

Results of experiments to determine the traction resistance of a disk working body

*Rustem Sakhapov**, *Ramil Gainutdinov*, *Marat Mahmutov*, and *Minsur Zemdikhanov*

Kazan state University of Architecture and Engineering, 420043 Kazan, Russian Federation

Abstract. Technical means used for soil surface treatment do not fully meet the technical requirements for high-quality soil treatment. In order to solve this problem more effectively, various rotary machines with working bodies that perform complex spatial movement are currently being developed. But, as practice has shown, that the work of these tools is unstable and that the cultivation of the soil is carried out unevenly. To eliminate these disadvantages, we developed a tillage tool with ellipsoid disk working bodies mounted on the shaft at a strictly defined angle [7, 13]. The analysis showed that to ensure the efficiency of work and reduce the traction resistance of tools for tillage, it is necessary that the angle of installation of the ellipsoid disk about rotation axis is also optimal. Here are the results of experimental studies of the traction resistance of disks conducted in the conditions of a soil channel. The mathematical model of the technological process was obtained by processing experimental data in the computer program "Statistica" and presented in the form of multiple regression equations in encoded and real physical quantities. The response surfaces are constructed based on the obtained equations.

1 Introduction

A mandatory part of the design stage of tillage machines and tools is to ensure the strength of structural elements, reduce energy consumption and determine the conditions for stable movement of equipment. Therefore, there is a need to determine the forces acting on the tool, the forces required for its movement on the surface of the processed field, i.e. in accordance with the generally accepted terminology - traction resistance.

To conduct laboratory research in accordance with the developed design and technological documentation and in accordance with the developed program, an experimental unit was created in the laboratory of the department. Experiments on measuring the traction resistance of an ellipsoid working body were carried out in the soil channel of the Kazan SAU [2, 5]. The soil type is medium loamy, with average values of humidity, density, and soil hardness - 20.5%, 1.15 g/cm³, and 1.4 MPa, respectively.

Significant contributions to the development and research of rotary tillage machines and tools were made by Goryachkin V.P. [2], Abdrakhmanov R.K. [1], Panov I.M. [12], Kanarev F.M. [8], Matyashin Yu.I. [11], Mazitov N.K. [10], Makarov P.I. [9], Sakhapov

* Corresponding author: rusakhapov@gmail.com

R.L. [14, 20, 21], Yakhin S.M. [16], Piotr F. B. [17], Soehne W. [18], Srivastava A. K. [19] et al.

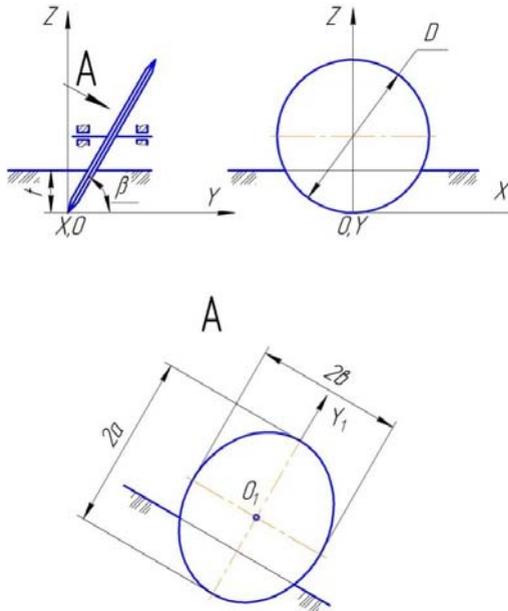


Fig. 1. Projections of an ellipsoid working body



Fig. 2. Experimental unit

2 Methods

In accordance with the requirements of state and industry standards (GOST 24057-80, OST 70.2.15-73, OST 70.2.2-2002), experimental studies of the working body of the rotary tool, as well as its economic and energy assessment, were carried out in the laboratory.

Dynamometry is a reliable experimental method that can be used to determine the traction resistance of surface tillage tools [4]. The direct measurement method allows to get the value of the required parameter through the force measuring link, and the indirect measurement method - based on the results of any other characteristics measuring. An electronic dynamometer is used as a link for force measuring, and various sensors [15] connected to a working body or tool are used to implement indirect measurement methods.

The experimental device developed by us was installed in a separate deformable beam, which was attached to the frame of the cart. Strain gauge resistors of the brand KF5P1-15-200 (hereinafter referred to as the load sensor) were installed on the beam in such a way that it was possible to measure the tensile strain, and therefore the traction resistance of the disk working body.

According to the prepared planning matrix, the experiment is repeated three times for different values of the tillage depth and the speed of ellipsoid disk movement. At the initial stage, in accordance with the operating instructions of the measuring information system IP 264, strain gauge bridges were calibrated.

As it is known, when the experimental tool moves forward along the soil channel, the strain gauge beam is stretched, as a result of which the electrical resistance of the load sensor attached to it changes. The measuring information system IP 264 processes the signals received from the strain gauge bridges and transmits them to a personal computer. With the help of computer software the measurement results are displayed graphically.

Then, taking the maximum values from the graphs using calibration data, they are converted to the unit of measurement - N (Newton).

When determining the traction resistance of an ellipsoid working body, the method of planning a complete factor experiment is used. Table 1 shows that the variable parameters of the experiments are as follows: working body speed (casrt) - 8, 10, 12 km/h, tillage depth (the depth of immersion of the working body in the soil) - 0.04; 0.06; 0.08 m. As a result of data processing, a quantitative assessment of the influence of various factors on the traction resistance of the disk was obtained.

Table 1. Physical and coded levels of the experiment factors

Name of factors	Designation of factors	Coded designation of factors	Natural levels of variation			Coded levels of variation		
			upper	basic	lower	upper	basic	lower
Tillage depth, m	t	X_1	0.08	0.06	0.04	+1	0	-1
Forward speed, km/h	V_e	X_2	12	10	8	+1	0	-1

The mathematical model of the technological process is compiled in the form of a linear multiple regression equation:

$$Y = b_0 + b_1X_1 + b_2X_2 + b_{12}X_1X_2 + b_{11}X_1^2 + b_{22}X_2^2, \quad (1)$$

where Y - response function; X_1, X_2 - the first, the second factors of the process under study, b_0 - characterizing the values of the response function Y in the centre of the plan; b_1, b_2 - coefficients characterizing the degree of influence of the first and second factors on response function Y ; b_{12}, b_{11}, b_{22} - coefficients characterizing the significance of the influence of relevant factors on the response function Y .

Table 2. Experiment planning matrix

Number of experiment	Natural experiment factors		Coded experiment factors	
	t	V_e	X_1	X_2
1	0.04	8	-1	-1
2	0.06	8	0	-1
3	0.08	8	+1	-1
4	0.04	10	-1	0
5	0.06	10	0	0
6	0.08	10	+1	0
7	0.04	12	-1	+1
8	0.06	12	0	+1
9	0.08	12	+1	+1

3 Results and Discussion

The results of the experiments are presented in table 3.

Table 3. Results of experiments on determining the traction resistance of the ellipsoid disk in soil channel

Experiment number	Traction resistance of ellipsoid disk, N			
	Y_1	Y_2	Y_3	Y_{cpi}
1	125.38	177.71	104.90	135.99

2	201.11	173.88	196.42	190.47
3	323.09	219.85	204.0	248.98
4	150.28	185.62	112.54	149.48
5	176.13	221.18	228.25	208.52
6	216.36	260.21	334.51	270.36
7	177.80	140.57	171.61	163.32
8	199.11	238.59	258.78	232.16
9	303.80	369.19	287.66	320.21

As a result of using the computer program Statistica for processing experimental data, the following encoded mathematical model of multiple regression is obtained:

$$Y = 225.5747 - 394.7083 X_1 - 33.4501 X_2 + 10850.004 X_1 X_1 + 1.4337 X_2 X_2 + 274.375 X_1 X_2 \quad (2)$$

Analysis of the standard form of the regression equation shows that the parameter Y is most affected by the mixed factor $X_1 X_2$, since the coefficient of the equation that characterizes it is 0.923, and this is the largest coefficient in this equation. The calculated value of the Student's criterion is less than its threshold value ($0.0061 < 0.05$), which indicates that the parameters of the mathematical model have statistical significance [3].

The validity of the mathematical model is confirmed by the Fisher criterion and its calculated value is 5.3. It was determined that the coefficient of determination $R^2 = 0,9984^2 = 0.9968$, that is, it occupies 99.68% of the total variability Y in the studied process due to changes in the factors X_1 and X_2 . Taking into account the degrees of freedom, the tabular value of the Fisher criterion is 9.01. Therefore, since the following condition $5.3 < 9.01$ is met, the coefficient of determination is statistically reliable, and the regression equation is statistically reliable.

The mathematical model of the technological process was obtained in the form of a multiple regression equation in real physical quantities by evaluating the importance of the studied factors and taking into account their interrelation:

$$Y = 241.365 - 789.4167 t - 33.45 V_e + 10850 t^2 + 1.4337 V_e^2 + 274.375 t V_e \quad (3)$$

The regression equation is analyzed statistically with a 95% confidence probability of the experiment. Table 4 shows the results of the analysis. The designations indicated here are the following: $Y_{cp i}$ - average experimental value of the traction resistance of the working body; Y - traction resistance of the working body according to the multiple regression equation (3); ε - unbiased error; ε^2 - dispersion of traction resistance; $|\varepsilon / Y_{cp i}|$ - module of the absolute error of approximation.

Table 4. Statistical analysis of the multiple regression equation

No.	$Y_{cp i}$	Y	$\varepsilon = Y_{cp i} - Y$	ε^2	$ \varepsilon / Y_{cp i} $
1	135.99	139.105	-3.115	9.701	0.0229
2	190.47	188.916	1.554	2.414	0.00816
3	248.98	247.408	1.572	2.471	0.00631
4	149.48	145.769	3.711	13.772	0.0248
5	208.52	206.556	1.964	3.859	0.00942
6	270.36	276.022	-5.662	32.062	0.0209
7	163.32	163.903	-0.583	0.34	0.00357
8	232.16	235.665	-3.505	12.284	0.0151
9	320.21	316.107	4.103	16.839	0.0128
Total values of indicators				93.741	0.124

Subsequently, the value of the absolute approximation error modulus, which is the deviation of the experimental values of the traction resistance from its theoretical values, is used to assess the reliability of the experiment [1, 6].

Table 4 shows that the total value of the absolute approximation error of the experiment is 0.124. Therefore, the average value of this indicator is– $(0.124/9) \cdot 100 = 1.38\%$. The results of the experiment are reliable, since the average value of the absolute approximation error does not exceed 10 %.

4 Conclusions

The multiple regression equation and the obtained experimental data allow to construct the response surface of the mathematical model (Fig. 3 and 4). From these figures, it can be concluded that as the speed of movement and the depth of tillage increases, the traction resistance of the ellipsoid disk working body also increases.

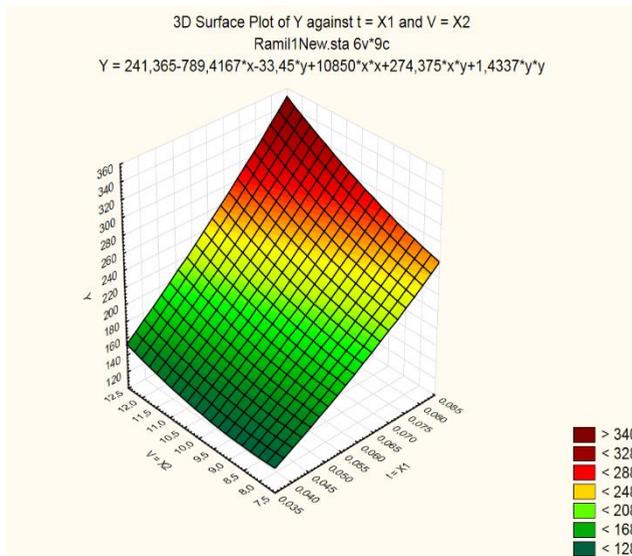


Fig. 3. Response surface by the multiple regression equation

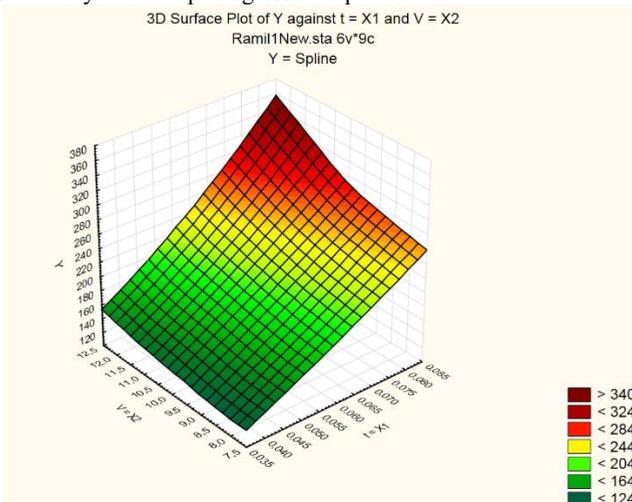


Fig. 4. Response surface by the experimental data

When the depth of the soil, equal to 0.08 m, and translational speed of the cart is 12 km/h traction resistance of rotary tools ellipsoid disc amounted to 320.2 N. For comparison,

with the minimum parameter values respectively 0.04 m and 8 km/h, underlying the experiment, the traction resistance was 135.9 N.

And so, an increase in the translational speed of the disk working body leads to a sharp increase in its traction resistance. Consequently, from energy and economic considerations, the most expedient is the area for tillage at a depth of 0.08 m and a speed of 10-11 km/h.

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