Study on the Dynamics of the Tilling Aggregate

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Abstract: *This paper has as main subject presenting some theoretical and experimental researches regarding the dynamic behaviour of the tilling aggregates. These are made of a tractor and an attached plow that allow emphasizing the influence of the work width adjustment system over the dynamics of the tilling aggregates when moving on different types of soil, in different work conditions.*

Keywords*: dynamics, tilling, aggregate*

1. Introduction

External forces acting on a vertical-longitudinal plane on a tilling aggregate that has an accelerated motion when climbing on a tilted surface at an angle of *α*, in respect to the horizontal, represents the equivalent dynamic model of the aggregate.
In this paper there are presented a theoretical research over the dynamics of the towed tilling plow and a theoretical research of the dynamics of the tilling aggregate made of a tractor and a towed plow with and without the copying wheel.

2. Theoretical researches on the dynamics of the towed plow

In Figure 1 there is presented an equivalent dynamic model [1], [2] of a towed plow with three mouldboards that is moving with an accelerated motion on a soil with tilted surface at an angle of *α*, in respect to the horizontal. The plow is equipped with a copying wheel and it is attached to the suspension mechanism in three points.

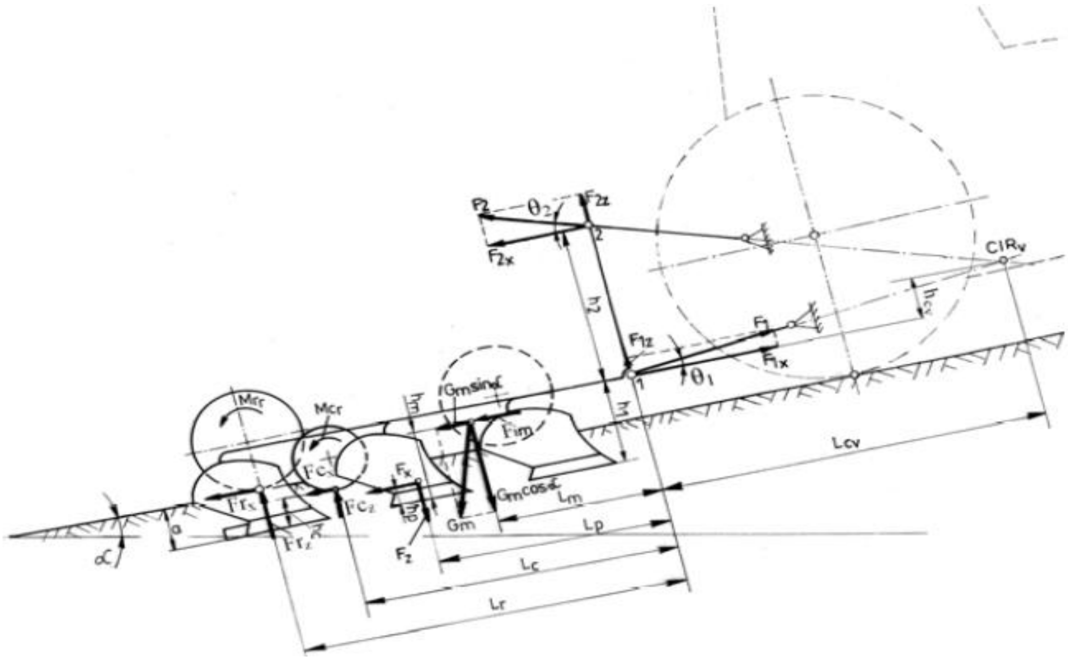

Fig. 1. Diagram of the forces acting on the towed plow, with copying wheel,
in vertical-longitudinal plane when moving with accelerated motion on a tilted terrain

Instantaneous rotation centre in vertical plane, CIR_y, is located at the intersection point of the central axel axis with the lower axels plane. The plow has the working depth of *a*; working width of a mouldboard is *b* (working width of the plow is B = 3b) [1].

Component F_x, parallel to soil's surface, represents the traction resistance force of the plow, that can be experimentally determined (through field or laboratory measurements) or through analytical calculus using the following equation:

$$F_x = k \cdot a \cdot b \cdot n \tag{1}$$

where:

k – global specific tilling resistance coefficient;
a – working depth;
b – working width of the first mouldboard;
n – total number of mouldboards.

Component F_z , perpendicular to soil's surface, of the tilling resistance force is determined using:

$$F_z = F_x \cdot \tan\beta \tag{2}$$

where:

β – angle between the two components of the tilling resistance force.
For normal working conditions, it is considered that:

$$F_z = (0{,}2 \ldots 0{,}3) \cdot F_x \tag{3}$$

The force acting on the disc knife has two components: one parallel with soil's surface, F_{cx}, and one perpendicular to soil's surface, F_{cz}. The dependency between the two components of the cutting resistance force is given by:

$$F_{cx} = F_{cz} \cdot f_c \tag{4}$$

where:

f_c – rolling resistance coefficient of the disc knife.

The force acting on the copying wheel has two components: one parallel to soil's surface, F_{rx} and one perpendicular to soil's surface, F_{rz}. Component F_{rx} represents the rolling resistance force of the copying wheel, being dependent on the size of the copying wheel, on the soil's characteristics and on the wheel load [3]. The dependence between the two components of the resistance force that acts on the copying wheel is given by:

$$Fr_x = Fr_z - f_r \tag{5}$$

where:

f_r – rolling resistance coefficient of copying wheel.

Components of the forces F_1 and F_2 acting on coupling points 1 and 2 of the suspension mechanism axels onto the aggregate's chassis can be written to each other using equations (6) and (7):

$$F_{1z} = F_{1x} \cdot \tan\theta_1 \tag{6}$$

$$F_{2z} = F_{2x} \cdot \tan\theta_2 \tag{7}$$

Given the above, the equilibrium equations can be written as:

$$F_{1x} - F_{2x} - F_{im} - G_m \sin\alpha - F_x - F_{cz} \cdot f_c - F_{rz} \cdot f_r = 0 \tag{8}$$

$$F_{1x} \cdot \tan\theta_1 + F_{2x} \cdot \tan\theta_2 - G_m \cdot \cos\alpha - F_x \cdot \tan\beta + F_{c2} + F_{rz} = 0 \tag{9}$$

$$F_{rz} \cdot [l_r + f_r(h_1 - a)] + Z_c \cdot [l_c + f_c(h_1 - h_c)] + F_x \cdot (h_1 - h_p - l_p \cdot \tan\beta) + \\ + G_m[(h_1 - h_m) \cdot \sin\alpha - l_m \cdot \cos\alpha] + F_{im}(h_1 - h_m) - F_{2x} \cdot h_2 - Mr_r - Mc_r = 0 \quad (10)$$

The system formed by the equations (8), (9) and (10) is a linear system [2] having three unknowns and can be a compatible determined system, the unknowns being the forces acting on the coupling points 1 and 2 of the suspension mechanism axels onto plow's frame (F_{1x}, F_{1z}, F_{2x} and F_{2z}) and the forces acting on the copying wheel (F_{rx}, F_{rz}) and M_{rr} torque. Solving through algebraic methods the system of equations it can be found the three unknowns: F_{1x}, F_{2x} and Fr_z.

3. Theoretical researches on the dynamics of the tilling aggregate made of a tractor and a towed plow with copying wheel

In this case, the plow is equipped with a copying wheel and it is attached to the suspension mechanism with three coupling points (functioning in a floating regime), having the instantaneous center of rotation in vertical-longitudinal plane, CIR_v, located at the intersection point of the central axel's axe with the lower axels plane.

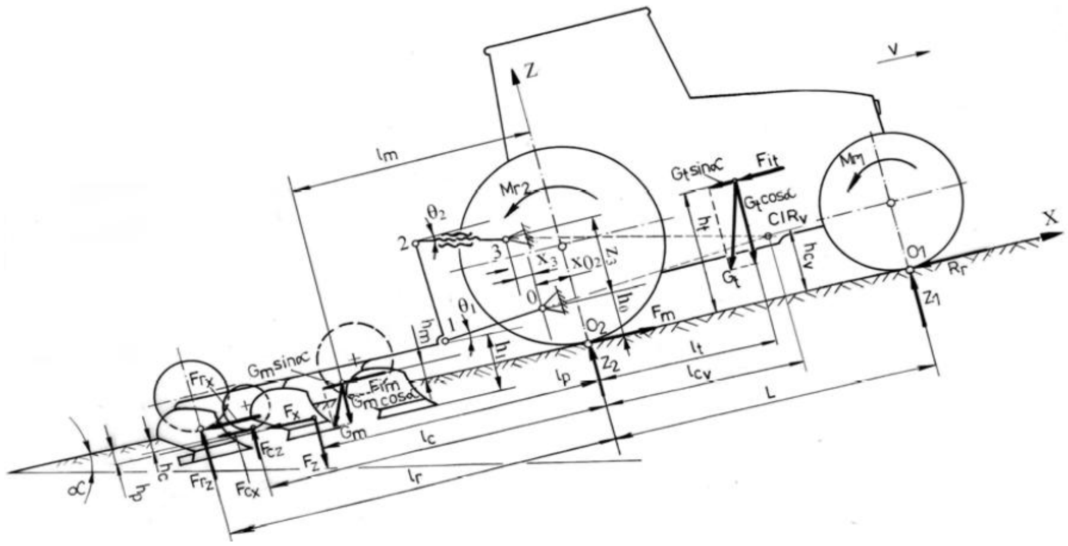

Fig. 2. Dynamic model, in vertical-longitudinal plane, of the tilling aggregate with towed plow equipped with a copying wheel (without automatic adjustment)

It is given a system of coordinates XOZ, having its origin in point O_2, representing the point of contact with the soil of the rear axel's wheels, where OX axis is parallel to the moving direction of the aggregate.
Therefore:

$$G_t = m_t \cdot g \quad (11)$$

where:

G_t – tractor's gravity force;

$$G_m = m_m \cdot g \quad (12)$$

F_{it} – inertia of the tractor:

$$F_{it} = m_t \cdot \frac{dv}{dt} \quad (13)$$

F_{im} – inertia of the aggregate:

$$F_{im} = m_m \cdot \frac{dv}{dt} \quad (14)$$

Since the suspension mechanism [4] is working in floating regime, the plow has the possibility to rotate in vertical-longitudinal plane around the instantaneous center of rotation, CIR_v, following the unevenness through the copying wheel's profile, keeping constant the working depth *a*. Therefore, the tractor-plow system is supported on the wheels of tractor's axels as well as on the copying wheel of the plow. Load forces acting on the tractor's axels are given by the torque equations of the forces acting on the tractor, in respect to points O_1 and O_2.

$$Z_1 = \frac{G_t \cdot (l_t \cdot \cos\alpha - h_t \cdot \sin\alpha) - G_m \cdot (h_m \cdot \sin\alpha + l_m \cdot \cos\alpha)}{L} - \frac{Fi_t \cdot h_t + Fi_m \cdot h_m - F_x \cdot (h_p - l_p \cdot tg\beta) + Fc_x \cdot (h_c + f_c \cdot l_c) + Mr_t}{L} + \frac{Fr_z \cdot l_r}{L}$$

$$Z_2 = \frac{G_t \cdot [h_t \cdot \sin\alpha + (L - l_t) \cdot \cos\alpha] + G_m \cdot [h_m \cdot \sin\alpha + (L + l_m) \cdot \cos\alpha]}{L} + \frac{Fi_t \cdot h_t + Fi_m \cdot h_m - F_x \cdot [h_p - (L + l_p) \cdot tg\beta] - Fc_x \cdot [h_c + f_c \cdot (L + l_c)] + Mr_t}{L} - \frac{Fr_z \cdot (L + l_r)}{L} \quad (15)$$

The system of equations given above represents the mathematical model that describes the system's dynamic behavior in vertical-longitudinal plane, when moving on a tilted terrain having constant speed. This mathematical model can be used for analyzing (computer simulation) the rollover stability, provided that the load on the front axle to be at least 20% of tractor's weight.
Given the equations above, it results that using a copying wheel only some of the forces of the aggregate are transferred onto the tractor because a part of these are being taken by the copying wheel.

4. Theoretical researches on the dynamics of the tilling aggregate made of a tractor and a towed plow without copying wheel

Given the case when the tractor is a part of the tilling aggregate and the plow is not equipped with a copying wheel (as shown in Fig.3), the suspension mechanism is operates in an automatic control regime (for force, position or mixed).

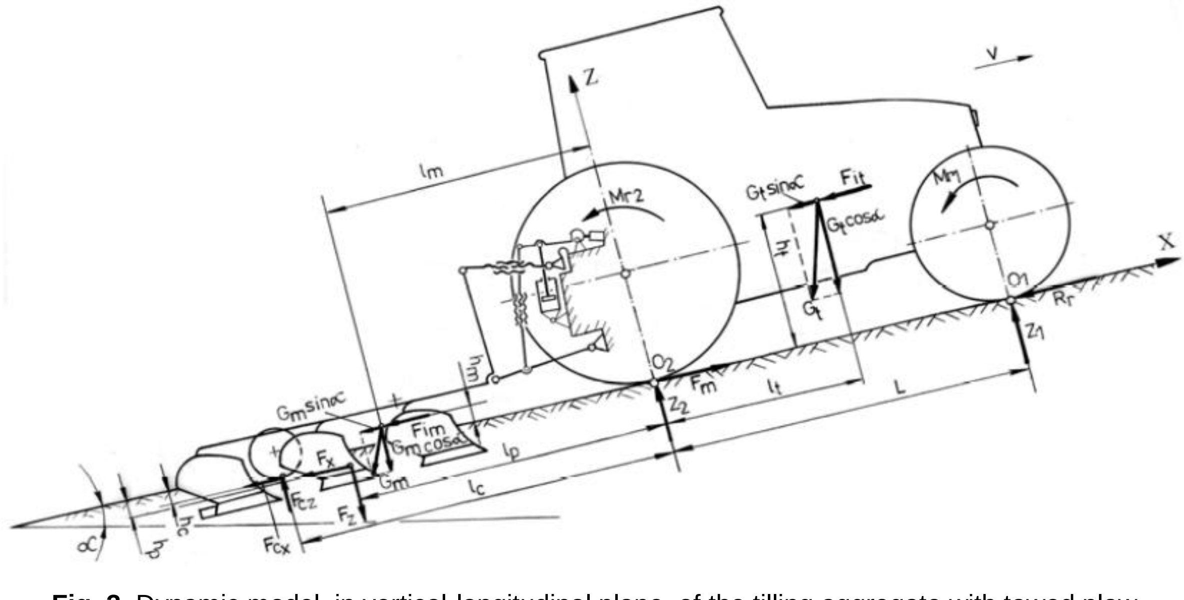

Fig. 3. Dynamic model, in vertical-longitudinal plane, of the tilling aggregate with towed plow without a copying wheel (automatic adjustment)

The case when the towed plow is not equipped with a copying wheel implies that its entire weight along with vertical components of the forces that act on the working bodies are transmitted to the

tractor's chassis through the suspension mechanism. Therefore, plow's frame is attached with the tractor's chassis [2].
Total load on the tractor's axels, Z_T, is given by summing the reaction forces, Z_1 and Z_2, on the two axels, as follows:

$$Z_T = Z_1 + Z_2 = (G_t + G_m) \cdot \cos\alpha + F_z - Fc_z \tag{16}$$

The reaction forces in the suspension points of the tractor's drivetrain are determined from the torque equilibrium equations in respect with support points O_1 and O_2 of tractor's axels, as follows:

$$Z_1 = \frac{G_t \cdot (l_t \cdot \cos\alpha - h_t \cdot \sin\alpha) - G_m \cdot (h_m \cdot \sin\alpha + l_m \cdot \cos\alpha)}{L} - \frac{Fi_t \cdot h_t + Fi_m \cdot h_m - F_x \cdot (h_p - l_p \cdot tg\beta) - Fc_x \cdot (h_c + f_c \cdot l_c) + Mr}{L}$$

$$Z_2 = \frac{G_t \cdot [h_t \cdot \sin\alpha + (L - l_t) \cdot \cos\alpha] + G_m \cdot [h_m \cdot \sin\alpha + (L + l_m) \cdot \cos\alpha]}{L} + \frac{Fi_t \cdot h_t + Fi_m \cdot h_m - F_x \cdot [h_p - (L + l_p) \cdot tg\beta] - Fc_x \cdot [h_c + f_c \cdot (L + l_c)] + Mr}{L} \tag{17}$$

Given the above it results that when the plow is not equipped with a copying wheel (automatic adjustment plow), the axels of the tractor have an additional load equal with the load that would have been taken by the copying wheel.

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