

STUDY ON STABILITY AT WORK FOR TILLAGE AGGREGATES

G. PARASCHIV^{1*}, E. MAICAN¹, I. PARASCHIV¹, D. BUCUR²

¹*Polytechnic University of Bucharest*

²*University of Agricultural Sciences and Veterinary Medicine of Iași*

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ABSTRACT - This paper shows the importance of stability at work for tillage aggregates, from the point of view of work quality and fuel consumption. The classic ploughing aggregates are analysed, from the point of view of stability at work, as agricultural milling cutler and aggregate plough – agricultural milling cutler, accentuating the way in which the soil reaction on socket-rod can be influenced. The value of socket-rod pressure on the vertical furrow wall must be optimized, because a higher value for this force leads to the friction force increase and to the destruction of the vertical wall, while a smaller value leads to the aggregates instability at work.

From this point of view, the aggregate made of plough and milling cutler carries under all the stability conditions.

Key Words: aggregates, stability, soil tillage, ploughing aggregates

REZUMAT – Studiul stabilității în lucru pentru agregatele de prelucrat solul. Lucrarea prezintă importanța stabilității în lucru pentru agregatele de prelucrat solul, din punctul de vedere al calității lucrului și al consumului de combustibil. Agregatele clasice de prelucrat solul sânt analizate în privința stabilității în lucru, precum freza și agregatul plug – freză, accentuând modul în care poate acționa reacția solului asupra plazului. Valoarea presiunii plazului asupra peretelui vertical al brazdei trebuie mărită, deoarece o valoare mai mare a acestei forțe duce la creșterea forței de fricțiune și la distrugerea peretelui vertical, în timp ce o valoare mai mică provoacă instabilitatea agregatelor în lucru. Din acest punct de vedere, agregatul, compus din plug și freză agricolă, lucrează în toate condițiile de stabilitate.

Cuvinte cheie: agregate, stabilitate, lucrarea solului, agregate de arat

* E-mail : paraschiv2005@yahoo.com

INTRODUCTION

One of the base conditions imposed to the tillage aggregates of any kinds is obtaining a work of good quality with minimum energy consumption. Quality of work and energy consumption are influenced by aggregate stability during working, being known (after experimental tests) that an instable aggregate leads to a poor quality of work, high fuel consumption and an increase in the number of manipulations carried out by the tractor.

The number and type of forces, which are acting on agricultural machines during the work, determine tillage aggregates stability. When these forces are found in equilibrium, both horizontally and vertically, the agricultural aggregate is stable (Babiciu, 1980; Toma, 1978)¹.

MATERIALS AND METHODS

Stability at work of carried plough. Plough resistance to traction, opposed in the ploughing process, is determined by many factors: physical and mechanical characteristics of soil (soil composition, texture, structure and moisture); dimensions of cut and turned over furrow in the ploughing process (depth and width); shifting speed and mass of plough. Plough resistance is also influenced by joint quality between ploughshare and mouldboard, respectively, their mounting on support and wear rate of ploughshare cutting edge, shape and polishing rate of mouldboard surfaces, wheels resistance to rolling, friction of socked-rod on furrow walls.

The resistance opposed by soil in the ploughing process has a great influence on the calculation of plough resistance to traction. This integrates the infinity of reactions created during the complex process of cutting, breaking and crumbling of furrow on the work surfaces of plough body.

To work properly during the process, the ploughs have to maintain the established working depth and width. This can be done if ploughs have an adequate stability, both in vertical and horizontal plane, respectively, if the forces that act on ploughs are found in equilibrium in the two planes.

During the process, the following forces are acting on a plough: weight of plough, traction force of tractor, resistance force to advance through soil, soil reactions on plough applied on its support points with land, and friction forces between working components and soil. During the process, these forces are modifying their direction, sense and value, because of different conditions of relief and soil in which plough is working. Therefore, the equilibrium of forces, which are acting on the plough during the process, and the plough stability during the work are influenced.

¹ Paraschiv, 2002 – *Research regarding realization and experimental verification of a software for modelling, simulation and computer-aided design of agricultural milling cutler*, PhD Thesis, Bucharest

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Plough stability in vertical plane. We consider that the resultant of all forces, which are acting in vertical plane, on the carried plough in O (the O point is the pressure centre of plough over soil), has the value of R_v (Figure 1) and the Q reaction acting on the limiter wheel of the plough working depth is deviated as a result of the friction force to the wheel rolling on soil F_r , with angle ϕ ; in this case, compounding forces R_v and Q results in the total resistance force in vertical plane R_{tv} :

$$\overline{R_{tv}} = \overline{R_v} + \overline{Q} \quad (1)$$

The condition for the plough to be in equilibrium in vertical plane is that the direction of resultant R_{tv} passes through the intersection point CIR_v of tie rods from the tractor suspension, named the instantaneous centre of plough rotation in vertical plane against the tractor.

Because the forces R_v and Q are modifying their direction and value, during working, for a good stability, it is necessary that the plough always have the tendency of penetration into soil, achieving a pressure force (N) on soil of the limiter wheel of working depth, of maximum 70 daN, in order not to increase too much the resistance force at wheeling on soil.

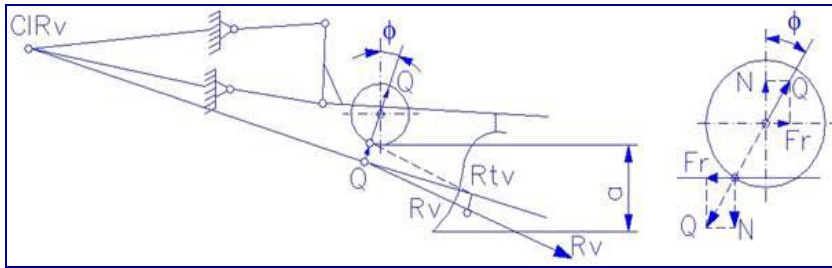


Fig. 1- Scheme of forces acting in vertical plane on the carried plough

If the direction of resultant R_{tv} passes over the instantaneous centre of rotation (CIR_v), the plough has the tendency to penetrate into soil, being limited by the limiter wheel of working depth. The higher the pressure, the higher is the distance from R_{tv} to CIR_v .

In the case of the R_{tv} direction passing under the instantaneous centre of rotation CIR_v , the plough has the tendency to get out of soil, the limiter wheel of working depth not achieving its function any more, which is not acceptable in use.

The stability in vertical plane is good and the adjustment in the vertical plane is well done, if the plough, during the work, achieves a working depth variation of maximum +10%, compared to the regulated depth.

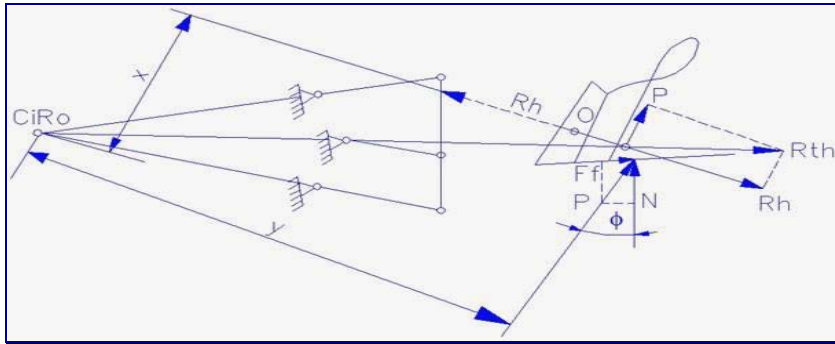


Fig. 2. - Scheme of forces acting in horizontal plane on plough

Plough stability in horizontal plane. In this case, we consider that the resultant of all the forces acting in horizontal plane on the plough in the O point – the pressure centre of soil over the plough – has the value R_h (Figure 2) and the P soil reaction is acting over the socket-rod, which is deviated with the angle ϕ , because of the friction force at sliding between soil and socket-rod, F_f . Compounding the forces R_h and P, the resultant is the total resistance force in the horizontal plane R_{th} :

$$\overline{R_{th}} = \overline{R_h} + \overline{P} \quad (2)$$

The condition for the plough to be in equilibrium in the horizontal plane: the direction of resultant R_{th} must cross the intersection point CIR_o of lateral tie rods from the tractor suspension, named the instantaneous centre of rotation of the plough in horizontal plane, compared to the tractor.

During the work, because the forces R_h and P are modifying their direction and value, to have a good stability in horizontal plane, it is necessary that the plough be in equilibrium, which is achieved by balancing the moment $R_h * x$ with the moment $P * y$.

In practice, it is necessary that the plough always have the tendency of pressing the furrow wall with the socket-rod, namely the P value must be always higher than zero; this can be achieved if the resultant R_{th} direction crosses the line of instantaneous rotation centre of CIR_o and the moment $R_h * x > P * y$.

The value of the P force must not create a pressure on the furrow vertical wall higher than $10 \div 80 \text{ N/cm}^2$, in order not to crush it and not to increase the friction forces, which are useless (Babiciu, 1980).

The stability in horizontal plane is good and the adjustment in the horizontal plane is well done if the plough, during the work, achieves a work width variation of maximum 10%, compared to the regulated width.

Stability of carried plough provided with a star harrow. Star harrows with straight fangs having the property of making ploughing grinding, easy and deep settlement of grinded soil, they are utilized in plough aggregates.

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During the work, the stability of star harrows with straight fangs is not a problem. In horizontal plane, because of the symmetrical layout of working components, the forces, which are acting on them, are in equilibrium, and in vertical plane, the stability is obtained through the specific mass, or by using supplementary mass, in order to achieve the necessary working depth.

The resistance force to traction of these harrows is calculated with the formula:

$$R = k \cdot B_i \quad (3)$$

Where k is the resistance per meter of the working width at the agricultural machine (daN/m) and B_i is the working width of the agricultural machine (m).

In practice, this force can be determined with dynamometer, as it was done during the experimental tests.

In the case in which the plough is equipped with harrow (the most usual case), the problem of aggregate stability is changed.

If, in vertical plane, the harrow does not have major influences on plough stability, in horizontal plane, its stability is changed.

The star harrow processes (grinds and settles) the previous furrow, so it is disposed laterally to CIR_o at distance x' (Figure 3).

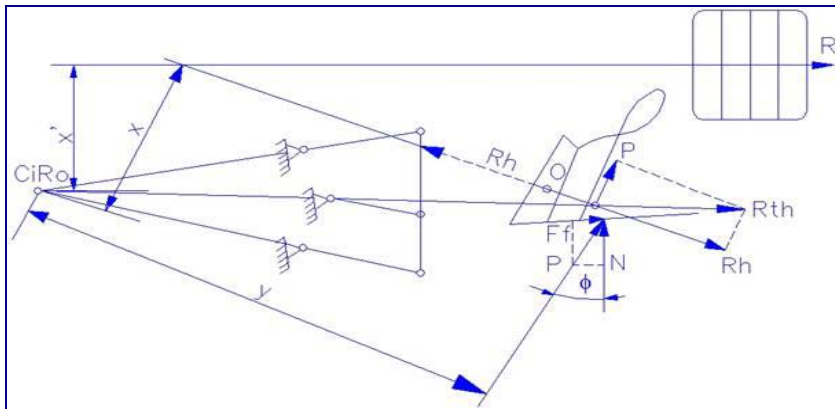


Fig. 3 - Scheme of forces acting in horizontal plane on plough equipped with star harrow

In order to have a good stability, the aggregate must be in equilibrium which is achieved by balancing the moments $R_h \cdot x$ and $R \cdot x'$ with the moment $P \cdot y$. Because the moment $R_h \cdot x$ has the same values as in the case of the plough working without harrow, the value of P force must increase.

From the equilibrium condition, one may write:

$$R_h \cdot x + R \cdot x' = P \cdot y \quad (4)$$

From which, the value of soil reaction on socket-rod can be deduced:

$$P = \frac{R_h \cdot x + R \cdot x'}{y} \quad (6)$$

From *Figure 3* it results:

$$\bar{P} = \bar{N} + \bar{F}_f \quad (7)$$

As the result, the soil reaction on socket-rod is:

$$N = P \cdot \cos \varphi \quad (8)$$

Or

$$N = \frac{R_h \cdot x + R \cdot x'}{y} \cdot \cos \varphi \quad (9)$$

The friction force between socket-rod and vertical wall of furrow has the following relation:

$$F_f = \frac{R_h \cdot x + R \cdot x'}{y} \cdot \sin \varphi \quad (10)$$

The new value of the P force determines an increase in soil reaction on socket-rod with $R \cdot x' / y$ (which can exceed the limit of 80 N/cm²), having as result an increase in the friction force between socket-rod and furrow wall with the same value, resulting in a higher energy consumption.

Milling cutler stability at work. During the working process developed by the milling cutler, the cutting forces are acting on milling knives. These are the resultants of the resistance forces, which appear because of the plastic and elastic deformations of soil, and of the friction forces between soil and working surface of knives.

We consider that the cutting force is equal to peripheral force applied on the milling rotor. Under the action of cutting force, a resistance force from soil, equal to the cutting force and with an opposite direction, also appears.

During the knife rotation, the resistance force of soil varies from maximum to zero.

Taking into account all these reasons, we may say that during the working process of milling cutler, in the case of upside down milling (case presented in the experimental tests), the following forces and moments are acting (*Figure 4*): G_t – milling cutler weight; R_1 and R_2 – reactions in contact points of wheels or crosshead slippers with soil; R_r – resultant of opposite resistances at the cutting and detachment of soil slices, created because of z_a knives acting in soil at a given time; M_r – moment at the rotor transmitted through power take off; M_o – resistant moment due to the opposite resistances at cutting and removing soil slices from knives.

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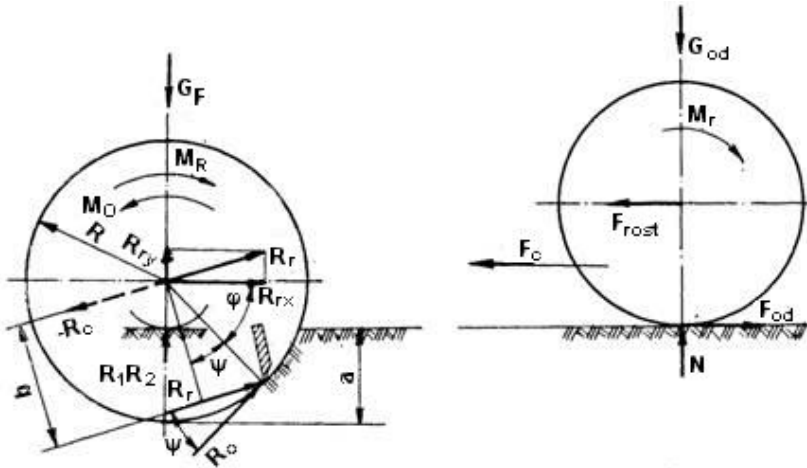


Fig. 4 - Forces and moments acting on milling cutler during working process

Knowing that the resultant direction R_r is determined by the angles φ and ψ , the moment M_0 is given by the expression:

$$M_0 = R_r \cdot b = R_r \cdot R \cos \psi \quad (11)$$

Where R is rotor radius. This moment is equal to the moment M_r conducted over rotor, through power taking device.

Applying in the O point (rotor axis) two R_r forces at equal and opposite sense, it was found that the moment M_r was cancelled by the moment $R_r \cdot b$, a force remaining unbalanced: $\overline{R_r} = \overline{R_{rx}} + \overline{R_{ry}}$.

R_{ry} component diminishes the value of forces R_1 and R_2 , and R_{rx} component acts by pushing. Therefore, a part of the power, which has to be conducted over the rotor for the working process, is used for its displacement.

R_{rx} component may have values between 2000 and 6000 N/m, in case of milling cutlers, which are working in virgin soils, having an effect of pushing the tractor. The sliding phenomenon appears at the tractor wheels, under the action of pushing force if $R_{rx} > f \cdot G_t + f \cdot G_f$, G_t - tractor weight, G_f - milling cutler weight, and f - resistance coefficient at rolling.

The stability of the plough equipped with milling cutler. This aggregate is different from ploughing classic aggregates because it has an agricultural milling cutler (machine with driven working components), instead of star harrows with straight fangs.

In this case, the milling cutler has the role of grinding, settlement and homogenizing the ploughland. It works beside of the longitudinal axis of the tractor and, as it can be seen in *Figure 5*, it modifies the equilibrium of forces acting during the plough work.

Placed at the distance x' against the instantaneous centre of rotation in horizontal plane, the pushing force of milling cutler R_{rx} , gives a moment $R_{rx} \cdot x'$.

In order to have a good stability at work, the plough must be in equilibrium, which can be achieved by balancing the moment $R_h \cdot x$ with the moments $R_{rx} \cdot x'$ and $P \cdot y$.

$$R_h = R_{rx} \cdot x' + P \cdot y \quad (12)$$

Consequently, the soil reaction on socket-rod has the expression:

$$P = \frac{R_h \cdot x - R_{rx} \cdot x'}{y} \quad (13)$$

From *Figure 5*, it results:

$$\bar{P} = \bar{N} + \bar{F}_f \quad (14)$$

Consequently, the soil reaction on socket-rod is:

$$N = P \cdot \cos \varphi \quad (15)$$

Or

$$N = \frac{R_h \cdot x - R_{rx} \cdot x'}{y} \cdot \cos \varphi \quad (16)$$

The friction force between socket-rod and vertical wall of furrow is calculated with the equation:

$$F_f = \frac{R_h \cdot x - R_{rx} \cdot x'}{y} \cdot \sin \varphi \quad (17)$$

In practice, it is necessary that the plough always have the tendency to press with the socket-rod on the vertical wall of furrow, namely the P value must always be higher than zero. The P force is limited, in order not to crush furrow wall and not to increase too much the friction forces, which are useless.

Consequently, the pushing force of milling cutler takes a part from the load of P force (it reduces the normal value to the socket-rod surface), bringing it around the value of 10-20 N/cm²; hereby, friction forces diminish and, implicitly, fuel consumption.

CONCLUSIONS

The agricultural aggregates stability represents an important element with direct influences on the quality of work and on the consumption of energy necessary for work.

In the case of classic ploughing aggregates (tractor + plough or tractor + plough + star harrow), an important element regarding their stability in horizontal plane is soil reaction to socket-rod. This reaction is positive but it can be too high, because it will lead to the furrow vertical wall crushing and friction forces increasing.

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As it was shown before, the use of star harrow with straight fangs for crumbling, equalization and settlement of ploughland, leads to the increase in the value of soil reaction on socket-rod with a direct result on increasing the values of friction forces.

Agricultural milling cutlers do not raise important problems regarding stability at work. From the study of forces acting on milling cutler during the work, it results that the horizontal component of soil reaction is important.

In the case in which the milling cutler rotor is rolling down to upside, this component opposes to displacement and, consequently, the value of the traction force developed by the tractor must increase in order to control this resistance.

When the rotation sense of rotor is from upside-down, this component becomes pushing force and, consequently, it helps the displacement. Taking into account that soil resistance force varies from zero to maximum, it results that the pushing force has the same variation. The pushing force can have values between 2000 and 6000 N per meter working width, for the case of virgin soils and sometimes (when its value increases very much), the sliding phenomenon of tractor wheels may appear.

In the case of using a plough equipped with milling cutler, the situation is inversely of the one of plough with harrow. The milling cutler determines a reduction in soil reaction on socket-rod and, implicitly, on friction forces.

In this case, the fuel consumption is a little higher than in the case of ploughing classic aggregates, but the work quality (the plough with milling cutler passing eliminates the necessity of harrowing work execution) fully compensates this.

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