Tractor plough designing with specified tillage quality

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Abstract. The required quality of the soil layer crumbling can be obtained by providing a certain movement of soil along the plough-bottom surface. The paper presents a technique for constructing a mathematical pattern for optimal soil movement, characterized by a smooth transition from the straight plane of the mouldboard to the curved surface of the plough-share. A distinctive feature of the experimental mouldboard sample is its capability to regulate three angles of the plough-bottom surface: the angle of the ploughshare position to the furrow bottom, the angle of the ploughshare position to the furrow wall and the angle of the plough-bottom surface bending.

1. Introduction
The productivity of any tractor unit is largely determined by the parameters of its working tool. As for agricultural tractor units, this dependence directly affects the yield and thus the economy of the whole country. At present, because of sanctions and with the most acute issue being the support of local agricultural producers, the design of the working elements for tillage machines is an urgent and timely task and a matter of nation-wide importance.

Many investigations [1-3] are devoted to the designing of plough-bottom surface to satisfy the existing agrotechnical requirements. The main parameters for the soil layer movement according to various agrotechnical requirements are determined in [4-5]. The authors consider the plough surface optimization according to different criteria [6-7]. The authors of this paper suggest constructing of an optimal plough surface to provide the required movement of the soil layer when it passes along the mouldboard [8].

The type of the plough-bottom surface affects the crumbling and turnover of the undercut soil layer. The parameters of the plough-bottom surface and their changes cause the quality and energy intensity of tillage.

The types of ploughs made in Russia are known to have unsatisfactory agreement of the share with the mouldboard. This is due to the irrational changes in the screw lead S which fails to provide a smooth transition from the straight plane of the share to the curved surface of the mouldboard. Thus, the authors of the paper proposed the following order in designing a tractor plough to provide the required quality of tillage [8]:

- To form the soil movement path according to the agrotechnical requirements.
- To determine normal forces from the share according to the differential equations of the soil movement,
- To construct the surface to obtain the required soil movement path according to the directions of normal forces,
• To design a real construction according to the ready-made mathematical pattern to be normally tested.

2. Materials and methods
The plough-bottom surface being cut with several planes parallel to the plane ZOX, the coordinate x for the position of the secant longitudinal-vertical plane Z0 was found.

\[ x = \sqrt{b^2 - z^2 - b_0} \tag{1} \]

where \( z \) is the coordinate of the working surface pattern point, \( b \) is the current rotation radius of the soil layer element in the plane \( Z0Y \) and \( b_0 \) is the plough base coverage.

In each section we obtained some pattern (the curve 4-4 in Figure 1). A set of patterns arranged at a certain predetermined interval from each other accurately describes the desired plough-bottom surface. Further, on the basis of the equations of the soil layer movements we obtained analytical expressions for constructing these patterns [8].

![Figure 1. A set of patterns for constructing the bottom surface of a plough base.](image1)

In the plane \( Z0Y \) the direction of the normal \( N \) to the curve in the plane is given with the tangent of the inclination angle \( \alpha \) of the tangent line to the movement path (Figure 2).

![Figure 2. Construction of the plough-bottom surface pattern in the direction of the normal reaction \( N \) to the movement path.](image2)

\[ \text{tg} \alpha = \frac{N_z}{N_y} = \frac{dz}{dy} \tag{2} \]

where \( N_y, N_z \) are the normal views on the axes \( Z \) and \( Y \), \( dy, dz \) are the increment of the coordinates \( y \) and \( z \) of the pattern point of the working surface.

Due to the condition of the layer classic turnover [8], the ratio of the normal views has the form
where \( g = 9.81 \text{ m/s}^2 \) is the gravitational acceleration, \( S \) is the screw lead at the joint point of the share with the mouldboard, \( V_k \) is the working speed of tillage.

When putting (3) into the equation (2), we obtained

\[
\begin{align*}
\frac{dy}{dz} &= \left( -\frac{2\pi V_k^2}{gS} \cdot \frac{z}{\sqrt{b^2 - z^2}} + \frac{S}{2\pi \sqrt{b^2 - z^2}} \right) dz
\end{align*}
\]

and after integration, the equation for the working surface pattern in the plane \( Z0Y \) has the form

\[
y = \frac{2\pi V_k^2}{gS} \cdot \frac{z}{\sqrt{b^2 - z^2}} + \frac{S}{2\pi} \arcsin \frac{z}{b} + C_1 + C_2 + C_3
\]

where \( C_1, C_2, C_3 \) are the integration constants determined from the initial or boundary conditions of the smooth transition of the flat share and the curved mouldboard surface (Figure 3).

**Figure 3.** Location of the current construction pattern of the mouldboard surface and integration constants.

The condition for a smooth transition of the share and the plough has the following form

\[
tg\alpha = tg\varepsilon \cdot sin\gamma = \frac{2\pi S \sqrt{b^2 - z^2}}{gS^2 - 4\pi V_k^2 z}
\]

where \( \varepsilon \) is the inclination angle of the share to the furrow bottom, \( \gamma \) is the angle of the share position to the furrow wall.

For smooth transition (6), it is necessary:

- to make a concave share,
- to change the screw lead \( S \) at the joint point or change the inclination angle of the share to the furrow bottom \( \varepsilon \).

We found the integration constants \( C_1, C_2, C_3 \) caused by the initial conditions \( z = 0, \ x = b_0 - b, \ y = x/tg\gamma_0 \)

\[
C_1 = \frac{b_0 - b}{tg\gamma_0}, \quad C_2 = \frac{-2\pi V_k^2 b^2}{gS}, \quad C_3 = 0
\]

We found the integration constants \( C_1, C_2, C_3 \) caused by the boundary conditions \( z = b, \ x = b_0, \ y = S/tg\phi + x/tg\gamma \), where \( \phi \) is the angle of external friction

\[
C_1 = \frac{b_0 - b}{tg\gamma_0}, \quad C_2 = \frac{2\pi V_k^2 b}{gS}, \quad C_3 = \frac{2\pi V_k^2}{gS}
\]

As a result, the equation of the pattern has the following form
\[ y = \frac{2\pi}{gS} \sqrt[2]{b_0^2 - x + b + z} + \frac{S}{2\pi} \arcsin \frac{z}{b} + \frac{b_0 - b}{\tan \gamma} \]  

(9)

The set of equations (9) represents the desired bottom surface for a particular type of plough. Today, there exist three main types of ploughs
- with a screw plough-bottom surface,
- with a semi-screw plough-bottom surface,
- with a cultural plough-bottom surface.

The optimal screw lead $S$ [9] for each of them is determined differently.

3. Results

The proposed procedure was implemented with MathCad package. As a result, the patterns of plough-bottom surfaces for all three types of mouldboards are constructed. In Figure 4 a mathematical model of the pattern for the cultural plough-bottom surface for a tractor is presented, it was obtained through calculations of the initial data from Table 1.

| Parameter | Plough base coverage | Tillage depth | Working speed | Angle of external friction | Angle of the ploughshare position to the furrow wall | Angle of the outer side of the mouldboard surface to the furrow bottom |
|-----------|----------------------|---------------|---------------|---------------------------|--------------------------------------------------|---------------------------------------------------------------------|
| Symbols   | $b_0$                | $\alpha$     | $V_k$         | $\phi$                    | $\gamma$                                         | $\varepsilon$                                                       |
| Dimension | m                    | m             | m/s           | degrees                   | degrees                                          | degrees                                                             |
| Value     | 0.35                 | 0.27          | 2             | 20                        | 40                                               | 10                                                                  |

Due to the calculations, there were made some experimental samples of working tools for tillage machines to be tested according to well-known experimental procedures [10-12] in laboratory and natural conditions, with the results of theoretical and experimental studies showing an error within the 5-10% range.

![Figure 4. Calculated pattern of the plough-bottom surface done with MathCad package.](image)

4. Implementation

According to the results of theoretical studies, there were found several different solutions for improving the existing types of ploughs [13-14], with the experimental samples of ploughs being made and tested at LLC "VarnaAgromash".

A distinctive feature of the experimental mouldboard is its capability to regulate the three angles of the plough-bottom surface [15]:
- the angle of the ploughshare position to the furrow bottom $\varepsilon$,
- the angle of ploughshare position to furrow wall $\gamma$. 


the angle of plough-bottom surface bending.

The mouldboard 2 at the depth of 2/3 has slots 3, parallel lines of its joining with the ploughshare 1. Between the slots there are vertically arranged elastic plates 4 with adjusting screws 5 (Figure 5).

The sequence for adjusting the plough parameters is as follows:

- the angle $\gamma$ of the ploughshare position to the furrow wall is to be changed by means of the two lower screws,
- the mouldboard surface bending is to be adjusted by means of vertical elastic plates,
- the angle $\varepsilon$ of the ploughshare inclination to the furrow bottom is to be changed to fix the length of the upper adjusting screw.

Before the plough started working, some certain parameters of the plough-bottom surface were established. They all are dependent on the soil and climatic conditions (the soil type, the humidity, the quality of previous treatments, the amount of plant residues, etc.). The parameters were readjusted according to the tillage quality achieved at the sample area, with the readjustments being done according to the above mentioned sequence for the tillage of the best quality.

![Figure 5. Experimental plough with variable parameters of the plough-bottom surface [15].](image)

The results of the tests prove the efficiency of the proposed ploughs and their capability to satisfy the agrotechnical requirements for various working modes.

**5. Conclusion**

The research proved the specified quality of the soil layer crumbling to be obtained with a certain path of soil movement along the plough-bottom surface.

A procedure for a mathematical pattern to find the optimal path for soil movement is developed; it is characterized by a smooth transition from the straight plane of the share to the curved surface of the mouldboard.

According to the proposed method, a program for finding the coordinates of an ideal plough-bottom surface with the help of MathCad package was compiled.

The theoretical results are realized in specific experimental designs of mouldboards successfully tested.

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