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

RESEARCHES REGARDING THE MATHEMATICAL SIMULATION OF KINETOSTATICS OF THE THREE-POINT HITCH COUPLERS USED TO AGRICULTURAL TRACTORS

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Abstract: *The paper presents an analytical method of the development and of analysis of three-point hitch couplers used to agricultural tractors. As we know, the object of kinetostatics is the study of all forces which acts upon the mechanism elements during their motion. This study is made starting from the following initial data: the kinematic scheme of the mechanism, the geometrical sizes of mechanism elements and the coordinates of kinematic couples. Within the calculations are not taken into account the inertia and the friction forces from the kinematic couples. The mechanism is dived in three kinematic groups. The study and the simulation of kinetostatics mechanism are made for each group depending on the piston position in the lift cylinder of the mechanism. Thus we determine the forces of the kinematic couples in all the mechanism elements, including the force from the piston rod, for each mechanism position, starting with the working position and finishing with the one of transport. We present the results of the researches made upon wheeled tractors U 650 and U 650 DT.*
Keywords: *kinetostatics, three-point hitch couplers, agricultural tractor.*

1. INTRODUCTION

The dynamic analysis of the three-point hitch couplers is to determine all the forces from its elements arising from the external drive tasks. Analysis is done by groups, starting from the group that we know as external forces.
Initial data for calculation are:

- the kinematical scheme of the three-point hitch couplers for which we know the dimensions and the coordinates of all the points, for the analyses position;
- the weight of the three-point hitch couplers farming machine (the elements mass of the mechanism, is usually neglected);
- the resultant of the exterior forces (of working resistances) which acts upon the mechanism

In calculations, the result of the exterior forces is represented by R_x and R_y components, applied to the point S_1. In the calculations that follow there are not taken into account the frictional forces of the mechanism and also the inertial forces.
The kinematics scheme of the mechanism is presented in figure 1.

2. THE FORCES AND REACTION CALCULUS

The calculus of ground reaction

The traction force from a plough is given by the relation:

$$F_t = R_x = R'_x + F_x, \qquad (1)$$

where: R'_x – the horizontal element of the useful resistances of the plough: $R'_x \cong khb$; k – the specific resistance of the ground; h – the working depth of the plough; b – the plough width; $F_x \approx 0.16R_x$ – the unwanted resistances of the plough (the frictions of the operating parts with the ground).
The resultant of the vertical forces (fig. 1) is given by the relation:

$$(R_y)_{\text{sum}} = Q + R_y, \qquad (2)$$

where Q is the plough weight.

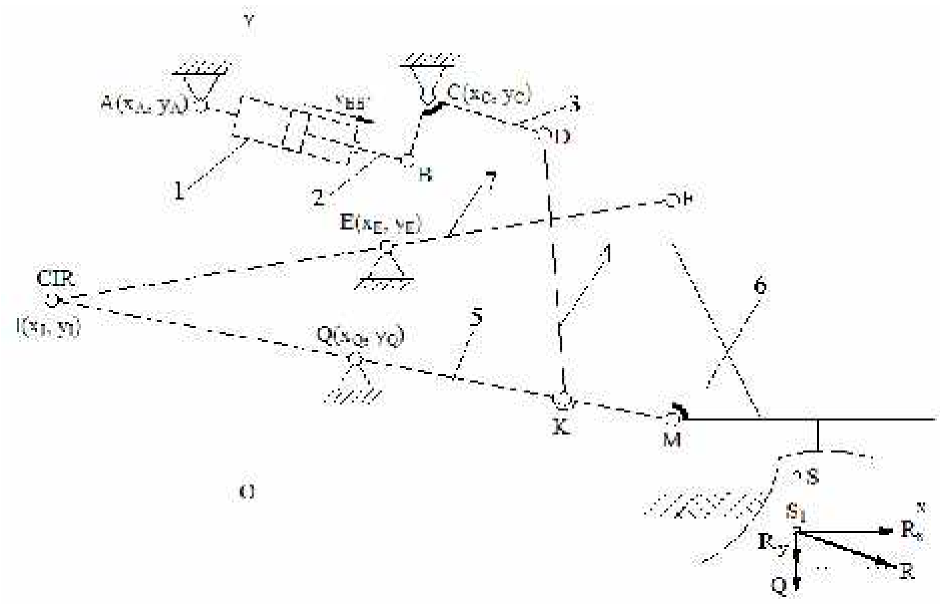

Figure 1: The scheme of the three-point hitch couplers.[1]

The forces and reactions calculus for the *6 – 7* groups

The reaction R_7, is equal with the force from the central couplin bar 7, and it is determined from the moments equation in ratio with se *M* point (fig. 2):

$$\sum M_M = 0; \quad \Rightarrow F_t(y_M - y_{S1}) + (R_y + Q)(x_{S1} - x_M) - (y_E - y_M)R_7 \cos\alpha_1 - (x_M - x_E)R_7 \sin\alpha_1 = 0; \quad \Rightarrow$$

$$F_t(y_M - y_{S1}) + (R_y + Q)(x_{S1} - x_M) + R_7[(y_M - y_E)\cos\alpha_1 + (x_E - x_M)\sin\alpha_1] = 0;$$

from where

$$R_7 = -\frac{F_t(y_M - y_{S1}) + (R_y + Q)(x_{S1} - x_M)}{(y_M - y_E)\cos\alpha_1 + (x_E - x_M)\sin\alpha_1}. \tag{3}$$

And the reaction elements are:

$$R_{7x} = R_7 \cos\alpha_1; \quad R_{7y} = R_7 \sin\alpha_1. \tag{4}$$

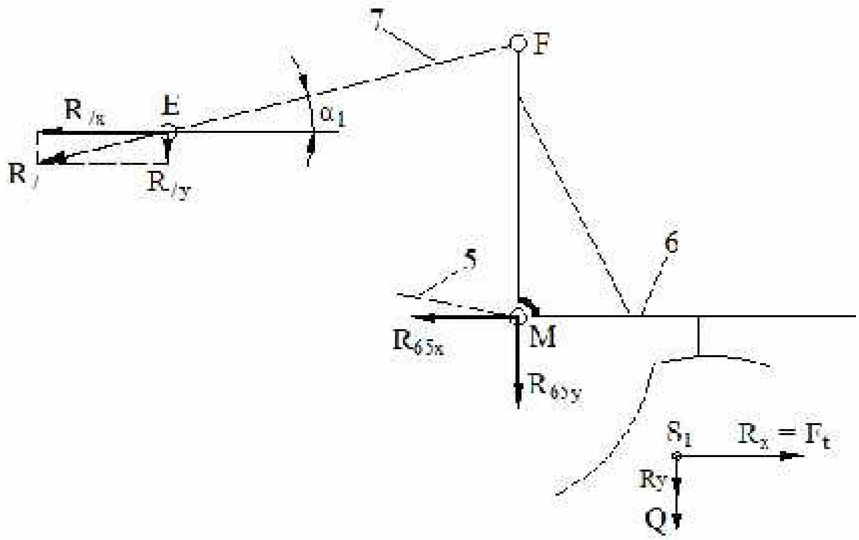

Figure 2: The scheme of the forces calculus of the group *6 – 7*.

The elements of the reaction R_{65} from the fixe hinge *M* are determinde from the forces projections from the two axes:

$$\sum F_x = 0 \quad \Rightarrow \quad F_t - R_{65} - R_{7x} = 0 \quad \Rightarrow \quad R_{65x} = F_t - R_{7x} \tag{5}$$

$$\sum F_y = 0 \quad \Rightarrow \quad -R_{7y} - R_{65y} - R_y - Q = 0; \quad \Rightarrow \quad R_{65y} = -(R_y + Q + R_{7y}). \tag{6}$$

The reaction resulted in this joint will be:

$$R_{65} = \sqrt{R_{65x}^2 + R_{65y}^2}. \tag{7}$$

The inclination angle α_1 is determined by the relation:

$$\alpha_1 = \text{arctg}\left(\frac{EF_y}{EF_x}\right) + \frac{\pi}{2}\left(1 - \frac{EF_x}{|EF_x|}\right) + 2\pi; \tag{8}$$

or

$$\alpha_1 = \text{arctg}\left(\frac{y_F - y_E}{x_F - x_E}\right) + \frac{\pi}{2}\left(1 - \frac{x_F - x_E}{|x_F - x_E|}\right) + 2\pi. \tag{8'}$$

The forces and reactions calculus for the *4–5* groups

In order to determine the forces (reactions) from this group we use figure 3. First, we determine, the elements of the reaction R_{43}, equal with the hanger *4*:

$$\begin{aligned} R_{43x} &= R_{43}\sin(90^\circ - \alpha_2) = R_{43}\cos\alpha_2; \\ R_{43y} &= R_{43}\cos(90^\circ - \alpha_2) = R_{43}\sin\alpha_2. \end{aligned} \tag{9}$$

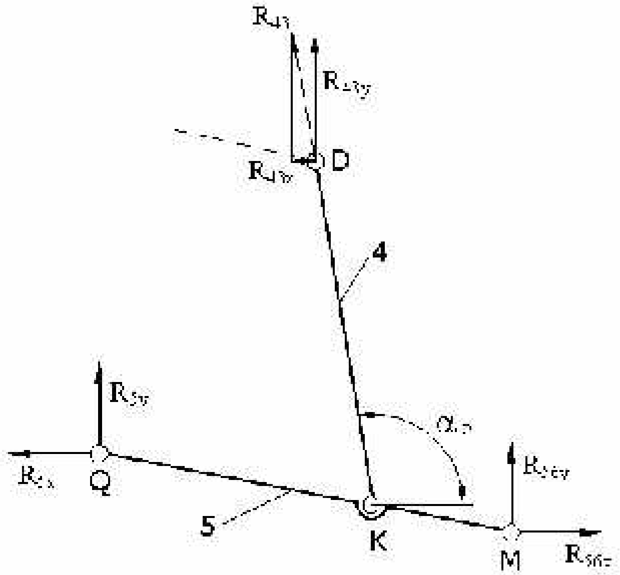

Figure 3: Scheme for the forces calculus of group *4 – 5*.[5]

The reaction R_{43} is determined from the equation moments of all the forces in proportion with all the forces with *Q* point:

$$R_{43}(y_D - y_Q)\cos\alpha_2 + R_{43}(x_D - x_Q)\sin\alpha_2 + R_{56x}(y_Q - y_M) + R_{56y}(x_M - x_Q) = 0,$$

From where

$$R_{43} = R_4 = -\frac{R_{56x}(y_Q - y_M) + R_{56y}(x_M - x_Q)}{(y_D - y_Q)\cos\alpha_2 + (x_D - x_Q)\sin\alpha_2}, \tag{10}$$

Next, we determine the reaction from the joint *Q*:

$$\begin{aligned} &\sum X = 0 \;\Rightarrow\; -R_{5x} - R_{43x} + R_{56x} = 0 \;\Rightarrow\; R_{5x} = R_{56x} - R_{43x}; \\ &\sum Y = 0 \;\Rightarrow\; R_{5y} + R_{43y} + R_{56y} = 0 \;\Rightarrow\; R_{5y} = -(R_{43y} + R_{56y}); \\ &R_5 = \sqrt{R_{5x}^2 + R_{5y}^2}. \end{aligned} \tag{11}$$

The inclination angle α_2 is determined by the relation:

$$\alpha_2 = \text{arctg}\left(\frac{KD_y}{KD_x}\right) + \frac{\pi}{2}\left(1 - \frac{KD_x}{|KD_x|}\right) + 2\pi \tag{12}$$

or

$$\alpha_2 = \text{arctg}\left(\frac{y_D - y_K}{x_D - x_K}\right) + \frac{\pi}{2}\left(1 - \frac{x_D - x_K}{|x_D - x_K|}\right) + 2\pi. \tag{13}$$

The forces and reactions calculus for *2–3* groups

The reaction R_{21}, is equal with the force from the core *2* of the lift cylinder, it is also determined, in this case, from the equation moments in proportion with *C* point (fig. 4):

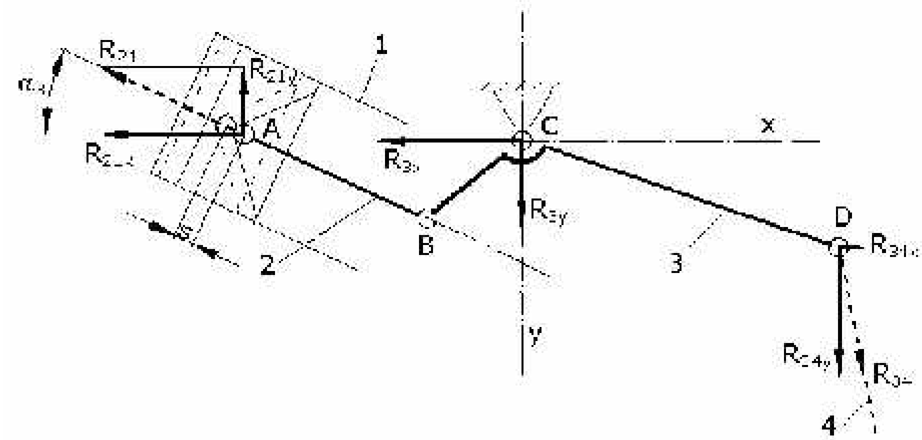

Figure 4: Scheme for the forces calculus of group *2* – 3.[6]

$$R_{34x}(y_C - y_D) - R_{34y}(x_D - x_C) + R_{21}(y_A - y_c)\cos\alpha_3 - R_{21}(x_C - x_A)\sin\alpha_3 = 0\,,$$

from where

$$R_{21} = -\frac{R_{34x}(y_C - y_D) - R_{34y}(x_D - x_C)}{(y_A - y_c)\cos\alpha_3 - (x_C - x_A)\sin\alpha_3}. \qquad (14)$$

The elements of this reaction are:

$$R_{21x} = R_{21}\cos\alpha_3; \quad R_{21y} = R_{21}\sin\alpha_3. \qquad (15)$$

The reaction in *C* joint is determined from the equation of forces projections:

$$\sum X = 0 \;\Rightarrow\; -R_{21x} - R_{3x} + R_{34x} = 0 \;\Rightarrow\; R_{3x} = R_{34x} - R_{21x};$$
$$\sum Y = 0 \;\Rightarrow\; R_{21y} - R_{3y} - R_{34y} = 0 \;\Rightarrow\; R_{3y} = R_{21y} - R_{34y}; \qquad (16)$$
$$R_3 = \sqrt{R_{3x}^2 + R_{3y}^2}.$$

The inclination angle α_3 of the lift cylinder is determined by the relations:

$$\alpha_3 = \mathrm{arctg}\left(\frac{AB_y}{AB_x}\right) + \frac{\pi}{2}\left(1 - \frac{AB_x}{|AB_x|}\right) + 2\pi \qquad (17)$$

or

$$\alpha_3 = \mathrm{arctg}\left(\frac{y_B - y_A}{x_B - x_A}\right) + \frac{\pi}{2}\left(1 - \frac{x_B - x_A}{|x_B - x_A|}\right) + 2\pi. \qquad (18)$$

3. APPLICATIONS OF THE THEORETICAL RESEARCES PERFORMED

In this section of the paper is presented a part of the theoretical researches performed on U 650 DT tractor, tractor which is representative for the Romanian fleet tractors. There have been used the following entrance data, according to the second category (v. SR ISO 730-1):

- the coordinates of the fix points (in mm): *A*(-1, 1156), *C*(230, 1143), *Q*(230, 495), *E*(400,891);
- the dimensions elements (in mm): *AB* = 160, *CB* = 94,8, *CD* = 260, *DK* = 760, *QM* = 900, *MF* = 850, *FE* = 637, *QK* = (459), *MS* = 820;
- the angles values: α = 25° (the inclination of the lift cylinder besides the horizontal plane), β = 124° (the angle between the levers *CB* and *CD*);
- the plough weight Q = 4,5 kN, the plug width *b* = 1.05 m, the working depth *h* = 0,3 m, the specific resistance of the ground *k* = 30 kN···110 kN.

The researches results are graphically presented: the forces variation in the elements of the three-point hitch couplers depending on the specific resistance of the ground (fig. 5); the force variation of the piston rod during the lifting up of the agricultural machine in the transport postion (fig. 6).

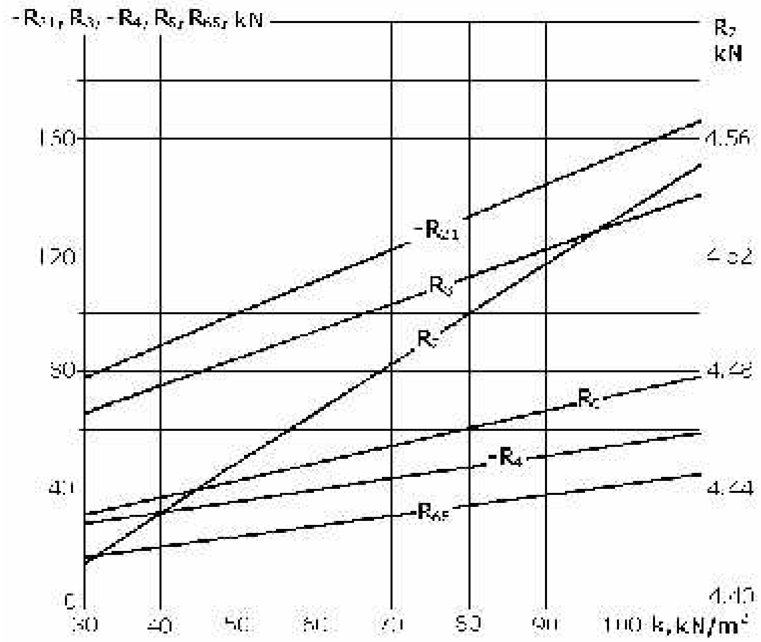

Figure 5: The forces variation of the three-point hitch couplers elements depending on the specific resistance of the ground

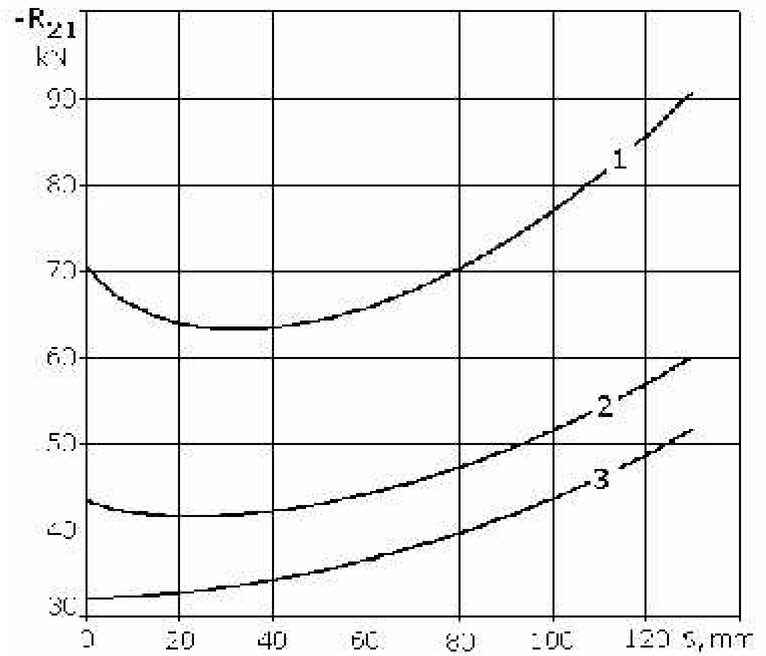

Figure 6: The force variation of the piston rod during the lift-up of the agricultural machine in transport position ($y_{E\,\min}$ = 857 mm): *1 – KQ* = 299 mm, *2 – KQ* = 459 mm, *3 – KQ* = 559 mm.

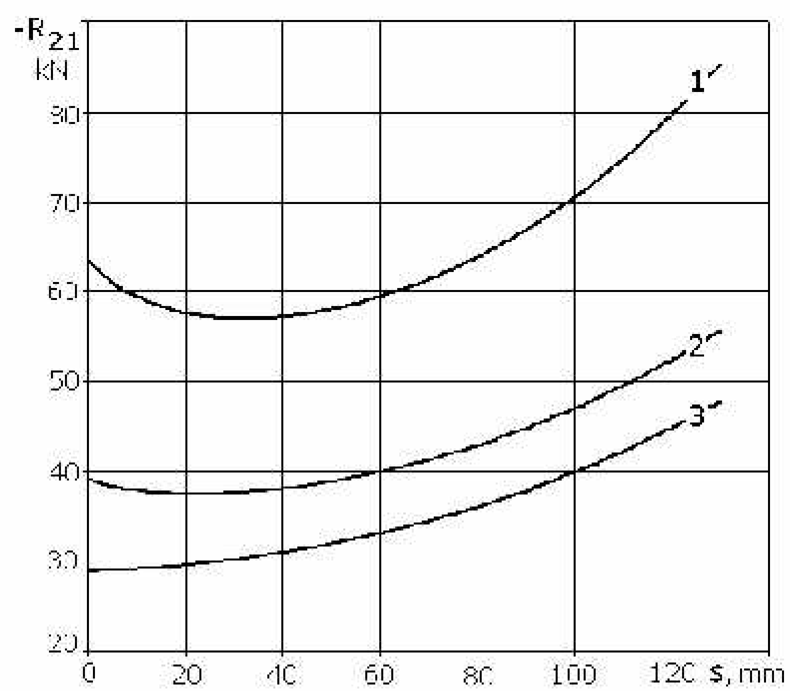

Figure 7: The force variation of the piston rod during the lift-up of the agricultural machine in transport position ($y_{E\,\max}$ = 964 mm): *1 – KQ* = 299 mm, *2 – KQ* = 459 mm, *3 – KQ* = 559 mm.

4. CONCLUSION

The calculus algorithm developed allows the determination of the forces in all the elements and the joints of each three-point hitch couplers.
Knowing the value of the piston rod we can correctly calculate the parameters of the acting lift cylinder.
The value of the rod piston force is insignificantly influenced by the position of the superior coupling bar, but, the position of the *K* point on the inferior couplin bar (the distance *KQ*) has a great influence upon the value of this force (over two times).

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