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Development of Parameters of A Gear Spring Harrow by Planning An Experiment

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Abstract: ***The article presents a method for developing parameters and operating modes of a gear spring harrow using a three-factor experiment of the B_k plan. The regression equation of the machine's working process, its optimal value (specific traction resistance 432.8 N, angle of inclination of the teeth of the harrow 61.9 degrees, angle of grinding of the tooth 20.98 degrees) and operating parameters (operating speed of the unit 11.7 km / h). The dependences of the response function (specific traction resistance of the tooth-spring harrow) on its parameters and operating modes are represented by mini-max. Hypersurface plots. To determine the nature of the response surface in canonical form near the optimum, two-dimensional sections of its surface are constructed with a family of conjugated isolines, with the help of which the interaction of factors is studied.***

Keywords **:** ***experimental design, regression equation, response function, factors, analysis, hypersurfaces, two-dimensional sections.***

I. INTRODUCTION

Optimization of the parameters of machines and assemblies engaged in the implementation of agricultural field work is an urgent task to increase the efficiency of use of equipment and reduce the cost of production of field products [1,2,3]. New resource-saving machine technologies [4,5,6] and energy-saving machine-tractor units ensure high competitiveness of manufactured products. The tasks of science are to find effective methods for creating a new generation of technology, reliable substantiation of their parameters and operating modes. The purpose of our article is to demonstrate the role of planning a multifactor experiment in increasing its efficiency using an actual gear-spring harrow machine as an example. Show at what optimal design and operational parameters of the harrow its effective operation is ensured with a minimum specific resistance.

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II. MATERIALS AND METHODS

Substantiation of the design and operating parameters of a gear spring harrow as an object of research was carried out by the method of planning a multifactor experiment [7, 8, 9] using the computer programs developed by us to analyze the obtained dependencies [10].

To set up a three-factor experiment, we chose a symmetric compositional plan of type B_k, whose stellar points are ± 1 [9]. Factors, intervals and levels of their variation for the experiment are presented in table 1.

Table - 1: Factors, Intervals, and Levels of Variation

Factors	Coded designation	Variation Intervals	Factor variation levels		
			- 1	0	+ 1
The angle β of the tilt of the spring harrow tooth, deg	x_1	30	30	60	90
The angle γ of the grinding of the tooth, deg.	x_2	10	10	20	30
Operating speed V of the movement of the unit, km / h	x_3	5	5	10	15

The levels of variation of the factors are selected taking into account the fulfillment of agrotechnical requirements for the quality of crushing of the soil, the uniformity of the depth of processing, the destruction of weeds and the evenness of the field surface.

Factors were determined as a result of previously conducted univariate experiments, as well as their fixed values at optimal levels in terms of specific traction resistance of a gear-spring harrow. The controlled factors (Table 1), in our opinion, have a significant effect on the specific traction resistance of the gear-spring harrow that we upgraded according to the patent according to the patent. Its other parameters, in addition to the width of the aggregate, do not affect the value of the specific traction resistance of the harrow. The upper and lower levels of factors are also taken into account the quality of the harrow. The first factor, the angle of inclination β of the harrow tooth was regulated during the experiment by turning the ridge with spring teeth rigidly fixed on it.

The angle was measured with a digital goniometer. The angle of grinding of the tooth was set by replacing the teeth on the bed with the corresponding angle according to the design of the experiment. The operating speed V of the movement of the unit was established using the tractor’s gearbox, the amount of fuel supplied and refined by measuring with a stopwatch the time of movement of the unit at a distance of 50 m with the direction of movement “there” and “back”. Dividing the distance by time, we got the speed of movement.

The planning matrix of the three-factor experiment provides for 14 experiments with various combinations of natural values of variables and values of the response function - specific traction resistance of the tooth-spring harrow (N / m).

When modeling the process of work on the field of the experimental setup, a second-order polynomial with three variables (β, γ, V) was used for the response function. After mathematical processing of the obtained experimental data on the developed computer program, we obtained a regression equation with coded values of factors (1):

$$y = 432,62 + 2x_1 + x_2 + 2,5x_3 - 15,75$$
$$x_1x_2 - 18,75x_1x_3 - 14,25x_2x_3 + \qquad (1)$$
$$+1,375x_1^2 + 2,375x_2^2 + 0,875x_3^2,$$

where y is the specific traction resistance of the gear spring harrow, N / m; x_1 is the encoded value of the angle β of the inclination of the teeth of the harrow, deg .; x_2 is the encoded value of the angle γ of the grinding of the tooth, deg .; x_3 - coded value of the operating speed V of the unit, km / h.

Equation (1) with the coded values of the factors was transferred to equation (2) with the actual values:

$$x_1 = 30x_1 + 60, \quad x_2 = 10 + x_2, \quad x_3 = 5x_3 + 10, \qquad (2)$$

where x_1 is the encoded value of the angle β of the inclination of the teeth of the spring harrow, deg .; x_2 is the encoded value of the angle γ of the grinding of the tooth, deg .; x_3 - coded value of the operating speed V of the unit, km / h.

According to experimental design theory [7 – 9], it is necessary to verify the obtained coefficients in the regression equation (1) for significance, after having calculated their confidence interval using Student's criterion. As a result of the calculations, it was found that all the coefficients of the regression equation (1) were significant:

$$db_0 = 3,69, \quad db_i = 0,65, \quad db_{ij} = 0,59,$$
$$db_{ii} = 0,69, \quad \text{at} \quad t = 2,57$$

To test equation (1) for adequacy according to the Fisher criterion according to the developed computer program, the obtained experimental data were used in the center of the plan to find the variance of the experiment. The natural values of the variables from experience in the center of the plan are presented in table 2.

Table - 2: Natural values of variables from experience in the center of the plan

Coded value of variables			The natural value of variables			Specific traction
x_1	x_2	x_3	the angle β of the inclination of the working bodies, deg.	angle for sharpening the tooth spring harrow, deg.	operating speed V of the unit, km / h	resistance of a gear-spring harrow R, kN / m
0	0	0	60	20	10	432
0	0	0	60	20	10	431
0	0	0	60	20	10	429
0	0	0	60	20	10	431
0	0	0	60	20	10	430

After calculation, the dispersion of the experiment was obtained, $S_y^2 = 1,3$ $F_{tab} = 4.88$, $F_{cal} = 3.98$. Since $F_{tab} \geq F_{calc}$, equation (1) is adequate.

Differentiating equation (1) with respect to each of their variables and equating the derivatives to zero, we obtained a system of linear equations:

$$\begin{cases} \dfrac{dy}{dx_1} = 2 + 2,75x_1 - 15,75x_2 - 18,75x_3 \\ \dfrac{dy}{dx_2} = 1 - 15,75x_1 + 4,75x_2 - 14,25x_3 \\ \dfrac{dy}{dx_3} = 2,5 - 18,75x_1 - 14,25x_2 + 1,75x_3 \end{cases} \qquad (3)$$

Solving the resulting system of equations (3), we obtained the coordinates of the center of the response surface: $x_1 = 0.0623$, $x_2 = 0.0976$, $x_3 = 0.0388$.

Substituting the values of the variables x_1, x_2, x_3 into the regression equation (1), we obtained the values of the optimization parameter (specific drag of the harrow) in the center of the response surface. We also found the value of the response at a new origin, for which the free term of the canonical equation $Y_S = 432,776$ was adopted.

We carry out the canonical transformation of formula (1). To do this, transfer this equation (1) to a new coordinate system and rotate the coordinate axes, after which equation 1 is simplified to the form (4):

$$Y - Y_S = B_{ii}x_i^2 + B_{jj}x_j^2, \qquad (4)$$

where B_{ii}, B_{jj} - canonical equation coefficients.

We found the rotation angle α of the initial coordinate axes of the response surface before aligning with the main axes of the figure. Its value was α = 41.99 degrees.

After transformations, equation 1 in canonical form takes the form (5):

$$Y - 432,776 = 1,375x_1^2 - 5,382x_2^2 + 8,632x_3^2, \qquad (5)$$

Further investigation of the response surface (4) is carried out using two-dimensional sections, which are formed by the intersection of the response surface by the planes: x_1S x_2, x_1S x_3, x_2S x_3. Two-dimensional sections allow us to establish the interaction of two factors of the regression equation when the third factor is in the center of the experimental design. Using the regression equation (5) in canonical form and the found coordinates of the center of the response surface, we find the value of the optimization parameter and all the corresponding variable values.

Below are the results of the obtained optimal parameters of the harrow with the optimal value of specific traction resistance.

III. RESULTS AND DISCUSSIONS

An analysis of the interaction of factors was performed using two-dimensional sections of the response surface (4) with the indicated planes ($x_1S\ x_2$, $x_1S\ x_3$, $x_2S\ x_3$). Consider the cross section of the response surface by the first $x_1S\ x_2$ plane. To do this, substitute x_3 = 0.0338 in equation 1 and get:

$$Y_{12} = 432,708 + 1,365x_1 + 0,518x_2 - \\ -15,75x_1x_2 + 1,375x_1^2 + 2,375x_2^2, \quad (6)$$

where Y_{12} – specific drag of a spring-loaded harrow with the interaction of 1 and 2 factors, when the 3rd is in the center of the experimental design.

Having performed the canonical transformation and solving the system of linear equations, we found the coordinates of the center of the response surface: x_1 = 0.0623, x_2 = 0.0976.

Substituting the found values of x_1 and x_2 into equation (5), we obtained the value of the optimization parameter in the center of the response surface Y_S = 432.776 with x_3 = 0.0623.

The angle of rotation of the coordinate axes, which is equal to 43.18 degrees, was determined, and the coefficients for unknowns in canonical form will be equal: when B_{11} = -6.016; at B_{22} = 9.766. Now, taking into account these coefficients, the response surface equation in canonical form will have the form:

$$Y_{12} - 432,776 = -6,016x_1^2 + 9,766x_2^2, \quad (7)$$

The resulting response surface (Fig. 1) is a hyperballoid of revolution, and the coefficients of the regression equation (7). having different signs confirm this. The optimal value of the response function is at the point with coordinates: x_1 = 61.86 degrees, x_2 = 20.98 degrees.

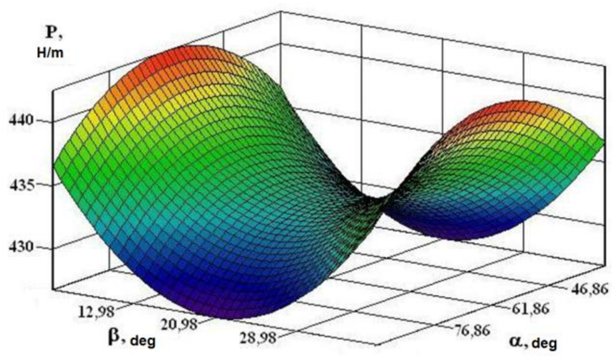

Fig. 1. The response surface of the dependence of the specific traction resistance of the harrow on the angle of inclination of the working bodies and the angle of grinding of the tooth of the spring harrow

Given the values of the variables and substituting them in the canonical equation (7), we obtained a family of conjugated isolines (Fig. 2). The contours obtained as a result of the cross section of the response surface are elongated along the axis corresponding to the factor x_1 — the angle of inclination of the working elements of the harrow. Therefore, this factor has a lesser effect on the specific traction resistance of the tooth-spring harrow than the second factor x_2, the angle of sharpening of the teeth of the harrow.

When x_3 = 0.0338 in coded form, i.e., when the specific drag of the harrow in the center of the plan is 432.776 N / m, the inclination angle β of the working bodies is 61.86 degrees, and the angle of sharpening of the teeth of the harrow is γ = 20.98 degrees

A two-dimensional cross section of the response surface of the $x_1S\ x_3$ plane is shown in Figure 2.

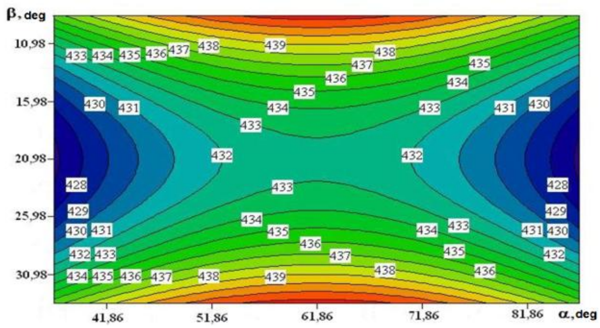

Fig. 2. Two-dimensional cross-section of the response surface of the dependence of the specific traction resistance of the tooth-spring harrow on the angle β of the inclination of the working bodies and on the angle γ of the grinding of teeth

The cross section in Fig. 2 is obtained by substituting the values of factor x_2 = 0.0976 into the regression equation (1). Then the regression equation took the form (8):

$$Y_{13} = 432,743 + 0,462x_1 + 1,109x_3 - \\ -18,75x_1x_3 + 1,375x_1^2 + 0,875x_3^2, \quad (8)$$

After performing canonical transformations and solving a system of linear equations, we found the coordinates of the center of the response surface: x_1 = 0.0623, x_3 = 0.0338. Substituting the found value of x_1 and x_3 into equation (1), we determined the value of the optimization parameter in the center of the response surface at x_2 = 0.0976. The value of the optimization parameter is the specific resistance of the spring-loaded harrow Y_{13} = 432.776 N / m. The angle α of rotation of the coordinate axes is equal to 44.24 degrees, and the regression coefficients in canonical form are equal to: at x1 B_{11} = 10.503; x_3 B_{33} = - 8.253.

Thus, we got the response surface equation in canonical form:

$$Y_{13} - 432,776 = 10,503x_1^2 - 8,253x_3^2, \quad (9)$$

The response surface has the form of a minimax rotation hyperboloid (Fig. 3), since the coefficients of the regression equation B_{11} and B_{33} are of different signs.

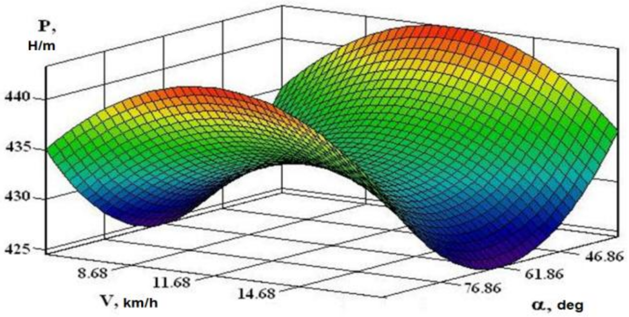

Fig. 3. The response surface of the dependence of the specific traction resistance of the spring-loaded harrow on the angle of inclination of the working bodies and the working speed

The optimal value of the response function is at the point with coordinates: x_1 = 61.86 degrees, x_3 = 11.68 km / h.

A two-dimensional cross section of the response surface with the x_1S x_3 plane (Fig. 4) was considered at the optimal value of the angle of sharpening of the teeth of the harrow, when x_2 = 0.0976. The cross sections of the response surface in the experiment area give isolines (Fig. 4), which implies that a change in the working speed of the harrow affects less specific drag of the harrow than the angle of inclination of the working bodies, because the elongation of the isolines is greater along the x3 axis, and the coefficient of the regression equation is n absolute value $|B_{11}| \geq |B_{33}|$

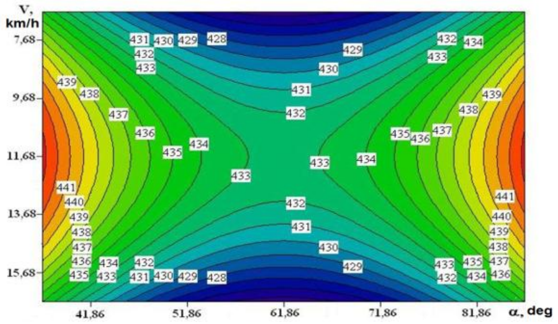

Fig. 4. Two-dimensional cross-section of the response surface of the dependence of the specific traction resistance of the gear spring harrow on the angle of inclination of the working bodies and the working speed of the harrow

The cross section of the response surface by the x_2 S x_3 plane (Fig. 4) was obtained by substituting x_1 = 0.0623 into the regression equation (1). As a result, we obtained expression (10):

$$Y_{23} = 432,743 + 0,0188x_2 + 1,332x_3 - -14,25x_2x_3 + 2,375x_2^2 + 0,875x_3^2, \quad (10)$$

Having performed the canonical transformations and solving the system of linear equations, we find the coordinates of the center of the response surface: x_2 = 0.0976, x_3 = 0.0338. Substituting the found values into equation (10), we determine the value of the optimization parameter in the center of the response surface at the optimal value x_1 = 0.0623.

Equation (10) has pair interactions (x_2 x_3), and the rotation angle α of the coordinate axes is equal to 44.24 degrees. The coefficients of the regression equation in canonical form are equal: for x_1 B_{22} = 8.789, for x_3 B_{33} = 5.539. The response surface equation in canonical form is:

$$Y_{23} = 8,789x_2^2 - 5,539x_3^2, \quad (11)$$

Since the coefficients of equation (11) have different signs, the response surface is the minimax rotation hyperboloid, and the optimal value of the response function is at the point with coordinates: x_2 = 0.0976, x_3 = - 0.0338 (Fig. 5).

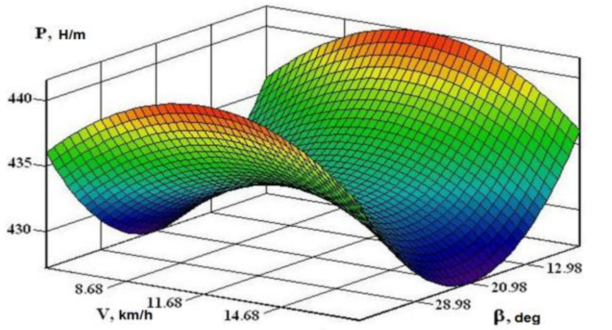

Fig. 5. The response surface of the dependence of the specific traction resistance of the spring-loaded harrow on the angle of sharpening of the teeth of the harrow and the working speed

From the analysis of Figure 5 it follows that the change in the values of the angle of sharpening of the teeth of the harrow affects more than the speed of the unit, this is confirmed by equation (11) by the values of the coefficients $|B_{22}| \succ |B_{33}|$ or 8.789 and -5.539, respectively.

The two-dimensional cross-section (Fig. 6) of the response surface by the x_2 S x_3 plane was considered at x_1 = 0.0623, i.e. with an optimal value of the angle of inclination of the teeth of the harrow, equal to 61.81 degrees. The contour lines of the response surface in the optimum region have minimax responses.

Figure 6 clearly shows the greater effect on the harrow specific resistance of the angle of sharpening of the teeth of the harrow compared to the working speed of movement.

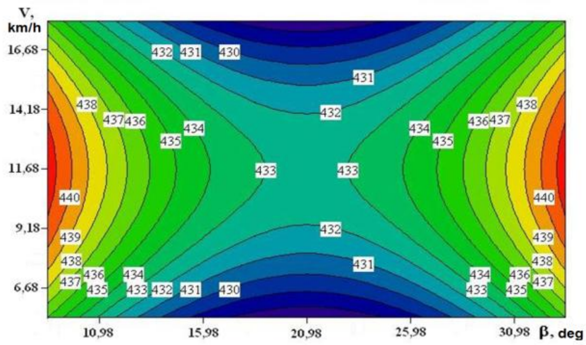

Fig. 6. Two-dimensional cross-section of the response surface of the dependence of the specific traction resistance of the tooth-spring harrow on the angle of sharpening of the teeth of the harrow and the working speed of the harrow

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IV. CONCLUSIONS

The possibility of using the method of planning a multifactor experiment for the study of agricultural machinery has been proved. The method of planning a three-factor experiment according to the B_k plan determined the optimal parameters of the working bodies of the gear-spring harrow, subject to the qualitative fulfillment of agrotechnical requirements.

According to the regression equation obtained as a result of theoretical and experimental studies, the parameters of the harrow teeth and its operation mode are justified according to the criterion of minimum traction resistance of the tooth-spring harrow: the angle of inclination of the teeth was 61.86 degrees, the angle of grinding of teeth 20.98 degrees, the working speed V the harrow movement is 11.68 km / h, and the optimal specific traction resistance is R = 432.776 N / m.

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