The 4th International Conference
"Computational Mechanics
and Virtual Engineering"
COMEC 2011
20-22 OCTOBER 2011, Brasov, Romania

CONTRIBUTIONS TO THE STUDY OF STABILITY IN THE TRANSVERSAL PLANE OF THE SYSTEM TRACTOR - TOWED FORAGE HARVESTER MACHINE

O. Stan[1], S. Popescu[2], E. Voicu[3]
[1]Transilvania University of Braşov, Romania : e-mail: octa_ca@yahoo.com
[2]Transilvania University of Braşov, Romania. e-mail: simipop38@yahoo.com
[3]National Institute of Research - Development for Machines and Installations designed to Agriculture and Food Industry - INMA Bucharest, Romania, e-mail:milivoicu@yahoo.com

Abstract. *The towed machines for mowing and crushing forage plants, also called forage vindrovers, performing cutting, crushing, collection and leaving plants in furrow on the stubble have got a large spreading. The towed vindrovers are disposed eccentrically, usually placed unbalanced in the lateral right side of tractors. The dynamics of systems tractor-working machine towed in unbalanced position to the longitudinal axis of the tractor has a certain particularity against the systems with symmetrically coupled to the tractor machines. The paper is an analysis of external forces acting in the transverse plane on the aggregate tractor - towed forage harvester combine at movement in working on horizontal land. From the equations of equilibrium of forces is determined equilibrium conditions and stability at sliding of the tractor in the transversal plane under the action of the machine eccentrically coupled to the tractor and elaborate the mathematical models that allow simulation of system behavior under different conditions of working and moving.*
Keywords*: tractor, semi-carried forage harvester, dynamics of the tractor- machine system, mathematical models, horizontal stability of the tractor- machine system.*

1. INTRODUCTION

The towed or semi-carried forage harvester machines are achieved as mowing machines, mowing and crushing machines (vindrovers) and combines, being coupled to the tractor drawbar and driven from its PTO. As a result, some of the machine weight is taken by the tractor by means of the linkage mechanism, both while operating as well as during transportation.

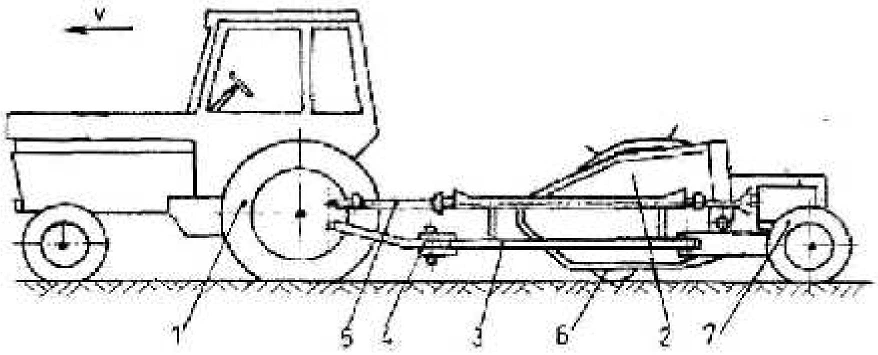

Figure 1. The scheme of the technical system tractor - towed forage harvester machine:
1 – tractor; 2- machine 3- traction (towing) hitch; 4- transversal traction (coupling) bar of tractor; 5 - cardanic transmission; 6- supporting skate (copying) of the mowing equipment; 7- supporting wheels of the machine

The actual harvesting equipments (cutting unit of plants) are articulated to the machine framework and rests on skates that copies the land irregularities, the down force on the ground of the skates being small due to some coil springs which take some of the weight of equipment. The working equipment are passed from transportation position in the working position and back, from working position in transportation position, their lifting and lowering being done by a mechanism driven by a hydraulic cylinder controlled by the hydraulic installation of tractor. A large spreading have taken the towed machines for mowing and crushing forage plants also called windrowers for forages, performing cutting, crushing, collection and leaving in furrow of plants on the stubble The towed forage harvester machines are located, usually, in the right side of tractors. The tractor 1 (Fig.1). is towing the forage harvester 2 coupled through the hitch 3 to the traction crossbar 4 of the tractor. Working bodies of the machine are operated from the tractor PTO through the cardan transmission 5. The machine rests on the soil by means of the wheels and the harvesting equipment for plants is articulated to the machine body and copy the soil surface by means of the skates 6.

2. DYANIMC AND MATHEMATICALMODELS FOR THE STUDY THE HORIZONTAL STABILITY OF THE TRACTOR- FORAGE HARVESTER SYSTEM.

The scheme of forces acting on the transverse plane on the displacement system on horizontal field (α = 0) with constant speed (a =0) is given in Figure 2.

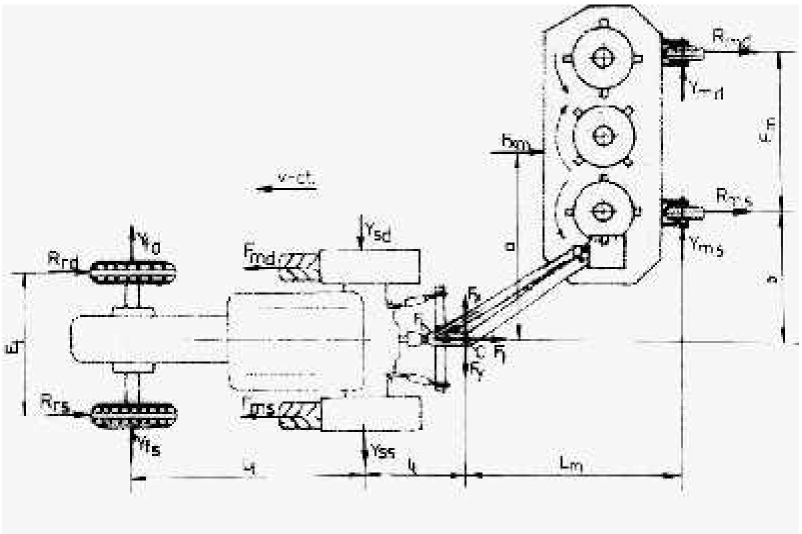

Figure 2. The scheme of forces acting on transverse plane on the displacement system on horizontal field (α = 0) with constant speed (v = ct)

The external forces acting on the tractor have the following meanings:
F_{md} and F_{ms} – driving forces (traction) developed by adherence of the wheels with the ground, on the right (F_{md}) and on the left side (F_{ms}). The total driving force is given by the traction balance equation of the tractor, expressed through the relation:

$$F_m = F_{md} + F_{ms} = \varphi \cdot Z_{ad}, \tag{1}$$

where: Z_{ad} is the adherence load of the tractor: Z_{ad} = Z_2 in the case of (4x2) tractors and Z_{ad} = Z_1+Z_2, Z_2 for the (4x4) tractors;
R_{rd} and R_{rs} – rolling resistance of tractor wheels, right and left wheels. The total rolling resistance R_{rt} of the tractor wheels is:

$$R_{rt} = R_{rd} + R_{rs} = f_t (Z_1 + Z_2) = f_t \cdot Z_t,$$

where: f_t is the coefficient of rolling resistance of the tractor Z_1 şi Z_2 - normal loads on the front and respectively rear axles; Z_t – the total load on tractor axles;
Y_{sd} şi Y_{ss} – lateral (cornering) forces acting at the rear wheels axle (right and left) caused by reaction through lateral adherence, opposing to lateral sliding of the tractor wheels. The total transversal reaction on the rear axle of the tractor is given by the relation:

$$Y_s = \mathrm{Y}_{\mathrm{sd}} + \mathrm{Y}_{\mathrm{ss}} = \varphi_{yt} \cdot Z_1,$$

where: φ_{yt} is the coefficient of adherence at skidding of the tractor wheels and Z_1 –the rear axle load;
Y_{fd} and Y_{fs} - lateral (cornering) forces due to lateral reaction (through lateral adherence), of the front wheel axle (right and left). The total transversal reaction on the front axle is:

$$Y_f = Y_{fs} + Y_{fd} = \varphi_{yt} \cdot Z_2,$$

where: φ_{yt} is the coefficient of adherence at lateral sliding of the tractor wheels; Z_2 – rear axle load;

F_t – tractive force developed by tractor acting in coupling point C. Based on the traction balance of the tractor at moving with towed machines on horizontal field in uniform motion ($v = ct$; $a = 0$), the traction force F_t is defined through the relation:

$$F_t = F_m - R_{rt} = \varphi \cdot Z_{ad} - f \cdot Z_t \quad (2)$$

where: φ is the coefficient of traction adherence of the tractor wheels; Z_{ad} - adherent load of the tractor (load on driving wheels: $Z_{ad} = Z_2$, in the case of tractors with traction on rear axle (4x2) and $Z_{ad} = Z_1 + Z_2$ - in the case of all-wheel drive tractors (4x4)); f - rolling resistance coefficient of the tractor wheels; $Z_t = Z_1 + Z_2$ - the total load on tractor axles;
F_Y – lateral force transmitted by the machine on the tractor through coupling point C at the tow bar (is determined from the dynamics of the machine during working);
The external forces acting on the machine have the following meanings:
F_x – the force of resistance to the machine movement resulting from the action of mowing device on the the material to be cut and depends on the working width of the cutting device and of the specific resistance at cutting per unit of working width;
R_{md} and R_{ms} – rolling resistance forces of the right hand wheels (R_{md}) and left (R_{ms}) of the machine. The total rolling resistance R_{rm} of the machine wheels is given by the relation:

$$R_{rm} = R_{md} + R_{ms} = f_m \cdot Z_3,$$

where Z_3 is the normal load on the machine axle and f_m is the coefficient of the rolling resistance of the machine wheels, which can be considered equal to the coefficient of rolling resistance of tractor wheels, $f_m = f_t = f$;
Y_{md} şi Y_{ms} are the lateral adherence forces at the displacement of the right hand wheels and, respectively, left hand. The total lateral adherence force of the wheels is given by the relation:

$$Y_m = Y_{ms} + Y_{md} = \varphi_{ym} \cdot Z_3,$$

where φ_{ym} is the coefficient of lateral adherence (at sliding) of the machine wheels, depending on tire construction of the wheels and the type and soil conditions (road);
F_t – the force of resistance to the machine traction by the tractor, placed in the longitudinal axis of the machine, at the lateral distance a on the right side relative to the longitudinal axis of the tractor. The value of this force resulting from the balance of resistance forces of the machine, expressed through the relation:

$$F_t = F_x + F_{rm} = F_x + f \cdot Z_3, \quad (3)$$

F_y – the lateral component of the force acting in the transversal plane in the coupling point C of the machine to tractor, placed on the tow bar at the distance l_t relative to the axis of the rear axle of the tractor.
Taking into account the traction balance of the machine expressed through the relation (3) and of traction balance of the tractor (2) is obtained the equation of traction balance of tractor-harvester system:

$$F_m = R_{rt} + F_x + R_{rm} = F_x + f(Z_1 + Z_2 + Z_3). \quad (4)$$

For the analysis of stability of the tractor-machine system in the transverse plane is determined, first, the lateral force F_y acting on of the machine towing pin at the tow bar. On the basis of equilibrium equations of the machine in the transverse plane, results the final relation:

$$F_y = \frac{F_x\left(b + \frac{F_m}{2}\right) + R_{ms} \cdot b + R_{ms}(b + F_m)}{L_m} \quad (5)$$

where l_m is the distance from the coupling point of the machine to the tow bar (point C, see Fig. 1) and the axis of supporting axle of the machine.
To the movement of tractor, the lateral force F_y which is a disturbing force in the transverse plane, gives rise to a disturbing torque in the transverse plane acting on the body of the tractor, tending to cause the skidding of tractor wheels and the tractor deviation from the trajectory of movement [1, 2]. To sliding process it oppose the lateral adherence forces, realized through the load on the tractor wheels, whose magnitude depends on vertical loads (normal on wheels) and on coefficient of adherence to skidding existing between the wheels and the road (soil). From the equations of equilibrium of the tractor in the transverse plane results, after transformations, the final relations:

- for the front axle of the tractor:

$$\varphi_y \cdot Z_1 = \frac{F_y \cdot l_c}{L_t} \quad (6)$$

- for the rear axle of the tractor:

$$\varphi_y \cdot Z_2 = F_y \cdot \frac{L_t - l_c}{L_t} \qquad (7)$$

representing equilibrium conditions and respectively stability to skidding of the tractor in the transverse plane under the action of the machine eccentrically coupled to the tractor.

From the analysis of the relations (6) and (7), results that the value of lateral force F_y developed by the machine eccentrically placed in relation to the longitudinal axis of the tractor, must not exceed the resultant of lateral forces opposing to sliding of tractor, achieved through the lateral adherence forces to the front axle ($\varphi_y \cdot Z_1$) and, respectively, to the rear axle ($\varphi_y \cdot Z_2$). Considering the previous relations, results that the lateral force F_y must not exceed the lowest value resulting from previously conditions, i.e.:

$$F_y \le \varphi \cdot \frac{Z_1 \cdot L}{l_c}; \; F_y \le \varphi \cdot \frac{Z_2 \cdot L}{L - l_c}. \qquad (8)$$

In the same time, the lateral (cornering) force F_y must be less than the lateral adherence force realized by the supporting wheels of the machine, given by the relation:

$$Y_m = Y_{ms} + Y_{md} = \varphi_{ym} . Z_3 , \qquad (9)$$

that is:

$$F_y = \varphi_{ym} . Z_3 . \qquad (10)$$

This relation represents the equilibrium and stability condition to the sliding in transversal plane of the towed machines eccentrically coupled relative to the longitudinal axis of the tractor.

To increase the lateral stability (at skidding) of the machine shall choosing wheels with tires with appropriate profile to an enhanced lateral adherence, performing increased lateral adherence coefficients φ_{ym} (for example tires with protruding circumferential ribs).

REFERENCES

[1]Popescu, S., Tane,N., Csatlos,C. Contribution à l'étude de la stabilité pendant le déplacement de travail des agregates tracteur-machine agricole. CONAT-ATMA, Braşov, (1988). vol. II, pp. MA-63-70.

[2]Popescu, S., Mugea, N. Study of the deviation of the trajectory of tractor - implement system moving under the action of lateral forces. The IXth International Conference CONAT '99, Braşov (România), 1999, vol. II.

[3]Voicu, E. Researches regarding the dynamic and energetic optimization of tractor-fodder harvesting machine unit. PhD Thesis, Transilvania University of Brasov/Romania, 2007.