

Process of soil destruction: experimental results

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Abstract. The article presents the results of experimental studies of the ripping resistance force on a tracked bulldozer-ripper manufactured by the Chelyabinsk Tractor Plant. The experiment covers three ripping depths and eight angles. It has been experimentally established that the dependence of the ripping resistance force on each of these parameters is quadratic. The authors propose the use of a complex parameter which is equal to the product of the ripping depth by the angle when studying the ripping process. The use of the complex parameter for two-factor analysis allowed them to reduce the degree of the studied dependence while preserving the required accuracy. The complex parameter reflects the relationship between the design parameters of the ripper tooth, the ripping depth, and angle.

1 Introduction

Ripping is an integral part of the technological cycle both for agricultural and road building machines [1, 2]. The scheme and parameters of the working tool and the hinged system mainly determine the soil cultivation nature [3, 4]. Two main types are identified among the variety of hinged systems: those with one-sided (Fig. 1a) and two-sided (Fig. 1b) force closure.

Systems with one-sided force closure do not provide positive penetration of the working tool into the soil or ensure its free movement relative to the tractor. Such systems are typical for agricultural tillage machines. Their theory is well-developed today [5, 6].

The hinged systems of road building machines designed for the destruction of firm, frozen, and rocky soils are fundamentally different from the hinged systems of ripping machines. Their hinged systems ensure the positive penetration of the working tool into the soil. The issues of ripping process optimization require additional studies.

It has been established that the forces acting on the working tool in relation to the soil depend on the ripping process parameters: ripping depth h and the angle α . At present, these dependences are mainly studied experimentally [7, 8]. Theoretical studies are reduced mainly to the models of a discrete element [9, 10, 11].

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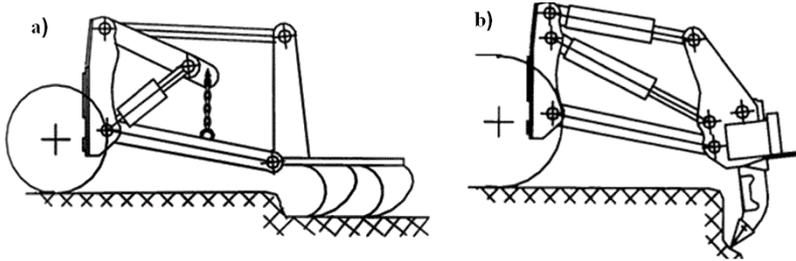


Fig. 1. Hinged systems with one-sided (a) and two-sided (b) force closure.

2 Methods of the experimental studies

Experimental studies were conducted using a tracked bulldozer ripper. Its controls allow for control of ripping depth h and angle α . Loam of medium density (in summer) and frozen loam (in winter) was utilized for these studies. The experiment was completed at various ripping angles $\alpha=38^\circ, 43^\circ, 45^\circ, 47^\circ, 50^\circ, 53^\circ, 55^\circ, 60^\circ, 65^\circ$ and depth ($h \approx 0.7m; h \approx 0.9m; h \approx 1.1m$). The depth h was measured every $0.1 m$ of the route.

The objective of the experiment was to determine traction resistance (horizontal component P_x) and penetration resistance (vertical component P_y) at different ripping parameters. Tension sensors were stuck to the ripper to measure the resistance forces.

By attaching tension sensors, we were able to measure the forces perpendicular to the front section P_K and on the foot P_N of the ripper (Fig. 2).

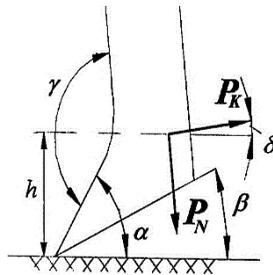


Fig. 2. Scheme for the determination of the components of the force of ripping resistance.

Based on the measured forces of P_K and P_N , we calculated the desired components of the force of ripping resistance of P_x and P_y :

$$\begin{aligned} P_x &= P_K \cos \delta + P_N \sin \delta \\ P_y &= -P_K \sin \delta + P_N \cos \delta \end{aligned} \quad (1)$$

where $\delta = 0,5\pi + \alpha - \gamma$ is slope angle of the ripper shank to the vertical, β is the slope angle of the ripper foot to the horizon, α is the ripping angle, and γ is the positive angle of the ripper shank.

3 Experiment results

Resistance forces were measured at constant values of ripping depth h or angle α . All the experimental dependences were approximated using the least square method.

The appearance of the approximating dependencies (Fig. 3) demonstrated the non-linear nature of the relationship between traction resistance force and ripping depth $P_x(h)$ and the angle $P_x(\alpha)$.

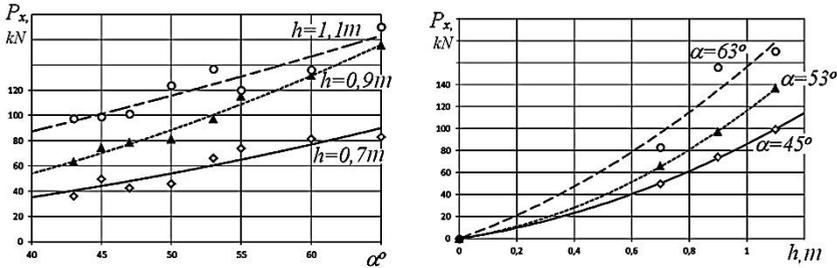


Fig. 3. Dependencies of traction resistance force P_x on ripping angle α (a) and ripping depth h (b).

For example, the dependencies presented in Figure 3 are as follows:

$$\text{for } h=0,7\text{m } P_x(\alpha) = 0,0197\alpha^2 + 0,0979\alpha ,$$

$$\text{for } h=0,9\text{m } P_x(\alpha) = 0,0383\alpha^2 + 0,115\alpha ,$$

$$\text{for } h=1,1\text{m } P_x(\alpha) = 0,0056\alpha^2 + 2,0895\alpha ,$$

$$\text{for } \alpha=45^\circ P_x(h) = 0,0071h^2 + 0,2175h ,$$

$$\text{for } \alpha=53^\circ P_x(h) = 0,0098h^2 + 0,3979h ,$$

$$\text{for } \alpha=65^\circ P_x(\alpha) = 0,0043h^2 + 1,2015h .$$

Analogous qualitative dependencies of $P_y(h)$ and $P_y(\alpha)$ are also observed for the vertical component of the resistance force.

4 Experimental data processing

When processing the experimental data, it was suggested to simultaneously use the dependence on the two parameters (α and h). However, the use of a quadratic form of

$$P(\alpha, h) = b_1\alpha^2 + b_2h^2 + b_3\alpha h + b_4\alpha + b_5h + b_6 , \tag{2}$$

where $b_1, b_2, b_3, b_4, b_5, b_6$ are empirical coefficients, does not lead to a good result because recording one of the parameters, for example h , and obtaining good approximations in the range of large values of α and h , does not correspond to the physical phenomenon at small values of these parameters. The function $P(\alpha, h)$ should give a rather close approximation in the range of values of the conducted experiment and meet the physical meaning in the range of extrapolation [12]. The following fourth-order polynomial meets these requirements:

$$P(\alpha, h) = b_1\alpha h + b_2(\alpha h)^2 . \tag{3}$$

In addition, function (3) is characterized by a smaller number of empirical coefficients b_i , than by formula (2). The results of processing the experiment using formula (3) are shown in Fig. 4.

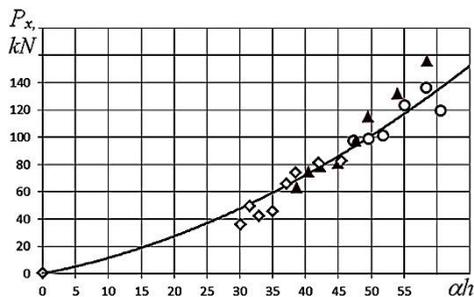


Fig. 4. The dependence of the force of traction resistance P_x from the complex parameter αh :
 $P_x = 2.10 - 6\alpha h + 0,0092(\alpha h)$

The results of experimental processing using formula (3) coincide with a sufficient degree of adequacy with theoretical studies dealing with the digging process [13, 14].

5 Conclusions

We experimentally established that the forces acting on the working part of the ripper are equally dependent on the ripping depth h [15] and the angle α [16].

Traction resistance P_x and penetration resistance P_y have a quadratic dependence on the ripping depth h and the angle α .

Using the complex parameter αh when describing the dependencies of $P_x(\alpha h)$ and $P_y(\alpha h)$ allows us to reduce the degree of the fourth-order polynomial to the second-order polynomial while preserving the required accuracy.

In addition, the complex parameter αh allows us to obtain a single dependence for each type of soil and reflects the relationship between the design parameters of the ripper tooth, ripping depth, and angle.

Our approach makes it possible to set the task of optimizing the ripping process depending on the type of the excavated soil [17].

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