BALANCING THE DEEP LOOSENING MACHINE WITH ACTIVE FURROWS

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Abstract: The stability of machines for soil preparation during the work process is influenced by a number of variable sizes of which the most important are the soil strength and configuration. The stability of deep soil loosening machines with fixed furrow during the work process is studied like vertical stability for the plow. Less studied in the scientific literature, is the stability of deep soil loosening machines with active furrows powered for the tractors PTO with a quadrilateral mechanism.

Keywords: balancing, deep loosening, soil

1. INTRODUCTION

Obtaining the optimal quality indices of agricultural work is influenced by the dynamics of the tractor - agricultural machine unit. The units dynamics with the machine mounted on the back or front of the tractor is studied in a number of specialty papers [1-4]. Influence of mounted machines in front of the tractor on aggregate stability is also a concern of specialists [4]. Research was performed on the dynamics of tractor - agricultural machine units mounted in front or behind and driven by the PTO [5-7].

The paper analyzes the stability of the deep soil loosening machine with active furrows where the soil reaction on the furrows is variable both in size as well as in direction. It is impossible to balance for one rotation of the quadrilateral action mechanism handle.

2. THEORETICAL CONSIDERATIONS

The stable movement of the deep soil loosening machine is determined by the force of action and the reaction on the surface of the supporting soil that change both the size and application point. If total resistance forces stand vertically through the instantaneous rotation center, CIR, at the intersection linkage suspensions, the machine is balanced in the vertical plane [8, 9]. For this, the support resultant Rs (Figure 1) must pass over the CIR. It is considered that the stability of the machine is adequate if the depth does not vary by more than ±10 % compared to the adjusted depth [8].

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Figure 1 shows the deep soil loosening machine coupled to the tractor through linkage of category 3 with the lower link B₁E and the upper link A₁D₁.

The length ED₁ is adjustable in n₁ steps, with the pitch c₁.

\[ ED₁ = c = 579.8 + n₁ \cdot c₁ \]  

(1)

To the horizontal, the lower link can rotate angles β₁ and β₂ corresponding to the two extreme positions of joint E. These relations can be calculated:

\[ β₂ = \arcsin \frac{y_{E_{\text{max}}} - y_{B₁}}{EB₁} \]  

\[ β₁ = \arcsin \frac{y_{B₁} - y_{E_{\text{min}}}}{EB₂} \]  

(2)

Fig. 1. The forces acting in the vertical plane of the deep loosening of soil machine.

The abscissa extreme articulation points of the lower link will be:

\[ x_{E_{\text{min}}} = x_{B₁} - EB₁ \cdot \cos β₁ \]  

\[ x_{E_{\text{max}}} = x_{B₁} - EB₁ \cdot \cos β₂ \]  

(3)

To ensure the horizontal position of the machine frame, the joint D₁ of the upper link and the joint E of the lower link must have the same abscissa:

\[ x_{D₁} = x_{E} \]  

(4)

This is done by modifying the length of the upper link A₁D₁. Knowing the length \( c = ED₁ \), the position of the maximum ordinate of point D₁ can be determined by the relation:

\[ y_{D₁_{\text{max}}} = y_{E_{\text{max}}} + c \]  

(5)

The deep soil loosening machine is lowered to working depth \( h \), and the joint upper link lowered from the maximum position \( D₁_{\text{max}} \) to the \( D₁ \) position with the ordinate given by:

\[ y_{D₁} = y_{D₁_{\text{max}}} - h \]  

(6)
The maximum blade tip position is raised from the ground, with the distance $h_1$. The length of the upper link is:

$$A_1D_1 = \sqrt{(x_{D1\text{max}} - x_{A1})^2 + (y_{D1\text{max}} - y_{A1})^2} \quad (7)$$

The joint coordinates $E$ of the lower link, depending on the depth $h$ are:

\[x_E = -EB_1 \cdot \cos(\beta_2 - \beta) + x_{B1} \]
\[y_E = y_{E\text{max}} - (h + h_1) = y_{B1} + \sin(\beta_2 - \beta) \quad (8)\]

where the angle of rotation of the upper link, corresponding to the $A_1D_1$ position is:

$$\beta = \beta_2 - \arcsin\left(\frac{y_E - y_{B1}}{EB_1}\right) \quad (9)$$

Instantaneous center of rotation vertically (CIR) is at the intersection of lines $D_1A_1$ and $EB_1$. Equations of this lines are:

\[y - y_{A1} = \frac{y_{D1} - y_{A1}}{x_{D1} - x_{A1}}(x - x_{A1}) \quad (10)\]
\[y - y_{B1} = \frac{y_E - y_{B1}}{x_E - x_{B1}}(x - x_{B1})\]

Instantaneous center of rotation coordinates are:

\[x_1 = \frac{m_1 \cdot x_{A1} - m_2 \cdot x_{B1} - y_{A1} + y_{B1}}{m_1 - m_2} \quad (11)\]
\[y_1 = m_1 \cdot x_1 - m_1 \cdot x_{A1} + y_{A1}\]

where:

\[m_1 = \frac{y_{D1} - y_{A1}}{x_{D1} - x_{A1}} \quad (12)\]
\[m_2 = \frac{y_E - y_{B1}}{x_E - x_{B1}}\]

The equation for the resultant support action forces of the soil in the furrow is:

\[y - y_D = \tan \alpha \cdot (x - x_D) \quad (13)\]

The resultant support of the forces acting vertically on the furrows intersects the horizontal lines $y_1 = 108$ cm in the $F$ point of the abscises

\[y_1 - y_D + x_D \cdot \tan \alpha \quad (14)\]

3. RESULTS AND DISCUSSIONS

Experiments were performed with an aggregate consisting of an equipment for deep soil loosening with driven active organs $EAA - 220$. Of the samples collected at a depth of 0.45 m on soil compactness, showed that the experimental group area 53.2 % is slightly compacted soil (penetration resistance values were between 2000 ... 2500 MPa), poorly compacted soil 30.5 % (penetration resistance values were between 2500 ... 3000 MPa) and on 16.3 % appear high resistance to penetration, over 3000 MPa, so strongly compacted soil. Medium soil moisture
was about 22.43 %, a value that is optimal permissible limit for deep soil loosening works. Average speed was 0.91 m/s resulting in an average tensile strength of 76530 N.

In XOY coordinate system (Figure 1), the lower link coupling has a minimum height of 230 mm and \( y_{\text{E_{min}}} = 230 \) mm and the maximum height \( y_{\text{E_{max}}} = 1065 \) mm [10].

The lower link length is \( EB_1 = 970 \) mm and the coordinates of the suspensions joints are \( B_1(-200, 540) \) and \( A_1(-400, 945) \). ED1 length is adjustable \( n_1 = 4 \) steps, with the pitch \( c_1 = 55.95 \) mm. For \( n_1 = 2 \) \( c_1 = ED_1 = 692 \) mm.

Figure 2 shows the variation of the CIR’s horizontal position when the working depth \( h = 0-80 \) cm. It is noted that the CIR has absissa \( x_1 \) with the variation \( x_1 = 22 - 121 \) cm for the maximum working depth \( h = 10 - 80 \) cm. Abscissa CIR has a linear variation depending on working depth:

\[
x_1 = 1.437 \cdot h + 4.42
\]

![Fig. 2. The CIR’s absciss variation depending on the working depth.](image)

The variation of point \( y_1 \) of CIR based on the working depth shown in Figure 3 can be calculated by the formula:

\[
y_1 = 0.015 \cdot h^2 - 0.416 \cdot h + 40.52
\]

![Fig. 3. The CIR’s \( y_1 \) variation depending on the working depth.](image)

During the work process, the forces that act in a vertical plane on the deep soil, the joint reactions \( D \) and \( Q_t \) and the soil reaction on the support wheel are shown in Figure 1. The projections \( R_{tv} \) on the coordinate axes are:

\[
R_{tx} = R_{DX} + Q_t \cdot \cos \varphi \\
R_{ty} = R_{DY} + Q_t \cdot \sin \varphi
\]

For the machine to be balanced vertically is necessary for the total resultants support \( R_{tv} \) to pass through the instantaneous rotation center of CIR found at the intersection of the hitch linkage [8].
For working depth $h = 80$ cm the support of the action force resultants of the soil on the plowshare has a slope:

$$tg\alpha = \frac{R_{try}}{R_{tvx}}$$  \hspace{1cm} (18)

The variation of the inclined angle of the resultants support ($\alpha$) depending on the angle of rotation of the plowshares quadrilateral crank action mechanisms ($f_1$) is shown in Figure 4.

The equations of the slope angle and resultant forces of rotation for the quadrilateral crank actions mechanisms angle $f_1 = 1.92 - 4.88$ rad are:

$$\alpha = 0.002\varphi_1^3 - 0.022\varphi_1^2 + 0.03\varphi_1 + 0.93$$  \hspace{1cm} (19)$$

$$tg\alpha = 0.006\varphi_1^3 - 0.051\varphi_1^2 + 0.051\varphi_1 + 1.367$$  \hspace{1cm} (20)

![Figure 4](image)

**a)**

Fig. 4. The variation of the inclined angle of the soil resultant forces acting on the furrow depending on the angle of rotation of the crank action mechanism:

a) for $f_1 = 0 - 6.28$ rad; b) for $f_1 = 1.92 - 4.88$ rad.

The graphical representation of the slope variation for the resultant support forces of the soil acting on the plowshare for a working depth of $h = 80$ cm, for $f_1 = 1.92 - 4.88$ rad, is shown in Figure 5 and has average value $1.241$.

For a working depth $h = 80$ cm, the instantaneous center of rotation has coordinates $x_1 = 121.4$ cm, $y_1 = 108$ cm and the D point where the total resultant forces acting vertically $R_v$ has the coordinates $x_D = -134.5$ cm, $y_D = -642.9$ cm.

Figure 6 shows the variation of the intersection point $x_F$ depending on the angle of rotation for the quadrilateral mechanism driving the cutter between the values of $f_1 = 1.92 - 4.88$ rad. This variation can be calculated using the equation:
\[ x_F = -0.936 \cdot \varphi^2 + 15.68 \cdot \varphi - 32.11 \] \hspace{1cm} (21)

Fig. 5. The slope variation of the resultant support forces of the soil acting on the plowshare for a rotation angle of the crank of \( f_1 = 1.92 - 4.88 \text{ rad} \).

![Graph showing the slope variation of the resultant support forces of the soil acting on the plowshare for a rotation angle of the crank.](image)

Fig. 6. The variation of the abscissa point \( F(x_f) \) depending on the working depth.

![Graph showing the variation of the abscissa point \( F(x_f) \) depending on the working depth.](image)

It is noted that the abscissa point for the intersection of the resultant forces of the soil acting on the plowshare \( x_f \) is less than abscissa CIR and therefore the deep soil loosening machine is balanced. This happens for the angle of rotation of the crank quadrilateral mechanism of the plowshare \( f_1 = 1.92 - 4.88 \text{ rad} \) (angle of rotation of the plowshare \( \omega_3 > 0 \)), the other rotation angles \( f_1 = 0 - 1.92 \text{ rad} \) and \( f_1 = 4.88 - 6.22 \text{ rad} \) (angle of rotation of the plowshare \( \omega_3 < 0 \)) balance is not possible given that the resultant angle of the support is negative. Balance can be achieved if the second plowshare is offset from the first with an angle \( \pi \) in this way compensate for the instability created by the first plowshare when the angle of rotation of the crank mechanism is \( f_1 = 0 - 1.92 \text{ rad} \) and \( f_1 = 4.88 - 6.22 \text{ rad} \).

4. CONCLUSIONS

From the balancing study of the deep soil loosening machine in a vertical plane resulted the following conclusions:

- The abscissa \( x_1 \) of the instant rotation center increases with the working depth;
- The abscissa point \( F \) increases when the crank angle of rotation of the driving quadrilateral mechanism is \( f_1 = 1.92 - 4.88 \text{ rad} \);
- The machine is balanced when the rotation angle of the plowshare has negative value for the angular speed \( \omega_3 > 0 \) and cannot be balanced by the positive rotation angle of the plowshare \( \omega_3 < 0 \);
- Shifting the second plowshare with an angle \( \pi \) improves the vertical stability of the machine considering that when a plowshare tends to leave the ground, the other goes into the ground.

REFERENCES