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RESEARCHES REGARDING THE INFLUENCE OF COUPLING METHODS OF IMPLEMENTS ON THE LOAD OF THE TRACTOR AXLES

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Abstract. *The paper presents the dynamic and mathematical modelling of the systems consisting of tractor and implement coupled at the rear of the tractor, based on which the dynamic loads can be determined, which act upon the tractor axle. The paper analyses the dynamic models for the systems consisting of tractor and semi-carried and carried machines (with and without supporting wheels), further mathematical models which allow computer simulation of the dynamic behavior of these systems are developed, aiming at the optimization of the constructive and functional parameters of the components (of tractor and implement)*
Key words: *tractors, implement, coupling methods, axles loads*

1. INTRODUCTION

In order implement mechanization technologies of farming cultures, agricultural machines can be placed on the tractor body at the rear (the most frequent system), at the front, laterally or in combined systems. For this purpose sate of the art tractors are endowed with normalized coupling devices and drives (power take-off), mounted at both the front and the rear of the tractor

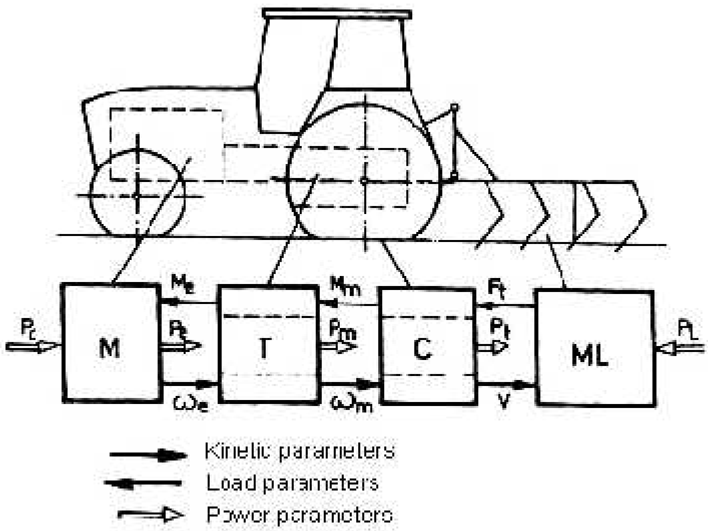

Figure 1. Energy flow of the structural model of the tractor – implement system.

On self-propelled frames machines (implements) can be coupled also between axles, and some specialised tractors have also the possibility of lateral coupling and driving of implements.
From the energy and structural point of view, the tractor - working machine technical system (tractor - implement system) includes several subsystems, linked functionally and by energy flow (fig.1) [2].
The power P_c obtained by fuel combustion in the IC engine *M* is transformed into the effective power P_e developed at the engine shaft (defined by the equation $P_e = M_e \cdot \omega_e$) and conveyed to the tractor transmission *T*. The driving wheels

of the tractor (driven by transmission *T*) develop power P_m (defined by equation $P_m = M_m \cdot \omega_m$), which by means of the adherence of the wheels to the track (soil) is transmitted to the tractor body *C* and, implicitly, to the coupling (driving) device of the implements, thus becoming the driving power P_t (defined by equation $P_t = F_t \cdot v$). The driving power P_t is transmitted to the working machine (implement) *ML* where it turns into useful power P_L required for carrying out the working process of the machine.

2. DYANIMC AND MATHEMATICALMODELS OF TRACTOR-IMPLEMENT SYSTEMS

The implements coupled at the back of the tractor can be pulled (having two own supporting axles), semi-carried (single own axle) and supported by the traction rod or hook, or can be carried by means of the three-point suspension mechanism tie bars of the tractor [1].Figure 2 shows the diagram of the external forces acting upon the tractor - semi-carried implement system during climbing a slope at constant speed. The significance of the external forces in figure 2 is: G_t – tractor weight applied in the mass centre (of coordinates a_c and h_c); G_m – implement weight applied in the mass centre (of coordinates a_m and h_m); Z_1 and Z_2 – normal loads on the front and rear axle of the tractor; Z_m – normal load on the supporting axle (wheel) of the implement; R_{r1} and R_{r2} – rolling resistances of the tractor wheels ($R_{r1} = f_1 Z_1$; $R_{r2} = f_2 Z_2$); R_{rm} – rolling resistance of the implement supporting wheels ($R_{rm} = f_m Z_m$).
While the rolling resistances of the tractor front and rear axle wheels are considered equal, that is $f_1 = f_2 = f_t$. The rolling resistance coefficient of the implement wheels is greater or equal to those of the tractor wheels, that is $f_m \geq f_t$.

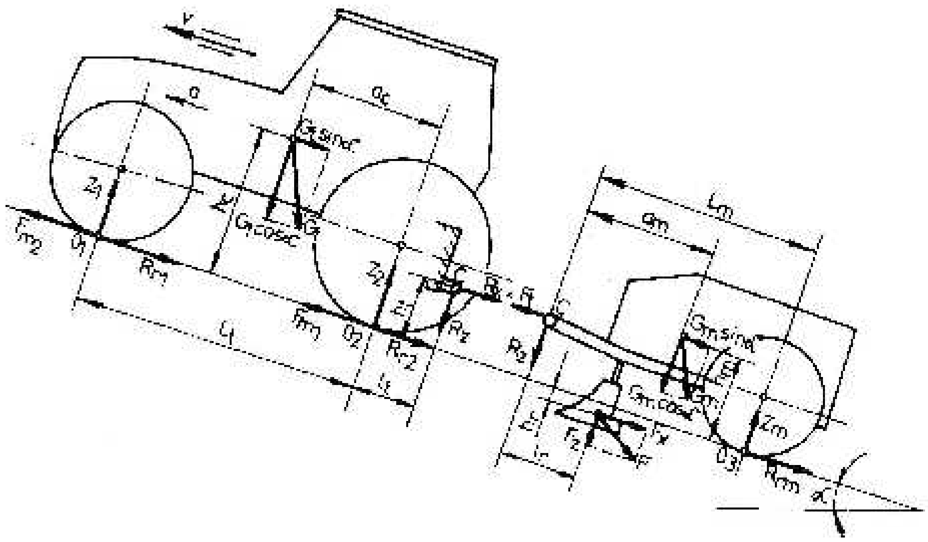

Figure2. External forces acting upon the working tractor - semi-carried implement system during climbing a slope.

The tangential traction forces (driving forces) F_{m1} and F_{m2}, developed by the tractor by means of wheel adherence to the soil, are limited by the value of the wheel – track (soil) adherence coefficient φ and by the normal load on the wheels: $F_{m1} \leq \varphi Z_1$ and $F_{m2} \leq \varphi Z_2$. In the case of four wheel drive tractors (4x4), the total driving force is $F_m = F_{m1} + F_{m2} = \varphi(Z_1 + Z_2)$, and for (4x2) tractors it is: $F_m = F_{m2} = \varphi Z_2$.
The resultant force *F*, occurring from the interaction of the implement working elements with the material (e.g. the soil), generally forms an angle γ with the road surface and can be decomposed into: the traction resisting force $F_x = F\cos\gamma$, parallel to the soil surface, and the compression force $F_z = F\sin\gamma$, normal to the soil surface. The magnitudes of components F_x and F_z and angle γ depend on the type of working process and the construction of the implement working elements.
The link between tractor and implement is achieved by means of the coupling device *C* (traction bar or hook), the force acting in the coupling point being decomposed into: the longitudinal force $R_x = F_t$ – parallel to the road surface and called traction (driving) force, and the force R_z –normal to the road surface and called the pressing force of the implement on the tractor.
From the equilibrium equations of the tractor and the implement (jointed in *C*) the values of the reactions on the axles Z_1, Z_2 and Z_m and of the pressing force R_z of the implement on the tractor body can be determined:

$$Z_1 = [G_t(a_c \cos\alpha - h_c \sin\alpha) - (F_t \cdot h_t + R_z \cdot l_t)]/L_t \quad (1)$$

$$Z_2 = \{G_t[(L_t - a_c)\cos\alpha + h_c \sin\alpha] + F_t h_t + R_z(L_t + l_t)\}/L_t \quad (2)$$

$$Z_m = \{G_m[(a_m \cos\alpha) + (h_m - h_t)\sin\alpha] - F_x(h_r + h_t) - R_{rm}h_t + F_z l_r\}/L_m; \quad (3)$$

$$R_z = \{G_m[(L_m - a_m)\cos\alpha - h_m \sin\alpha]F_x h_r + F_z(L_m - l_r) + F_t h_t\} / L_m \qquad (4)$$

The following linking relationships can be determined from the equilibrium of the forces acting upon tractor and implement along the motion direction of system:

$$F_m = F_t + R_{rt} + G_t \sin\alpha ; \qquad (5)$$

$$F_t = R_x = F_x = G_m \sin\alpha + R_{rm} \qquad (6)$$

where $R_{rt} = f_t(Z_1 + Z_2)$ is the total rolling resistance of the tractor wheels, and $R_{rm} = f_m Z_m$ is the rolling resistance of the implement axle wheels.

Equation (5) represents the equation of the tractor traction balance, and equation (6) represents the balance of traction resistance of the implement, at constant motion speed.

Considering the above equations and also that $f_t = f_m = f$, the equation of the traction balance of the tractor – implement system will have the following form:

$$F_m = F_x + (G_t + G_m)\sin\alpha + f[(G_t + G_m)\cos\alpha + F_z] \qquad (7)$$

For load-free running of the tractor (with no implement attached), that is $F_t = 0$ and $R_z = 0$, the reactions on the wheels have the values:

$$Z_{10} = \frac{G_t(a\cos\alpha - h_c \sin\alpha)}{L_t}; \qquad (8)$$

$$Z_{20} = \frac{G_t[(L_t - a_c)\cos\alpha + h_c \sin\alpha]}{L_t} \qquad (9$$

Consequently, the additional loads on the tractor axles under the influence of the implement are given by the following equations:

$$\Delta Z_1 = Z_1 - Z_{10} = -(F_t h_t + R_z l_t + G_t \sin\alpha)/L_t \qquad (10)$$

$$\Delta Z_2 = Z_2 - Z_{20} == [F_t h_t + R_z(L_t + l_t) + G_t \sin\alpha]/L_t \qquad (11)$$

It follows that under the influence of the implement, the front axle is unloaded by ΔZ_1 which is added to the rear axle together with load R_z.

The additional loading of the tractor as a whole under the influence of the implement is given by equation:

$$\Delta Z_t = \Delta Z_1 + \Delta Z_2 = R_z \qquad (12)$$

The pressing R_z exerted by the implement is given by equation (4), in which traction force F_t is replaced by expression (6).

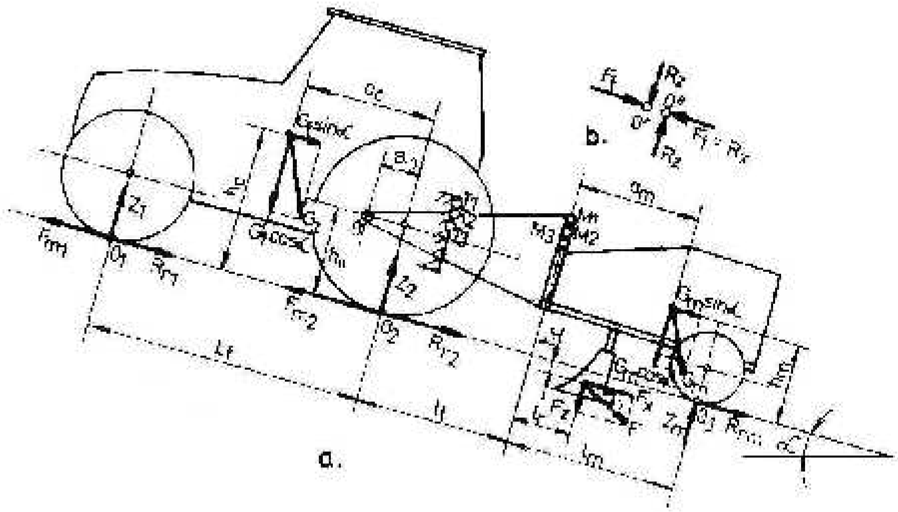

Figure 3. External forces acting upon the tractor – implement system (carried implement endowed with supporting wheels) during climbing a slope (a) and forces in the instantaneous rotation centre O (b)

In the case of carried implements, coupling to the tractor is achieved by means of the three-point suspension mechanism tie bars that endow the tractors. Implements with supporting wheels copy the surface of the soil by means of the supporting wheel (fig. 3), the hydraulic cylinder of the suspension mechanism being in free (floating) position, so that the implement oscillates around the instantaneous rotation centre *O* of the suspension mechanism (positioned by coordinates a_0 horizontally, and h_0 vertically), which result by the intersection of the directions of the suspension mechanism bars.

In this situation the behaviour of the implement is similar to that of the semi-carried one (see fig. 2), considering the shaft jointed in point O, where forces R_x and R_z act, transmitted from the implement to the tractor body (O'-tractor; O''-implement).The reactions on the tractor axles, Z_1 and Z_2, and on the implement supporting wheel, Z_m, as well as the pressing force R_z of the implement on the tractor body are determined from the equilibrium equations of the tractor and the implement (oscillating in relation to point O). The relationships thus obtained are similar to those of the previous case, where coordinate $l_t = - a_0$ and $L_m = a_0 + L_t + l_s$.
The additional load of the tractor (as a whole) ΔZ_t is given by equations:

$$\Delta Z_t = \Delta Z_1 + \Delta Z_2 = R_z \qquad (13)$$

It follows that only part of the forces of the implement (implement weight G_m and normal force F_z acting upon the working elements) are transferred to the tractor, as part of these are born by the supporting wheel of the implement by reaction Z_m.

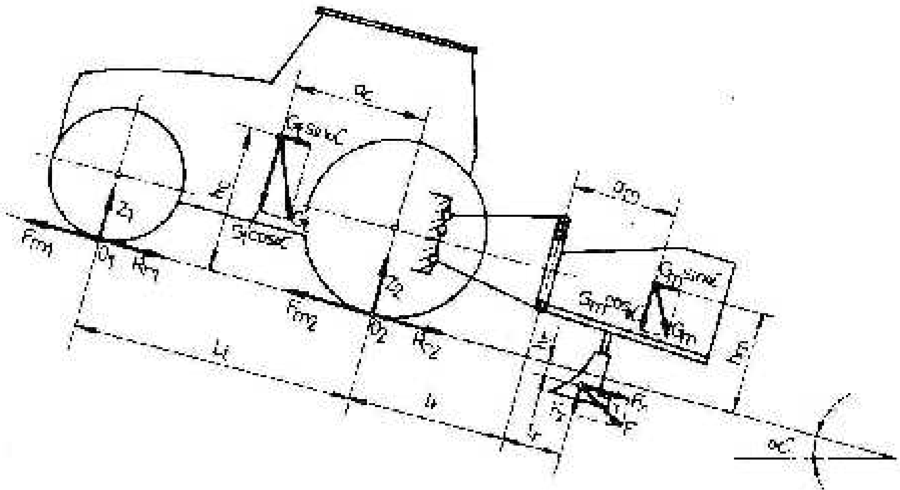

Figure 4. External forces acting upon the tractor – implement system, (carried implement with no supporting wheels) during running at constant speed along a longitudinal slope

From equation (3) it can be noticed that the reaction on the supporting wheel, Z_m, is influenced by coordinates a_0 and h_0 of the instantaneous rotation centre. These can be modified by mounting the superior tie bar of the suspension mechanism in various positions (T_1, T_2, T_3) on the tractor body and the implement body (M_1, M_2, M_3). Thus, by computation the optimum positions can be identified in which the implement wheel carries a minimum load Z_{mmin} (necessary for copying the soil), the rest being transferred to the tractor.
Carried implements with no supporting wheels (fig. 4) are used in order to achieve an integral transfer to the tractor of the forces acting upon the implement. In this case, during operation the implement is maintained in a fixed position in relation to the tractor body (the hydraulic cylinder is in "blocked" mode), and the working parameters (depth or height of the working elements) are maintained by automatic adjustments (of force, position or combined) [1]. The absence of the supporting wheel renders integral the additional loading of the tractor body by the implement, given by the equation:

$$\Delta Z_t = G_m \cos\alpha + F_z \,. \qquad (14)$$

Thus the adherent load of the tractor is increased, slipping is reduced, and implicitly traction related qualities are improved.

3. CONCLUSIONS

- In order to study the influence of the implement coupling modality to the tractor on the load on the tractor axles and implicitly on the increase of the tractor adherence load (in view of increasing the tractor traction force) , the technical tractor – implement systems can be replaced by equivalent dynamic models.
- Knowing the magnitude and action of the exterior forces included by the dynamic model, the dynamic balance of the systems can be analysed and mathematical models can be developed accordingly.
- By replacing in the mathematical models the external forces and constructive and functional parameters of the concrete components of the system (tractor and agricultural implements) the values of the additional loads of the tractor can be established, in order to determine the growth of the tractor traction force by means of increasing the adherent load.
- The optimum solutions can be identified for coupling implements to tractors, as well as optimum constructive and functional parameters of the implement and coupling mechanisms, in view of improving traction related qualities of tractors aggregated with agricultural implements.

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