

# Investigation of the power interaction of the ploughshare digger working body with the soil and sugar beet root for the conditions of its vibratory digging

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**Abstract.** *the basic principles of the theory of interaction of the vibrating digging working body with the body of the root crop fixed in the soil at vibrating digging of sugar beets are developed. The force interaction of ploughshare diggers with the soil is considered in the work. The values of normal soil reactions acting on the ploughshare of the excavating working body are determined, which, when vibrating in the longitudinal-vertical plane, can dig out the bodies of sugar beet roots from the soil. Based on the obtained equations describing this process, the prerequisites for finding the kinematic and structural parameters of the excavating working body are developed.*

**KEY WORDS:** WEDGE THEORY, VIBRATION DIGGING OF ROOT CROPS, NORMAL REACTION, PARAMETERS OF DIGGING ORGAN

## 1. Introduction

Vibratory digging of sugar beet roots has become widespread in many beet-growing countries. It has a number of advantages over other methods of excavation. Therefore, this technological process requires a detailed analytical study and further development of advanced vibrating excavations. When performing any technological process, the necessary conditions are to ensure productivity, reduce energy consumption and improve the quality of the technological process. With regard to beet harvesters, a necessary condition for ensuring the quality of the technological process is, first of all, non-damage of roots during their digging. It is quite obvious that the greatest probability of damage to the roots exists in the presence of shock interaction of the working body of the beet harvester with the body of the root, fixed in the soil. Therefore, there is a need to investigate the theoretically specified shock interaction and on the basis of the results to determine the kinematic and structural parameters of the excavating working bodies from the conditions of non-damage of roots during their vibrational excavation.

## 2. Preconditions and means for resolving the problem

Fundamental theoretical studies of the process of vibratory digging of roots were carried out in [1] - [7]. However, the interaction of the vibrating digging organ with the body of the root crop fixed in the soil is not considered here. Only in [8] and [9] are some experimental results of the shock interaction of the pendulum copier with the root head. In this paper, the interaction of the vibrating digging organ at the moment of its meeting with the body of the root crop, ie at the moment of simultaneous impact of both plowshares on the root crop, is investigated.

## 3. Results and discussion

Consider the force interaction of ploughshare diggers with the soil, using the basic provisions [1]. For this purpose we will make the power scheme on which we will represent an element of a soil layer  $KL$ , inside which, in the center, is the root, which is approximated by a body having a conical shape (Fig. 1). Under the action of soil support forces, which are presented in the form of evenly distributed intensity load  $\bar{q}$ , layer element  $KL$  is in the channel of the ploughshare digger between its working surfaces and is consistently compressed at translational movement of the digger. The force of soil support, which is transmitted directly to the root, is denoted as  $\bar{Q}$ . In the soil layer  $KL$  there is a stressful state, which is due to the action of normal forces  $\bar{N}$  and friction forces  $\bar{F}$  at the points of his contacts  $K$  and  $L$  with the working surfaces of wedges. As a result on the part of the root that is inside the layer  $KL$ , (the lower part of the root remains trapped in the undeformed layer of soil) the force  $\bar{Q}$ , acts, which is due to the forces of soil

support  $\bar{q}$ . On the other hand, forces  $\bar{P}'_{xi}$ ,  $\bar{P}'_{yi}$ ,  $\bar{P}'_{zi}$  act directly on this part of the root, ( $i = 1, 2$ ), which are transmitted from the work surfaces of the wedges, where the corresponding forces arise  $\bar{P}_{xi}$ ,  $\bar{P}_{yi}$ ,  $\bar{P}_{zi}$ , ( $i = 1, 2$ ).

Fig. 1 shows each of these forces acting from the working surfaces of the plowshares with the corresponding index. Thus, the forces acting from the working surface  $A_1B_1C_1$  on the soil layer, marked with index 1 –  $\bar{P}_{x1}$ ,  $\bar{P}_{y1}$ ,  $\bar{P}_{z1}$ , and forces acting directly on the root from this surface –  $\bar{P}'_{x1}$ ,  $\bar{P}'_{y1}$ ,  $\bar{P}'_{z1}$ . Forces acting on the soil layer from the work surface  $A_2B_2C_2$  marked with index 2 –  $\bar{P}_{x2}$ ,  $\bar{P}_{y2}$ ,  $\bar{P}_{z2}$ , and forces acting directly on the root from this surface, respectively –  $\bar{P}'_{x2}$ ,  $\bar{P}'_{y2}$ ,  $\bar{P}'_{z2}$ . The action of these forces on the root is determined by their formation on the working surfaces of wedges and the nature of transmission in the deformed layer of soil. The force of the bonds with the soil is designated as  $\bar{R}$ , it is conditionally located on the axis of the root and is directed in the general case vertically downwards, but at direct extraction of a root from soil it can be laid out along the corresponding axes of coordinates (on fig. 1 it is presented by projections  $R_x$  and  $R_z$ ).

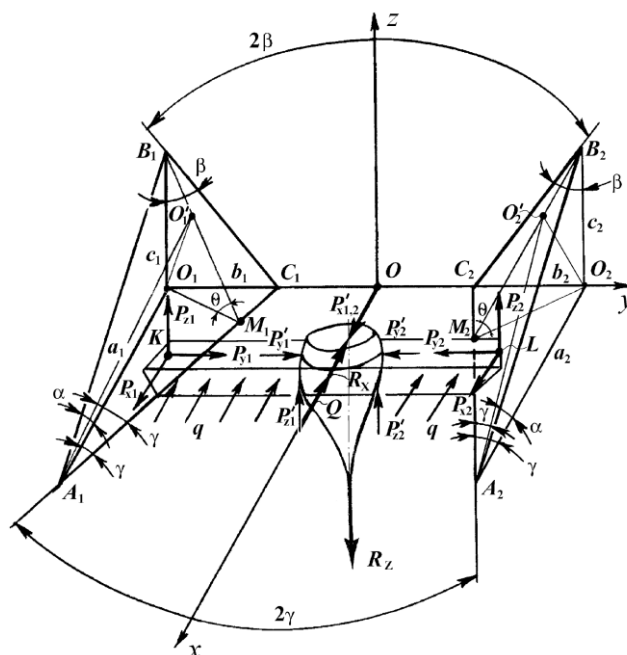


Fig. 1. Interaction of the ploughshare digging working body with the soil and sugar beet root

We will define these forces. In general, as shown in Fig. 2, a, b, c, forces  $\bar{P}_{xi}$ ,  $\bar{P}_{yi}$ ,  $\bar{P}_{zi}$  ( $i = 1, 2$ ) in vector form will be equal to:

for the plane  $A_1B_1C_1$ :

$$\begin{aligned} \bar{P}_{x1} &= \bar{N}_{x1} + \bar{F}_{x1}, \\ \bar{P}_{y1} &= \bar{N}_{y1} + \bar{F}_{y1}, \\ \bar{P}_{z1} &= \bar{N}_{z1} + \bar{F}_{z1}. \end{aligned} \tag{1}$$

similarly for the plane  $A_2B_2C_2$ :

$$\begin{aligned} \bar{P}_{x2} &= \bar{N}_{x2} + \bar{F}_{x2}, \\ \bar{P}_{y2} &= \bar{N}_{y2} + \bar{F}_{y2}, \\ \bar{P}_{z2} &= \bar{N}_{z2} + \bar{F}_{z2}. \end{aligned} \tag{2}$$

where  $\bar{N}_{xi}, \bar{N}_{yi}, \bar{N}_{zi}, (i=1,2)$  – normal reactions of working surfaces of wedges in projections on corresponding axes of coordinates;  $\bar{F}_{xi}, \bar{F}_{yi}, \bar{F}_{zi}, (i=1,2)$  – the forces of friction of the soil layer against the working surfaces of the wedges are also in projections on the corresponding coordinate axes.

We will analyze the action of each of the forces included in expressions (1) and (2) and form an effort that transmitted directly to the root. Thus, the vertical forces from blade surfaces  $\bar{P}'_{z1}$  and  $\bar{P}'_{z2}$  try to squeeze the root out of the soil (especially that part of it that is pinched in the soil); horizontal transverse forces  $\bar{P}'_{y1}$  and  $\bar{P}'_{y2}$  also try to squeeze the root, like a wedge-shaped body from the ground. Horizontal forces  $\bar{P}'_{x1}$  and  $\bar{P}'_{x2}$  (in Fig. 2.1 they are marked as the total force  $\bar{P}'_{x1,2}$ ), acting in the direction of the ploughshare digger, together with the force  $\bar{Q}$  also try to push the root out of the soil, but the direction of the force  $\bar{Q}$  is opposite to the digger movement. However, depending on soil properties and other factors, the strength of the support  $\bar{Q}$  may be insignificant, and then  $P'_{x1,2} > Q$ , and the root will move forward under the action of horizontal force  $R_z = P'_{x1,2} - Q$ , from which it is possible to break off the root in the area of its pinching in the undeformed layer of soil. Therefore, the quality of work of ploughshare diggers will be in the case of creating a significant amount of effort by the digger  $\bar{P}_{zi}$  and  $\bar{P}_{yi}$  and, conversely, small values of forces  $\bar{P}_{xi}$ .

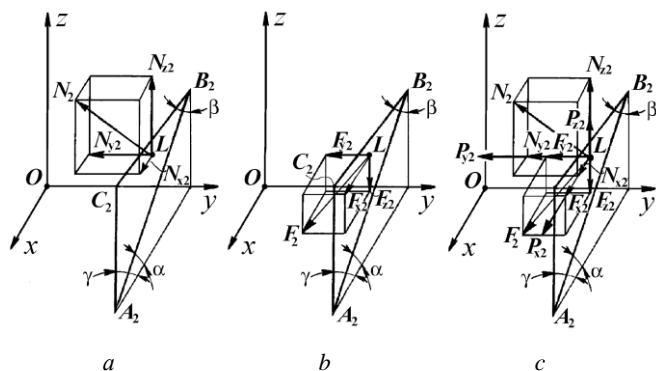


Fig. 2. Scheme of forces acting on one of the wedges of the ploughshare digging body:

*a* – normal component  $\bar{N}_2$  and its projections on the coordinate axis; *b* – friction force  $\bar{F}_2$  and its projections on the coordinate axis; *c* – the total forces transmitted from the surface of the wedge:  $\bar{P}_{x2}, \bar{P}_{y2}, \bar{P}_{z2}$ .

Values and directions of forces  $\bar{N}_i$  and  $\bar{F}_i$ , which determine the forces  $\bar{P}_{xi}, \bar{P}_{yi}, \bar{P}_{zi}, (i=1,2)$ , depend on many factors: the properties and condition of the soil, the value of root-to-soil bond forces  $\bar{R}$ , geometrical parameters of digger wedges and angles of

their installation in relation to the direction of movement, speed of translational movement, etc.

Consider further the effect of angles  $\alpha, \beta$  and  $\gamma$  on the forces values  $\bar{P}_{xi}, \bar{P}_{yi}, \bar{P}_{zi}, (i=1,2)$ , which form the pressure of the working plane of the wedge on the soil layer and on the root crop. Consider this on the example of one of the planes of the ploughshare, assuming that the second plane will be similar. As you can see from Fig. 2.2, a, at the point of contact *L* there is a normal reaction  $\bar{N}_2$ , which can be represented as projections on the corresponding coordinate axes –  $N_{x2}, N_{y2}, N_{z2}$ . If you find these projections of the normal reaction, it is possible to find the force of friction  $\bar{F}_2$ , which can also be represented as projections on the same coordinate axes –  $F_{x2}, F_{y2}, F_{z2}$  (fig. 2, b).

We find further the values of the forces  $\bar{N}_{xi}, \bar{N}_{yi}, \bar{N}_{zi}$ , which are directed along the corresponding coordinate axes and depend on the direction of the force vector itself  $\bar{N}_i (i=1,2)$ . But we will make analytical expressions at once for two planes of the digger. For the plane  $A_1B_1C_1$  they will be equal:

$$\begin{aligned} N_{x1} &= N_1 \cos(x, \bar{N}_1), \quad N_{y1} = N_1 \cos(y, \bar{N}_1), \\ N_{z1} &= N_1 \cos(z, \bar{N}_1). \end{aligned} \tag{3}$$

For the plane  $A_2B_2C_2$  in accordance:

$$\begin{aligned} N_{x2} &= N_2 \cos(x, \bar{N}_2), \quad N_{y2} = N_2 \cos(y, \bar{N}_2), \\ N_{z2} &= N_2 \cos(z, \bar{N}_2), \end{aligned} \tag{4}$$

where  $\cos(x, \bar{N}_i), \cos(y, \bar{N}_i), \cos(z, \bar{N}_i)$  – guides cosines of the force vector  $\bar{N}_i (i=1,2)$ .

Now we find the dependence of these guide cosines on the angles  $\alpha, \beta$  and  $\gamma$ , which determine the construction parameters of the ploughshare digger. To do this, denote by  $a_i, b_i$  and  $c_i, (i=1,2)$ , segments of coordinate axes that cut off the working faces of the wedges. And for the plane  $A_1B_1C_1$  it will be the segments  $a_1, b_1, c_1$ ; for the plane  $A_2B_2C_2 - a_2, b_2, c_2$ . Then the coordinates of the three points of each plane of the wedges ( $A_1B_1C_1$  and  $A_2B_2C_2$ ) in the adopted coordinate system  $Oxyz$  will be respectively equal:

$$\begin{aligned} x_{A1} &= a_1; \quad y_{A1} = -\frac{A_1 A_2}{2}; \quad z_{A1} = 0; \\ x_{B1} &= 0; \quad y_{B1} = -\frac{A_1 A_2}{2}; \quad z_{B1} = c_1; \\ x_{C1} &= 0; \quad y_{C1} = -\left[ \left( \frac{A_1 A_2}{2} \right) - b_1 \right]; \quad z_{C1} = 0; \\ x_{A2} &= a_2; \quad y_{A2} = \frac{A_1 A_2}{2}; \quad z_{A2} = 0; \\ x_{B2} &= 0; \quad y_{B2} = \frac{A_1 A_2}{2}; \quad z_{B2} = c_2; \\ x_{C2} &= 0; \quad y_{C2} = \left( \frac{A_1 A_2}{2} \right) - b_2; \quad z_{C2} = 0. \end{aligned} \tag{5}$$

We use the basic provisions of analytical geometry [2] and, on the basis of (5), we make the equations of planes  $A_1B_1C_1$  and  $A_2B_2C_2$  in the form of such determinants:

$$A_1B_1C_1: \begin{vmatrix} x_{A1} - a_1 & y_{A1} + \frac{A_1A_2}{2} & z_{A1} \\ -a_1 & b_1 & 0 \\ -a_1 & 0 & c_1 \end{vmatrix} = 0; \quad (6)$$

$$A_2B_2C_2: \begin{vmatrix} x_{A2} - a_2 & -y_{A2} - \frac{A_1A_2}{2} & z_{A2} \\ -a_2 & -b_2 & 0 \\ -a_2 & 0 & c_2 \end{vmatrix} = 0.$$

From fig. 1 we see that the values of the corresponding segments  $a_i, b_i, c_i$ , ( $i = 1, 2$ ) on the corresponding coordinate axes will be equal to:

$$a_1 = \frac{b_1}{\tan \gamma}; \quad a_2 = -\frac{b_2}{\tan \gamma}; \quad c_1 = \frac{b_1}{\tan \beta};$$

$$c_2 = -\frac{b_2}{\tan \beta}; \quad b_1 = b_2 = \frac{(A_1A_2 - C_1C_2)}{2}. \quad (7)$$

If we reveal the obtained determinants (6), we have the following equations of the surfaces of the wedges of the ploughshare digger:

$$A_1B_1C_1: (x_{A1} - a_1)[b_1c_1 - 0 \cdot 0] + \left(y_{A1} + \frac{A_1A_2}{2}\right) \times$$

$$\times [0 \cdot (-a_1) - (-a_1) \cdot c_1] + z_{A1}[(-a_1) \cdot 0 - b_1(-a_1)] = 0, \quad (8)$$

$$A_2B_2C_2: (x_{A2} - a_2)[(-b_2) \cdot c_2 - 0 \cdot 0] + \left(-y_{A2} - \frac{A_1A_2}{2}\right) \times$$

$$\times [0 \cdot (-a_2) - (-a_2) \cdot c_2] + z_{A2}[(-a_2) \cdot 0 - (-b_2)(-a_2)] = 0.$$

After substitution (7) in (8) and the corresponding transformations, we find the equation of the working planes of the ploughshare. They are as follows:

$$A_1B_1C_1: x_{A1} \tan \gamma + y_{A1} + z_{A1} \tan \beta + \frac{C_1C_2}{2} = 0, \quad (9)$$

$$A_2B_2C_2: x_{A2} \tan \gamma - y_{A2} + z_{A2} \tan \beta - \frac{C_1C_2}{2} = 0. \quad (10)$$

It is known that for vectors normal to the planes expressed by equations (9) and (10), the guide cosines will have the following values:

$$\cos(x, \vec{N}_i) = \frac{\tan \gamma}{\sqrt{\tan^2 \gamma + 1 + \tan^2 \beta}},$$

$$\cos(y, \vec{N}_i) = \frac{1}{\sqrt{\tan^2 \gamma + 1 + \tan^2 \beta}}, \quad (11)$$

$$\cos(z, \vec{N}_i) = \frac{\tan \beta}{\sqrt{\tan^2 \gamma + 1 + \tan^2 \beta}}.$$

Now, if we substitute (11) in (3) and (4), we obtain the values of the projections of the normal components of the forces  $\vec{N}_i$  ( $i = 1, 2$ ) of the surfaces of the wedges on the corresponding coordinate axes. For the plane  $A_1B_1C_1$ :

$$N_{x1} = \frac{N_1 \tan \gamma}{\sqrt{\tan^2 \gamma + 1 + \tan^2 \beta}}; \quad N_{y1} = \frac{N_1}{\sqrt{\tan^2 \gamma + 1 + \tan^2 \beta}};$$

$$N_{z1} = \frac{N_1 \tan \beta}{\sqrt{\tan^2 \gamma + 1 + \tan^2 \beta}};$$

for the plane  $A_2B_2C_2$ :

$$N_{x2} = \frac{N_2 \tan \gamma}{\sqrt{\tan^2 \gamma + 1 + \tan^2 \beta}}; \quad N_{y2} = -\frac{N_2}{\sqrt{\tan^2 \gamma + 1 + \tan^2 \beta}};$$

$$N_{z2} = \frac{N_2 \tan \beta}{\sqrt{\tan^2 \gamma + 1 + \tan^2 \beta}}. \quad (13)$$

Since the found values of projections of the normal components of the working surfaces of the wedges, that is, the ability to determine other forces transmitted from them to the ground layer and directly to the root.

Thus, the values of normal soil reactions, which act on the ploughshares of the digging working body, have been determined. When providing vibrations in the longitudinal-vertical plane, the bodies of sugar beet roots may dig out of the soil.

#### 4. Conclusions

The basic principles of the theory of interaction of the vibrating digging working body with the body of the root crop fixed in the soil at vibrating digging of sugar beets are developed.

The values of normal soil reactions acting on the ploughshare of the excavating working body are determined, which, when vibrating in the longitudinal-vertical plane, can dig out the bodies of sugar beet roots from the soil.

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