Analele Universităţii din Craiova, seria Agricultură – Montanologie – Cadastru (Annals of the University of Craiova - Agriculture, Montanology, Cadastre Series) Vol. XLVI 2016

THEORETICAL RESEARCH ON THE WORKING PROCESS OF COMPLEX AGGREGATES FOR SOIL TILLAGE - REVIEW

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Keywords: soil, optimization, agreggate, quality indices, conservative soil

ABSTRACT

The paper presents a summary of theoretical research developed in the country, related to the design and optimization of complex aggregates for soil processing and the improvement of their quality indices of work.

INTRODUCTION

Soil preparation for crop establishment (seeding) is one of the most important agricultural works, which is performed with high energy consumption and high costs. The quality of this work greatly affects the germination of crops and work productivity that can be obtained per hectare. Therefore, at present there are different equipment found in classical cultivation technologies, which, with a single pass can be achieved with a minimal energy consumption, thus creating optimum conditions for seeding and to obtain a higher yield, without degradation soil. These devices are called combiners.

Following the extension of soil degradation due to conventional and technological mistakes, over the years were studied and implemented in practice the so-called agricultural conservative technologies. These conservative technologies have contributed significantly to the reclamation and improvement of soil fertility and productivity and consequently of other environmental resources. The most important component of conservative technology systems, as in case of conventional one, is soil processing – loosening type, processing and placing the seed in the soil. Passing from conventional tillage to the conservative was not easy and gave rise to a lot of questions that needed relevant answers, well grounded scientifically, part of which was obtained through fundamental and applied research carried out under specific local conditions. Conservative systems rely on less intensive loosening of soil, carried out by different methods, without furrow overturning and only while preserving at soil surface a certain amount of plant debris, for this reason being considered ecological strategies of protection [2].

Agricultural cultivators are equipment having an increasingly widespread for seedbed preparation in crop establishment, especially in the current conservative tillage technologies. Besides the fact that such equipment must achieve soil processing with superior quality and energy indices, their weight must be as small and reliability to be as good. At present it is possible to shorten spectacularly the cycle of conception-design-test-manufacture of this equipment by using the finite element method for analyzing the distribution of stresses and strains in their elements of resistance (frames, racks for tools, working tools, etc.)

MATERIAL AND METHOD

In order to obtain a well prepared soil for seeding, it is important for seedbed preparation to be well done, the quality of this work largely affecting germination of crops and work productivity per hectare. Currently, there are various equipment in the classic tillage technologies, which in a single pass can achieve a very good processing of soil, with low energy consumption, thus creating optimum conditions for seeding, without soil degradation. Conservative tillage technologies have emerged as a necessity and a response to the expansion of soil degradation over the years, which contributed significantly to the recovery and improvement of soil fertility and productivity. Conservative systems for soil processing are based on a less intensive processing of the soil, achieved by various methods, without overturning the furrow and at the same time, keeping at soil surface a certain amount of plant residues, and therefore they are considered to be ecological strategies of protection [1].

Combiners are equipment allowing a good processing of soil for crop establishment, used primarily in current conservative tillage technologies, which allow to achieve soil processing with superior indices in terms of quality and energy [7].

RESULTS AND DISCUSSIONS

Research on optimizing the energy consumption in the operation of opening gutters with the cultivator in the technological process of seedbed preparation in greenhouses were made by [2] which determined the traction resistance of cultivator starting from Goreacikin's equation, dividing into four components the total energy consumption for this operation. Analysis of energy consumption was done through two parameters: the specific cut area and the specific mechanical work required for the displacement of soil volume unit. Thus, were studied the influences of lister working depth and working width, respectively the movement speed of technical-agricultural system on the mentioned parameters, finding that by increasing the working depth and width, both the specific cut area, and the specific mechanical work decrease, meaning that energy consumption is decreased, while by increasing the speed of movement, the specific energy increases.

Cultivators for open gutters in greenhouses (Fig. 1) are built according to the requirements of specific buildings to protection spaces and usable energy base in these spaces.

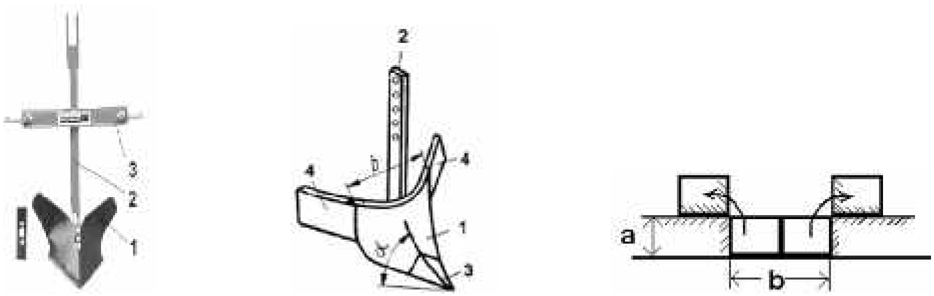

Fig. 1 – Design of cultivator with working bodies type lister and the working process [2]

The working body of the cultivator (left) is lister 1, which is mounted on the support 2, attached to the cultivator frame 3, which is a tube with square section. The cultivator is coupled to the tractor through the triangle grip, and during work is supported on two wheels. The lister (right) consists of two surfaces type mouldboard, meeting each other, forming the brisket of lister, mounted on the support 2. At the bottom of lister is mounted the coulter 3, and on the sides are fixed the wings 4. Some cultivators allow the adjustment of the wings layout. The main constructive-functional feature of the listers is working width b.

Figure 2 shows the functional parameters of the cultivator lister, which shows that the trajectory of a point M (x,y) on the edge of the coulter, compared to a fixed reference system, is a right parallel to the soil surface to the depth of work, ie:

$$y = -a;\ x = v_m \cdot t \quad (1)$$

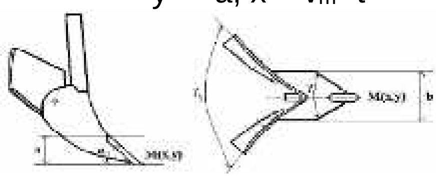

Fig. 2 – Functional parameters of cultivator lister [2]

The relative speeds of the point M (x, y) are obtained by deriving the equation (1) with respect to time, and the relative accelerations, by deriving the relative speed with respect to time. The lister behaves like a plough with double mouldboard, the bottom part of the mouldboard dislodges the soil that is lifted on their surface and overturned sideways. During lifting and overturning, the soil receives a kinetic energy, which influences the traction resistance of the cultivator.

Figures 3 and 4 show the variation of specific cut area during he work of gullies opening in greenhouses by the cultivator, depending on the working depth, respectively the variation of the specific mechanical work with the width of lister.

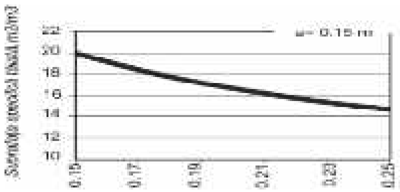
Lister brisket width [m]

Fig. 3 – Variation of specific cut surface with the width of lister brisket [2]

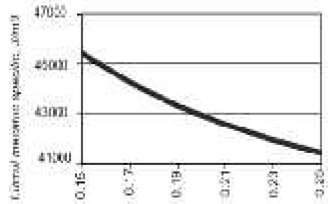
Lister width [m]

Fig. 4 – Variation of specific mechanical work with lister width [2]

Soil processing is the basic activity within the agricultural production system and represents a process of mechanical handling of soil by changing soil bulk density, size of the aggregates and other physical properties of the soil. The objective of soil processing is to provide a suitable environment for seed germination, root system development, weed control, erosion control and soil moisture control. Based on these considerations, in his PhD thesis [3] observed that a large proportion of the energy consumed in agricultural works is attributed to the mechanical processing of the soil by soil processing tools. Even if soil processing depth does not exceed 100 mm, the processing area is large and the amount of manipulated soil is enormous.

Soil processing also results in another component that includes a high coefficient of friction and considerable wear losses to the tools for soil processing.

Fig. 5 - Development of the model of tool used for soil processing [3]

According to Swick and Perumpral, the idealized model of soil breaking (Fig. 6) is divided into a central tetrahedron wedge and two side tetrahedron wedges with circular edges.

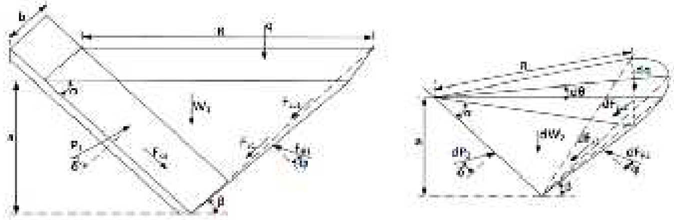

Fig. 6 – Idealized model of soil breaking: a) central wedge; b) side wedge [3]

For the central wedge, the equations of equilibrium to limit for forces on the horizontal and vertical directions are:

$$\sum \overline{F_x} = 0$$
$$P_1 \cdot \sin(\alpha + \delta) + F_{ca} \cdot \cos\alpha - F_{a1} \cdot \cos\beta - F_{ca1} \cdot \cos\beta - F_{R1} \cdot \sin(\beta + \varphi) = 0$$
$$\sum \overline{F_y} = 0 \qquad (2)$$
$$P_1 \cdot \cos(\alpha + \delta) - F_{ca} \cdot \sin\alpha - W_1 - (F_{a1} + F_{ca1}) \sin\beta + F_{R1} \cdot \cos(\beta + \varphi) = 0$$

where: P_1 - force required to dislodge the volume of soil corresponding to the central wedge; α - angle of attack of the tool; δ - angle of external friction (tool - soil); φ - angle of internal friction; F_{Rl} - soil reaction to the breaking plan; β - angle of soil breaking plan.

The relation for determining the total value of force necessary to drive the tool for soil processing will be: $H = H_a + F_r + F_p$ (3)

Table 1 [3]

Parameters of soils used in the analytical models

Soil type	Angle of internal friction φ [°]	Angle of soil-metal friction δ [°]	Cohesion c_c [kPa]	Adhesion c_a [kPa]	Specific weight γ [kN/m^3]
Soil 1 - clayey	37.3	27.3	33.5	9.4	11.5
Soil 2 - clayey	29.8	25.2	35.3	8.1	11.0
Soil 3 - sandy	36.0	23.3	6.3	2.2	14.5
Soil 4 – clayey sand	33.1	22.1	11.9	2.7	13.2

Figure 7 shows by comparison for to the 4 models, the variation of drag force with modifying the angle of attack from 15° to 90° - φ, because starting from this value will appear significant overestimation of the measured values.

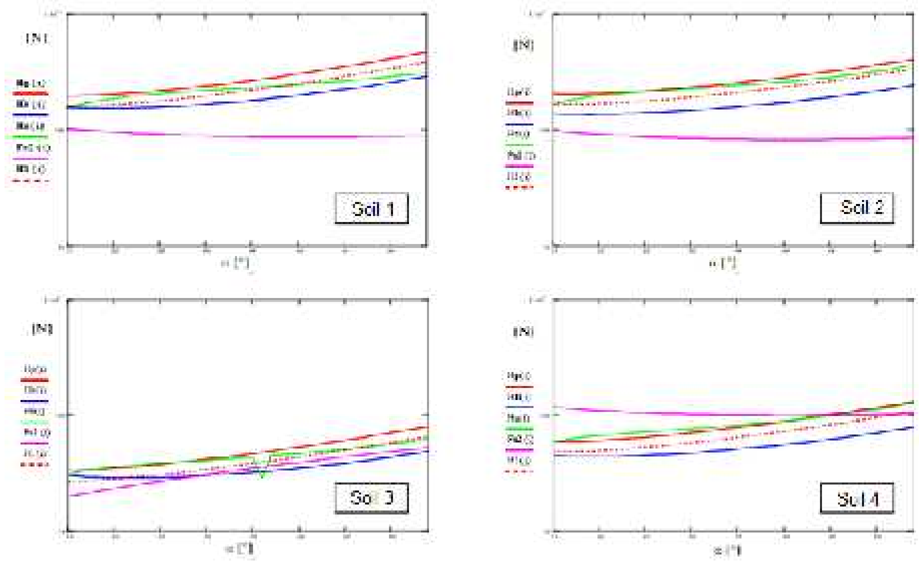

Fig. 7 – Variation of drag force with modifying the angle of attack of the tool [3]
Hp - MISS model; Hk - Zhang-Kushwaha model; Hz – Zheng model; Fx1 - Luth-Wismer model; Fx2 - Wismer-Luth model; H1 - MISS model (without spraying component)

Figure 8 shows by comparison for the 4 models, the avriation of drag force by modifying the working depth, a parameter that changes within the range 0 - 0.2 m. Based on these results we can say that the proposed MISS model can provide valid values in the estimation of resistance forces to the advance of the tool for soil processing in the soil, if the basic parameters of tool-soil interaction are known.

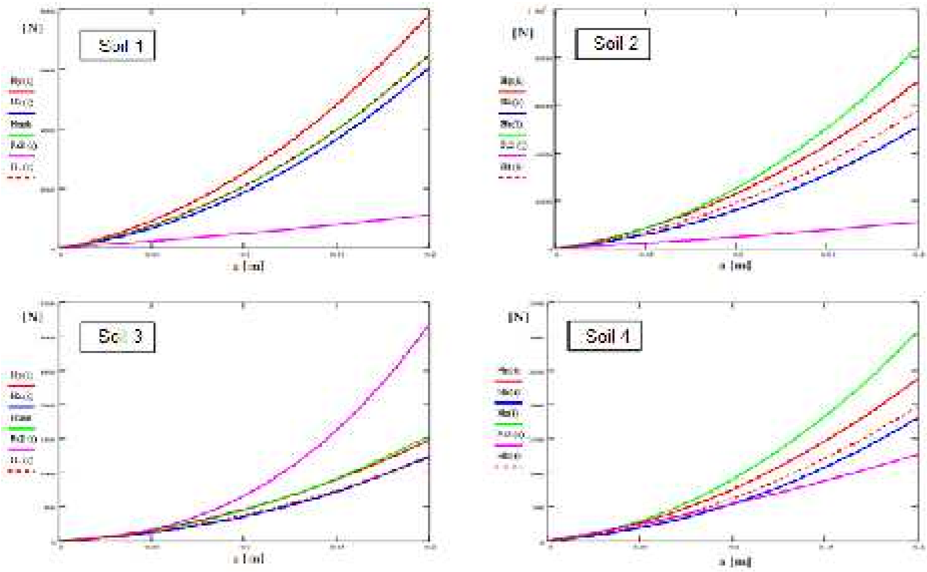

Fig. 8 - Variation of drag force with modifying the working depth of the tool [3]
Hp – MISS model; Hk - Zhang-Kushwaha model; Hz – Zheng model; Fx1 - Luth-Wismer model; Fx2 - Wismer-Luth model; H1 - MISS model (without spraying component)

Paper [4] presents the theoretical foundations of an analog dynamic system of a technological process of deep and semi-deep loosening of soil. It also presents the complex processes consisting of systems and subsystems related to soil loosening by combined methods. Depending on the complexity of the analyzed problem, a certain mechanical system can consist of multiple component systems, which are called subsystems.

Stages of solving a dynamic technical problem [4]:
1. drawing the physical model;
2. specifying the dependencies of form:

$$f_1 = f_1(x_{i1},...,x_{i1},x_{e1},...,x_{eu},t) = 0$$
$$f_w = f_w(x_{i1},...,x_{i1},x_{e1},...,x_{eu},t) = 0 \qquad (4)$$

3. processing the relations (4) in order to obtain the output quantity, a vector of linear displacement $y = y(t)$ and / or a vector of angular displacement:

$$\theta = \theta(t) \qquad (5)$$

4. developing a set of measures to improve the behavior of dynamic system;
5. intervention on the parameters of physical model or on its configuration.

The physical model is an oversimplification of the concrete problem, in most cases its simplification. It is acquired by accepting a number of simplifying assumptions.

A physical model accurately designed must ensure, at least within a certain range of variation of input quantities, the obtaining of the same output quantities as for the original dynamic system (unaffected by simplifying assumptions).

For the mechanical systems, the *mathematical model*, i.e. the equations of the form (4) is obtained frequently using the *D'Alembert principle* or *Lagrange equations*.

D'Alembert's principle is preferred when it can easily be highlighted the external forces $F_i^{(e)}$ (or moments $M_i^{(e)}$), the internal forces $F_i^{(i)}$ (respectively moments $M_i^{(i)}$) and forces in the connections $F_i^{(l)}$ (respectively moments $M_i^{(l)}$), acting on the body with mass m_i. By noting: a_i the acceleration of the body of mass m_i, in translation movement and with ε_i the acceleration of the body, and the moment of inertia J_i, which is found in rotation movement, the following equations can be written:

$$m_i a_i = F_i^{(e)} + F_i^{(i)} + F_i^{(l)}, (i = \overline{1,u_1}),$$
$$J_i \varepsilon_i = M_i^{(e)} + M_i^{(i)} + F_i^{(l)}, (i = \overline{1,u_2}) \qquad (6)$$

where: u_1, u_2 represent the number of freedom degrees of the considered mechanical systems.

Lagrange's equations (of type II) are almost irreplaceable when must be specified the dependencies (114) of mechanical systems with several degrees of freedom, for which the forces and / or moments (couples) of bonds can not be highlighted. In general form, these equations are written:

$$\frac{d}{dt}\left(\frac{\partial E_c}{\partial \dot{q}_i}\right) - \frac{\partial}{\partial q_i}(E_c - E_p) = Q_i, (i = \overline{1,u}) \quad (7)$$

where: q_i and Q_i are generalized coordinates, respectively generalized forces, and E_c and E_p are kinetic energy, respectively potential energy of the considered system. Generalized forces encompasses all forces and / or moments that occur in the system, except those arising from a potential.

Dynamical system of processing [4]

Dynamical processing system consists of elastic structure of the machine-tools (SE) which is interdependent with the process of soil scarification (PS). Establishing the dependencies of type (4) must be preceded by a description of input and output quantities of the considered dynamical system. The mode of going through this basic step in mathematical modeling of the processing system is shown below. In Figure 9, for processing, the active body is positioned to the adjustment size d_r. Assuming that the force of scarification would remain strictly constant throughout the process of soil loosening, and the elastic structure of the machine-tools would suffer no elastic deformations, the relative movement of the active body to the soil coincides with the trajectory I. In reality, due to a large number of disruptive factors, the instant force of scarification F=F(t) differs from its set (nominal) value F=const. (corresponding to the nominal depth of scarification a_0). On the other hand, the elastic structure of the machine tools, by acting as an elastic body, undergoes deformations which change over time in accordance with the dependence F=F(t). As a result, the actual trajectory of the active body to the soil may be like curve 2. Instantaneous deviation y=y(t) between the real trajectory and the adjusted (nominal) trajectory I, represents an indicator of the machine-tool performance. As the maximum value of this quantity is lower, the dimensional accuracy of the processed surface is higher. For a given soil structure and a certain process of scarification, the relative displacement y=y(t) between the tool and the surface is a function of the nominal force of scarification. Therefore, for the dynamic processing system associated to the processing it can be written:

$$x_i=x_i(t)=F_0(t),\ x_e=x_e(t)=y(t) \quad (8)$$

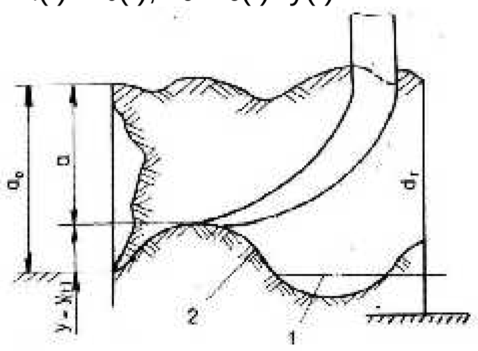

Fig. 9 - Positioning of the active body [4]

Paper [5] presents the structural analysis of MATINA, a complex equipment for soil processing and seedbed preparation (combiner) comprising the calculation of resistance, expressing the forces of interaction with the soil, modeling the joint to the tractor and the main results usable in the design. The paper includes elements of optimiziation of equipment structure and directions to follow in order to improve the constructive qualities and behavior during operation of the aggregate tractor-MATINA equipment.

The multifunctional aggregate for soil processing in farms, whose analysis is presented in this article, promotes the system of conservative agriculture, system that provides competitive production in quantity and quality terms, to those obtained in the classic system, but with low costs and high profit, in terms of improving soil characteristics and environmental protection. On a single pass, the MATINA multifunctional aggregate for soil processing performs: deep soil loosening (25÷30 cm), seedbed preparation (12÷15 cm) and additional grinding and leveling of the soil.

The structural analysis of the resistance structure and some annex structures of the MATINA equipment aimed:

O1) Checking the resistance of the structure in different working situations.

O2) Checking the sufficiency or excess of traction force and their likely effect.

O3) Investigation of the existence of optimized variants, in order to reduce material consumption, and by default, weight.

O4) Extracting the main stereodynamic elements, useful to calculate the dynamics of movement in transport.

O5) Designing of complex variants of the machinery (eventually by addition of working bodies or elements of protection).

- **Mathematical model** [5]

The mathematical model of resistance structure of the MATINA equipment for soil processing is a structural model with finite elements with one size, type rod, called BEAM3D, in the library of finite elements of software COSMOS/M 2.8.

In addition to the structure of resistance, the model includes some additional rods, which are elements that are not real, but models real elements that is not necessary to physically represent on the model, but only by the forces generated by them on the structure.

The introduction of these elements is justified by the fact that in this way it makes a distribution of forces acting on the structure, very close to reality.

✓ ***Geometry of the structure***

Geometry of the model is represented by the central axis of the component rods of the structure developed by the designer, having the additional elements mentioned before with the role to better distribute loads in line with reality.

The structural model of MATINA machinery consists of 89 rods, numbered and placed according to Figure 10.

Features of their sections, as well as other information about each of these rods, are given in the table (see paper). In the model also appear rods necessary for construction and which have not been deleted in order to use them, possibly in an evolved model - rods 76, 77, 78, 79, 80, 81, 82, 83, and three rods - 98, 99, 100 - which represents the coupling of the tractor, which are discretized in finite elements with characteristics listed in the table. Rods 1 and 4 actually form a single rod (separation is done for reasons of efficient meshing), forming the binding element to the tractor for MATINA equipment (what in other equipment is called a draw-bar).

Rods 2, 3, 4, 5, 6, 7, 8 and 55 are components of the central rod of resistance, having the same section. In reality, rod 8 has a variable section, but for this model we equated it with a rod of constant section, and does not have the role of resistance during operation [5].

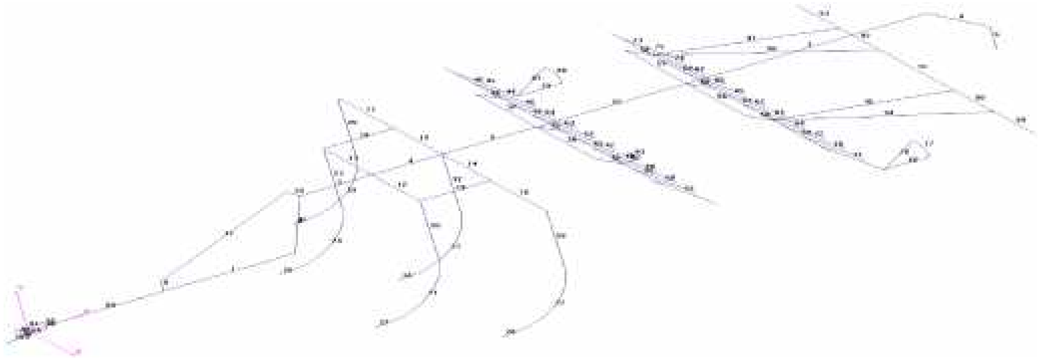

Fig. 10 – Component rods of the structure model [5]

In the main resistance beam, maximum stress occurs in the intersection between it and the rod 9, toward the front of the machine and has a value of 49 MPa. Horizontal reaction of the system, in the coupling point on the tractor, has a value of 38077 N, which signifies the traction force necessary to overcome the resistance of the machine in operation. To these are added the friction forces and the force required for self-movement of the tractor.

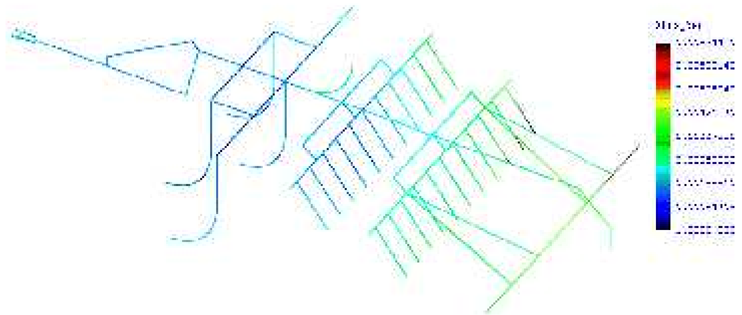

Fig. 11 - The state of relative displacement resulting in the structure [m] [5]

Theoretical research on the dynamics of ACPG-3 aggregate for seedbed preparation, were conducted by [6]. In Figure 12 is presented a schematic diagram of the external forces acting on the ACPG-3 aggregate for seedbed preparation while working, on the movement on horizontal soil with constant speed, also being represented the reactions of the joints of rods (hitchs) of suspension mechanism of the tractor. In the same Figure are given the distances of these forces to vertical reference line (passing through the coupling points of the machine) and compared to the initial surface of the soil. The resultant forces (or equivalent) which acts on the loosening and decompaction blades, on the rotor with blades, the roller with lugs and the aggregate as a whole, are shown in Figure 12, where the following notations have been made [6]:

- G_m – the force of gravity of the machine as a whole, applied to the center of mass (coordinates l_m compared to baseline and h_m compared to the initial surface of soil);
- R_{xce} and R_{zce} – equivalent forces to the interaction with the soil of the 4 blades for soil loosening or decompaction, applied to point A of coordinates l_c to the reference line and h_c from soil level;
- R_{xr} and R_{zr} – horizontal, respectively vertical components of soil resistance to the cutting and dislocation of soil parts, being created by the z_a blades on the rotor that act at one point in the soil, applied in point *B* of coordinates l_r to the axis Oz and h_r to the axis Ox;
- X_r and Z_r – components of soil reaction on limiting skids of rotor depth and leveling shutter, applied in point C, at distance l_r from the axis Oz;

- M_r – torque transmitted from the tractor's PTO to the rotor with blades, to which it opposes the rotor's equivalent resistance moment, M_{Rr};

On the rotor with blades, in contact point C between the skid and the soil also acts the moment M_{ro} created by the resistance of shutter to soil leveling, can be neglected because it has low values compared to other quantities;

- R_{xt} and R_{zt} - components of soil reaction on the roller with lugs applied at the point D of coordinates l_t towards baseline and h_t compared to soil level. On the roller with lugs is also acting the moment of resistance to rolling M_{rtv}.

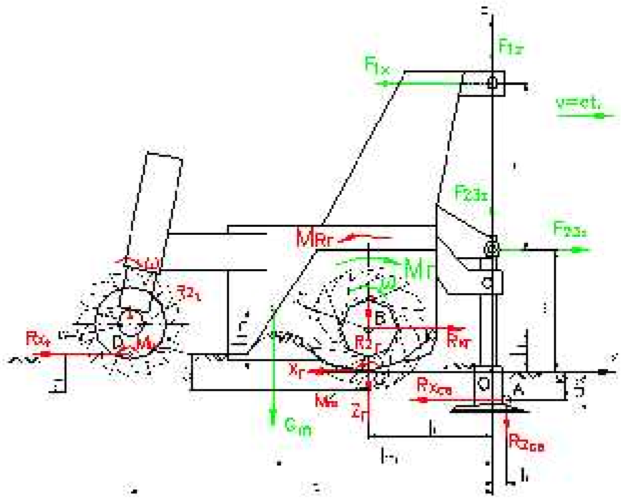

Fig. 12 - The dynamic equivalent model of the aggregate for seedbed preparation, ACP 3 at the movement in work, on horizontal soil, at constant speed [6]

F_{1x} and F_{1z} - forces in the connection coupling of the upper rod (central link) of the suspension mechanism of the tractor; F_{23x} and F_{23z} - the reactions of the lower left and right links of the couplings of the suspension mechanism of the tractor

Taking into account the action of outer forces and moments on the machine frame from the loosening or decompaction blades (resulting forces Rxce and Rzce) from the rotor with blades, skate and shutter (resulting forces Rxr and Rzr, Xr and Zr, and moment Mro), from the roller with lugs (resulting forces Rxt and Rzt, and the resulting moment Mrtv), can be written the equations of equilibrium of the machine for seedbed preparation on the basis of the dynamic model presented in Figure 12, from which are determined the following forces: the vertical load transmitted through the joints of rods of the linkage mechanism of the tractor [6]:

$$F_z = F_{1z} + F_{23z} \tag{9}$$

- traction force (resistance) at machinery movement in work. Traction balance is determined, namely:

$$F_t = F_{23x} - F_{1x} \tag{10}$$

Pushing force push, Fz, exerted by the aggregate on the tractor in the coupling points is determined from the equation of balance of forces in the vertical direction:

$$F_z = F_{1z} + F_{23z} = G_m + R_{zce} - R_{zr} - Zr - R_{zt} \tag{11}$$

Traction balance of the combined aggregate for seedbed preparation, ACPG-3, during the movement in operation on horizontal soil with constant speed is given by:

$$F_t = F_{23x} - F_{1x} = R_{xce} - R_{xr} + X_r + R_{xt} \tag{12}$$

Analyzing the dynamic equivalent model and the traction balance of the aggregate for seedbed preparation during the movement into operation, at a steady speed, on horizontal soil, it was found that the total resistance force acting on the machine during working F_t, formed of horizontal components of the resistant forces acting on the working bodies of the machine, is diminished by the value of thrust, R_{xr}, created by the rotor with blades during operation under the action of moment M_r. Basically, this horizontal reaction of the soil on the rotor with blades contributes to the reduction of overall resistance to traction opposed by the machinery in operation.

CONCLUSIONS

In our country, the equipment dor soil processing without furrow overturning began to be used on a larger scale, of these the vibro-combiners and complex combiners being the most common.

The advantages of using vibro-combiners and combiners are: necessary seedbed preparation in hard conditions and retention of soil moisture. Such important factors can ensure rapidly, uniform and early germination of seeds, these requirements being mandatory in order to obtain high yields. Advanced Numerical Methods (finite element analysis, modal analysis, etc.) began to be used successfully in recent years, to analyze the stress state of resistance structure and working bodies of vibro-combiners, and for the study of soil behavior at the interaction with their working bodies.

Equipment for soil processing with vibrating elements reduce the power requirements of the tractor, allowing the use of a tractor with a relatively lower power that can also be used to perform other agricultural works.

ACKNOWLEDGEMENT

This work has been funded by Ministry of National Education and Research through the UEFISCDI, within the project entitled ***„Conservative Technology for Soil Processing”,*** contr. 181/2014.

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