braking forces surpass the adherence limit and all the wheels block.

In point *M* the adherence limit is reached at both shafts simultaneously, so for this operating regime is obtained the biggest braking force.

If braking is performed with disengaged engine and decelerations are not high, we may consider:

$$X_{fj} \cong F_{fj}, j = 1,2 \tag{14}$$

So, within the diagram we can work directly with $\frac{F_{f1}}{G_t}$ and $\frac{F_{f2}}{G_t}$.

We define coefficient of repartition of shaft braking force, ν, report:

$$\nu = \frac{F_{f1}}{F_f} = \frac{F_{f1}}{F_{f1} + F_{f2}} \tag{15}$$

Hence, it results:

$$F_{f1} = \nu \cdot F_f \text{ şi } F_{f2} = (1-\nu) \cdot F_f \tag{16}$$

From relations (16) through dividing, it results:

$$\frac{F_{f1}}{F_{f2}} = \frac{F_{f1}/G_t}{F_{f2}/G_t} = \frac{\nu}{1-\nu} = const.$$

or

$$\frac{F_{f1}}{G_t} = \frac{\nu}{1-\nu} \cdot \frac{F_{f2}}{G_t} \tag{17}$$

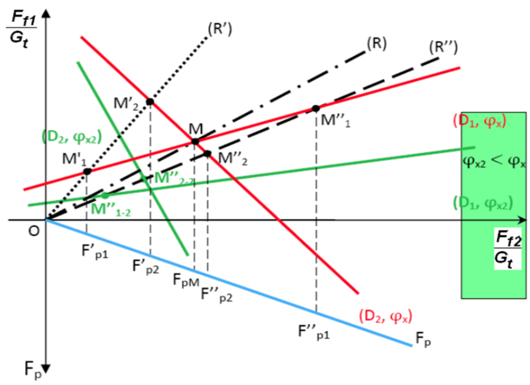

Fig. 3 – Equation of straight line repartition at shaft axles [1]

Equation (16) represents the equation of straight line of shaft braking forces, noted by (R). It passes through the origin of axes system (F_{f1}/G_t, F_{f2}/G_t).

In figure, are represented three repartition straight lines (R), (R') and (R''). The straight lines (R') and (R'') cross the adherence lines (D_1, ϕ_x) and (D_2, ϕ_x) in points M'_1, M''_1, respectively M'_2, M''_2. Straight line (R) crosses the adherence lines exactly in their crossing point, M.

In case of straight line (R'), when pressing the pedal with a force up to F'_{p1}, the braking is performed without blocking the wheels. For acting forces comprised between F'_{p1} and F'_{p2}, the front wheels are blocked, and when the forces get higher all the wheels block.

The same thing happens with repartition straight line (R''), but the wheels blocking orderd is inverted, the rear wheels being blocked the first.

If repartition of braking forces takes place after straight line (R), then the adherence limitis simultaneously reach at both wheels shafts, in point M, after which, if the pedal force keeps growing, all the braked wheels are blocked.

If the adherence coefficient value changes, the tilting angles of adherence straight lines modify and along with them also modify the positions of crossing points with repartition straight lines, which results in a reverse order of wheels blocking. For exemple, points M''_{1-2} and M''_{2-2} appropriate to $\phi_{x2} < \phi_x$ show that in repartition straight line case (R''), first the front wheels block, inversely than for ϕ_x (to which correspond points M'_2, M''_2).

Modification of repartition straight lines can be made by suitably placing the load centre or adjusting the acting pressure at rear wheels braking mechanisms by means of special devices with which the tractor brake system is endowed..

From the form of repartition straight lines equation it results that their inclination in diagram field depends on the value of repartition coefficient ν.

As we have already shown (14) and (13):

$$\nu = \frac{F_{f1}}{F_f} = \frac{F_{f1}}{F_{f1} + F_{f2}} = \frac{F_{f1}}{X_{f1} + X_{f2}}$$

Neglecting the rolling resistence and aerodinamic effects, for a tractor braked when mounting a ramp, it results:

$$X_{f1} = \varphi_x \cdot Z_1 = \varphi_x \cdot \frac{G_t}{L}\left(b \cdot \cos\alpha_p - h_g \cdot \sin\alpha_p + \frac{h_g}{g} \cdot \frac{d\nu}{dt}\right), \tag{18}$$

$$X_{f1} + X_{f2} = \varphi_x \cdot G_1 \cdot \cos\alpha_p \tag{19}$$

It results:

$$\nu = \frac{X_{f1}}{X_f + X_{f2}} = \frac{b}{L} - \frac{h_g}{L} \cdot \tan\alpha_p + \frac{1}{\cos\alpha_p} \cdot \frac{d\nu}{dt} \tag{20}$$

On horizontal field:

$$\nu_0 = \frac{b}{L} + \frac{h_g}{g} \cdot \frac{d\nu}{dt} \tag{21}$$

4. DETERMINATION OF IDEAL BRAKING PARABOLAS [1]

Crossing point of adherence straight lines (point *M* in diagram) represents the regime in which braking is efficiently and stably performed because in this case the adherence limit is simultaneously reached at all the wheels. This point's position changes in diagram plan comparing to value of adherence coefficient which modifies the slope angles of adherence straight lines.

The geometric place of crossing points of adherence straight lines will represent the ideal curve of braking. Mathematical expression of this condition is:

$$\varphi_x(D_1) = \varphi_x(D_2) \tag{22}$$

From equation (10):

$$\left(1 - \varphi_x \cdot \frac{h_g}{L}\right) \cdot \frac{X_{f1}}{G_t} - \varphi_x \cdot \frac{h_g}{L} \cdot \frac{X_{f2}}{G_t} = \varphi_x \cdot \frac{b}{L} \cdot \cos\alpha_p$$

It results:

$$\frac{X_{f1}}{G_t} - \varphi_x \cdot \frac{h_g}{L} \cdot \frac{X_{f1}}{G_t} - \varphi_x \cdot \frac{h_g}{L} \cdot \frac{X_{f2}}{G_t} - \varphi_x \cdot \frac{b}{L} \cdot \cos\alpha_p = 0$$

or

$$\frac{X_{f1}}{G_t} = \varphi_x \cdot \left(\frac{h_g}{L} \cdot \frac{X_{f1}}{G_t} + \frac{h_g}{L} \cdot \frac{X_{f2}}{G_t} + \frac{b}{L} \cdot \cos\alpha_p\right),$$

from where it results:

$$\varphi_x = \frac{X_{f1}}{G_t} \cdot \frac{1}{\frac{h_g}{L} \cdot \frac{X_{f1}}{G_t} + \frac{h_g}{L} \cdot \frac{X_{f2}}{G_t} + \frac{b}{L} \cdot \cos\alpha_p} \tag{23}$$

We introduce ϕ_x determined in relation (11) of straight line (D_2):

$$\varphi_x\cdot\frac{h_g}{L}\cdot\frac{X_{f1}}{G_t}+\left(1+\varphi_x\cdot\frac{h_g}{L}\right)\cdot\frac{X_{f2}}{G_t}=\varphi_x\cdot\frac{a}{L}\cdot\cos\alpha_p,$$

Thus, obtaining:

$$\left(\frac{X_{f1}}{G_t}\right)^2\cdot\frac{h_g}{L}\cdot\frac{1}{\frac{h_g}{L}\cdot\left(\frac{X_{f1}}{G_t}+\frac{X_{f2}}{G_t}+\frac{L}{h_g}\cdot\frac{b}{L}\cdot\cos\alpha_p\right)}+\frac{X_{f1}}{G_t}+\frac{X_{f2}}{G_t}+\frac{h_g}{L}\cdot\frac{X_{f1}}{G_t}\cdot\frac{1}{\frac{h_g}{L}\cdot\left(\frac{X_{f1}}{G_t}+\frac{X_{f2}}{G_t}+\frac{L}{h_g}\cdot\frac{b}{L}\cdot\cos\alpha_p\right)}-$$
$$-\frac{a}{L}\cdot\frac{X_{f1}}{G_t}\cdot\frac{1}{\frac{h_g}{L}\cdot\left(\frac{X_{f1}}{G_t}+\frac{X_{f2}}{G_t}+\frac{L}{h_g}\cdot\frac{b}{L}\cdot\cos\alpha_p\right)}\cdot\cos\alpha_p=0 \quad (24)$$

Reducing to the same denominator the left term of expression (3.55) and equalizing the numerator with 0, we obtain:

$$\left(\frac{X_{f1}}{G_t}\right)^2\cdot\frac{h_g}{L}+\cdot\frac{X_{f2}}{G_t}\cdot\frac{h_g}{L}\cdot\left(\frac{X_{f1}}{G_t}+\frac{X_{f2}}{G_t}+\frac{L}{h_g}\cdot\frac{b}{L}\cdot\cos\alpha_p\right)+\frac{X_{f1}}{G_t}\cdot\frac{X_{f2}}{G_t}\cdot\frac{h_g}{L}-\frac{a}{L}\cdot\frac{X_{f1}}{G_t}\cdot\cos\alpha_p=0;$$
$$\left(\frac{X_{f1}}{G_t}\right)^2+\frac{X_{f1}}{G_t}\cdot\frac{X_{f2}}{G_t}+\left(\frac{X_{f2}}{G_t}\right)^2+\frac{X_{f2}}{G_t}\cdot\frac{b}{h_g}\cdot\cos\alpha_p+\frac{X_{f1}}{G_t}\cdot\frac{X_{f2}}{G_t}-\frac{a}{L}\cdot\frac{L}{h_g}\cdot\frac{X_{f1}}{G_t}\cdot\cos\alpha_p=0; \quad (25)$$
$$\left(\frac{X_{f1}}{G_t}\right)^2+2\frac{X_{f1}}{G_t}\cdot\frac{X_{f2}}{G_t}+\left(\frac{X_{f2}}{G_t}\right)^2+\frac{X_{f2}}{G_t}\cdot\frac{b}{h_g}\cdot\cos\alpha_p-\frac{X_{f1}}{G_t}\cdot\frac{a}{h_g}\cdot\cos\alpha_p=0$$

General equation of quadric curves is:

$a_{11}x^2 + 2a_{12}xy + a_{22}y^2 + 2a_{13}x + 2a_{23}y + a_{33} = 0.$

If term $\delta = a_{11}a_{22} - a_{12}^2 = 0$, then the quadric curve is a parabola.

In this case, $a_{11} = 1$, $a_{12} = 1$, $a_{22} = 1$, $a_{13}=0{,}5\frac{b}{h_g}\cdot\cos\alpha_p$,

$a_{23}=-0{,}5\frac{a}{h_g}\cdot\cos\alpha_p$, $a_{33} = 0$.

It results $\delta=1\cdot1-1^2=0$, so quadric curve is a parabola.

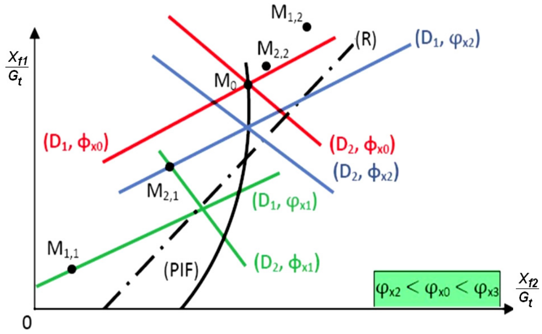

Fig. 4 – Equation of braking parabola [1]

5. CONCLUSIONS

Each point of ideal braking parabola is corresponding a certain value of adherence coefficient. For a braking system with steady repartition of shaft braking forces , the optimum braking condition is met only for a single value of adherence coefficient, ϕ_{x0}, which corresponds to repartition straight line (R) crossing with (PIF). If the displacement is performed on a smaller adherence coefficient road, $\phi_{x1} < \phi_{x0}$, then the repartition straight line will first cross the straight lline (D_1, ϕ_{x1}), which means that the front wheels will be blocked – point $M_{1,1}$; continuing to act the brake pedal by increasing forces; therefore, subsequently the point $M_{1,1}$,will be reached, point where rear weels will be also blocked. If the displacement is on a road with bigger adherence than the reference adherence, $\phi_{x2} > \phi_{x0}$, then the wheels will be blocked in reverse order – points $M_{2,2}$ and $M_{1,2}$.

Braking systems may be endowed with devices – braking distributors – which model the pressoure transmitted to brake mechanisms of rear shaft wheels, so that an approximation (PIF) through two straight lines could be obtained.

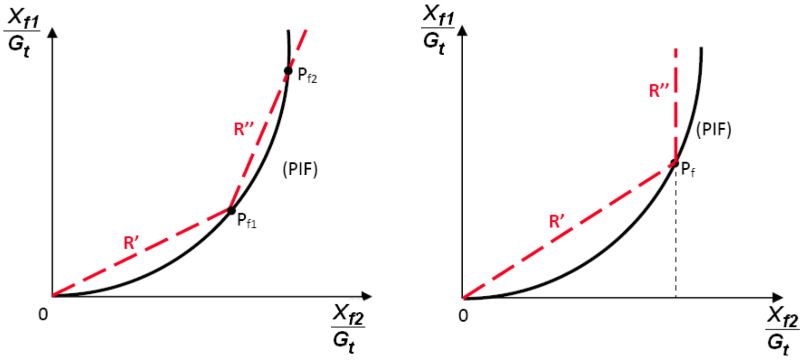

Fig. 5 - Approximation (PIF)of pressure transmitted to braking mechanismes of rear shaft wheels

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