IMPROVING THE RELIABILITY OF AGRICULTURAL MACHINERY, USING THE METHOD OF RESTORATION OF PARTS UNDER SUBMERGED ARC WELDING, AND ITS TECHNICAL AND ECONOMIC EVALUATION

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Summary: *The basic features of calculating the reliability of agricultural machinery are shown, in contrast to industries such as mechanical engineering, radio and television equipment, automation systems and etc., in which machines and apparatus operate in steady modes, while agricultural machines do in difficult soil and climatic and dynamic conditions.*

Economic aspect of reliability is substantiated and patterns of change in the efficiency of use of agricultural machinery in time are established, the economic parameters of reliability are determined. With the help of the theory of similarity and dimensions as well as the planning of multifactor experiments, through the original installation manufactured by us, the basic physical and mechanical properties of metal coatings are studied, obtained by welding under flux, there are relevant similarity criteria determined that characterize the process of restoration of worn parts and, after processing of experimental data an analytical view of criterion equation is formed and rational modes of the restoration of parts under submerged arc welding are set. Further, to optimize the process, the scheduling theory of extreme experiments has been used and as factors in the regression equation there have been chosen most significant similarity criteria. In methodics elaborated by us, it was obtained an adequate equation and by a method of steep ascent (movement along the gradient), there were determined optimal modes of recovery for metal coatings with high physical and mechanical properties (hardness, wear resistance).

Under these regimes there were recovered worn ploughshares and their operational check showed an increase of resource as many as 1.4 ... 1.5 times. For surfacing worn parts with complex configurations (ploughshare plows, cultivators paws), we have manufactured a special copier allowing to recover the items automatically, in a continuous mode. The feasibility study of the developed resource-saving innovative technology has shown that the restoration of 800 ploughshares provides an yearly economic effect of EURO 1,462.

KEYWORDS: *RELIABILITY, AGRICULTURAL MACHINERY, SUBMERGED WELDING, SIMILARITY CRITERION, REGRESSION EQUATION, OPTIMIZATION, ECONOMIC EFFICIENCY.*

Of all the technical issues currently existing on the global scale, the problem of reliability is the most important. This circumstance is caused by the fact that it relates to the quality of machines, complex systems, devices, as well as to the economy, human security and high competitiveness in the world market.The increase in the reliability of agricultural machinery is of significant importance, as it does not yet meet the modern requirements of science and production by its technical, economic and other indicators.This is due to the fact that it operates in very difficult soil and climatic conditions with high alternating dynamic loads and an aggressive environment. In addition, the culture of design, production, use, repair and maintenance of these machines is still low.It is necessary not only to create new, high-performance agricultural machines, but also to ensure minimum costs for their upkeep in working order, maintenance and repair.The last two components determine their highly effective use and maximum return.The economic aspect of reliability is very important [1]. The diagram below shows the change in the economic efficiency of agricultural machinery in time (Fig. 1)

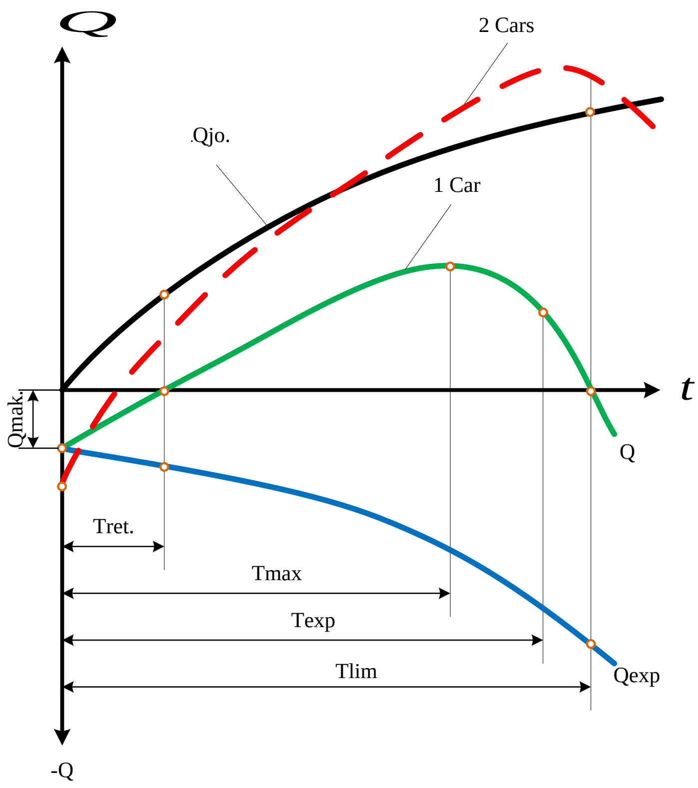

Figure 1: Changing the economic efficiency of a machine in time

According to this diagram, the comparison of machines with different reliability levels should be based on the condition of achieving maximum returns, taking into account the costs of production and operation, as well as the positive effect that is gained through their use by intention.

In the general case, the change in the total economic effect over time in the operation of machines consists of two factors: on the one hand, it is necessary to take into account the manufacturing costs-Qmak., which includes their design, manufacture, testing, transportation to the workplace, as well as the costs of use (maintenance, repairs, diagnostics and other preventive measures). These costs -Qmak. + Qexp. are negative in the balance of economic efficiency.The use of agricultural machinery for its intended purpose produces a positive effect (profit) - .Qjo. The costs of operation in time Qexp. are increasing in connection with the aging of machines, while the change in Qjo., on the contrary, is decreasing, as a result of frequent downtime of agricultural machinery due to preventive work.Therefore, the curve of the total economic efficiency Qmak. + Qexp. + .Qjo.has a maximum and twice intersects the axis of abscissas-t.T = Tret. is the time of the return of agricultural machinery.From this point on, the agricultural machinery generates a profit, but the process gradually abates due to the increase in operating costs to t = Tlim., when again .Qjo = Qmak. + Qexp. When t>Tlim. the costs of operating a machine is greater than the economic effect that the machine can provide.The duration of the economic feasibility of using machines is in the limit Tmax<Texp<Tlim. From the standpoint of reliability, the comparison of different variants of machines is made taking into account the profit that it gives in exploitation.

For example, in Figure 1, the initial cost of the machine 2 is greater than the machine 1, but due to its high productivity, quality and reliability, it gives a greater economic effect and can be used in a longer time.

To improve the reliability of agricultural machines, we have developed and manufactured an installation for the restoration of worn parts by resource-saving technology with automatic surfacing under a layer of flux.The installation differs from analogues in that it allows stepless regulation of the surfacing modes.Theoretical and experimental studies have been carried out to optimize the surfacing process.As theoretical basis, it was used the theory of similarity and dimensions [3, 4,5, 6], which makes it possible to scientifically substantiate the setting of experiments and, with the help of the similarity criteria, to take into account the simultaneous influence of various factors on the optimization parameter.As a parameter of optimization, we chose the hardness of the welded metal coatings on which the wear resistance and the life of the restored parts mainly depend.Table 1 presents the main factors that, according to the literature, have an essential effect on the hardness of the coatings [1, 2,3]:

Table 1

The list of factors affecting the hardness of metal coatings received

by means of submerged arc welding.

№	Name of Parameter optimization and factors	Symbol	Dimension in the Si	Dimension, expression of symbol values
1	The hardness of the metal coatings	H_{μ}	MPa	$ML^{-1}T^{-2}$
2	Size of restorable parts	L	m	L
3	Amperage	$\mathcal{J}$	A	$\mathcal{J}$
4	Voltage	υ	v	$ML^2T^{-3}\mathcal{J}^{-1}$
5	Feed rate of electrode	V	$m.s^{-1}$	LT^{-1}
6	Electrical resistance of the electrode	R	Om	$ML N^{-3}\mathcal{J}^{-1}$
7	Deposition rate	V_1	$m.s^{-1}$	LT^{-1}
8	Electrode density	ρ	$kg.м^{-3}$	ML^{-3}
9	Flux density	ρ_1	$kg.м^{-3}$	ML^{-3}
10	Departure electrode	e	m	L
11	Flux consumption	Q	$kg.s^{-1}$	MT^{-1}

According to the method developed by us, we obtained characteristic similarity criteria and a general form of the criterial equation for carrying out experiments:

$$\frac{H_{\mu}L^2}{QV} = \varphi\left(\frac{\upsilon\mathcal{J}}{QV^2}, \frac{V_1}{V}, \frac{R\mathcal{J}^2}{QV}, \frac{\rho L^2 V}{Q}, \frac{e}{L}, \frac{\rho}{\rho_1}\right) \ldots (1)$$

After some transformations, according to our methodology, the equation takes the form as follows:

$$\frac{H_{\mu}L^2}{QV} = A\left(\frac{\upsilon\mathcal{J}}{QV^2}\right)^a \left(\frac{V_1}{V}\right)^b \left(\frac{R^{\mathcal{J}2}}{QV}\right)^c \left(\frac{\rho L^2 V}{Q}\right)^d \left(\frac{e}{L}\right)^e \left(\frac{\rho}{\rho_1}\right)^f \ldots (2)$$

Whereas$A = \sqrt[6]{c \cdot c_1 \cdot c_2 \cdot c_3 \cdot c_4 \cdot c_5}$; $a = \frac{x}{6}; b = \frac{x_1}{6}; c = \frac{x_2}{6}; d = \frac{x_3}{6}; e = \frac{x_4}{6}; f = \frac{x_5}{6};$

$c, c_1, c_2, c_3, c_4, c_5$ – constantratios and$x, x_1, x_2, x_3, x_4, x_5$-exponents.They characterize the simultaneous influence of individual parameters on the hardness of metal coatings and are determined experimentally.The figure shows the results of our experiments.

After mathematical processing of the experimental results, an analytical form of the criterial equation is obtained:

$$\frac{H_{\mu}L^2}{QV} = 0,28 \cdot 10^{10} \left(\frac{\upsilon J}{QV^2}\right)^{0,12} \left(\frac{V_1}{V}\right)^{-0,13} \left(\frac{R^{J2}}{QV}\right)^{0,1} \left(\frac{\rho L^2 V}{Q}\right)^{0,06} \left(\frac{e}{L}\right)^{0.1} \left(\frac{\rho}{\rho_1}\right)^{-0,23} \ldots (3)$$

The checking of the equation for adequacy showed that the relative error of the theoretical and experimental results did not exceed 3%.Further optimization of the reduction process was carried out, where $X_1=\frac{\upsilon J}{QV^2}$, $X_2=\frac{V_1}{V}$andX$_3=\frac{\rho}{\rho_1}$were chosen as factors that significantly influenced the hardness of the coatings.

The task was set so as to obtain the hardness response function depending on the similarity criteria:

$$Y = f(X_1, X_2, X_3) \quad . . . (4)$$

Y-Optimization parameter

$Y=\frac{H_{\mu}L^2}{QV}$ -.

The experiments were planned and the data were processed according to the Box-Bencin plan [3,4,5] and the methodology developed by us [8,9].With a small number of experiments-N = 15, this plan is convenient because the similarity criteria change at three levels and have good statistical characteristics.The mathematical model has the form [6]:

$$y = b_0 + b_1 X_1 + b_2 X_2 + b_3 X_3 \ldots (5)$$

The constant coefficients/ratios b_0, b_1, b_2 и b_3 are determined by the experiments. Table 2 shows the experiment planning matrix

Table 2: Experiment Planning Matrix

№ of Experiments	Code Designation of Factors				Alphabetic Designation
	x_0	x_1	x_2	x_3	
1	+1	+1	-1	-1	a
2	+1	-1	-1	-1	(1)
3	+1	+1	+1	-1	ab
4	+1	-1	+1	-1	b
5	+1	+1	-1	+1	ac
6	+1	-1	-1	+1	c
7	+1	+1	+1	+1	abc
8	+1	-1	+1	+1	bc

As a zero level, there were selected:

$$X_{10} = 60 \cdot 10^8; X_{20} = 0,45; X_{30} = 195;$$

Variation intervals: $I_1= 20 \cdot 10^8$, I_2=0,35, I_3=25

Table 3 shows the results of the experiments conducted.

Table 3: Results of the Experiments

№ of Experiments	X_0	$X_1 \cdot 10$	X_2	X_3	$y \cdot 10^6$
1	+1	80	0,1	170	1,48
2	+1	40	0,1	170	1,50
3	+1	80	0,8	170	1,62
4	+1	40	0,8	170	1,64
5	+1	80	0,1	220	1,66
6	+1	40	0,1	220	1,62
7	+1	80	0,8	220	1,59
8	+1	40	0,8	220	1,57

After mathematical processing of the experimental results, we obtain:

$$b_0 = \frac{\sum_{i=1}^{n} y_i}{n} = 1,6.10^6 \quad . \quad b_i = \frac{\sum_{i=1}^{K} y_i x_{ij}}{n}, \quad (j = 1,2,3) \quad b_1 = 2,5.10^3; \quad b_2 = 20.10^3; \quad b_3 = 25.10^3.$$

The regression equation has the form:

$$y = (1600 + 2,5X_1 + 20X_2 + 25X_3).10^3 \ldots (6)$$

The equation was tested for the adequacy, significance of the coefficients, homogeneity of the variance and satisfactory results were obtained. After this, the regression equation is obtained in its natural form:

$$\frac{H_{\mu}L^2}{QV} = (1379,2+0,13\frac{\upsilon J}{QV^2}+57,14\frac{V_1}{V}+\frac{\rho}{\rho_1})10^3 \ldots (7)$$

Next, optimization was carried out using the steep ascent method [9,10].The gradient of the function is:

$$\Delta\vec{\varphi} = \frac{\partial\varphi}{\partial x_1}\vec{i} + \frac{\partial\varphi}{\partial x_2}\vec{j} + \frac{\partial\varphi}{\partial x_3}\vec{k} \quad \ldots (8)$$

$$\frac{\partial\varphi}{\partial x_1} = b_1 = 2,5 .10^3, \qquad \frac{\partial\varphi}{\partial x_2} = b_2 = 20 .10^3,$$

$$\frac{\partial\varphi}{\partial x_3} = b_3 = 25 .10^3$$

With the change in the regression coefficients, a movement is made in the direction of the gradient of the response function. For this, the gradient components are defined:

$$b_1 I_1 = 2,5 \cdot 10^3 .20.10^8 = 5.10^{12};$$

$$b_2 I_2 = 20 \cdot 10^3 .0,35 = 7.10^3;$$

$$b_3 I_3 = 25 \cdot 10^3 .25 = 6,25 \cdot 10^5.$$

Multiplying the gradient components by an arbitrary positive integer gives points that are also on the gradient:

$$I^1{}_1 = 50 \cdot 10^{11} \cdot 0.469 = 2,35.10.^{11};$$

$$I^1{}_2 = 7 \cdot 10^3 \cdot 0.469 = 0,33 \cdot 10^4;$$

$$I^1{}_3 = 6,25 \cdot 10^5 \cdot 0.469 = 29.10^4.$$

If gradient components are added to the main level, you will get a series of steep ascent, which are given in Table 4.

Table 4: Data for a Steep Ascent

Factors	$X_1 \cdot 10^8$	X_2	X_3	$y \cdot 10^6$
Main Level	60	0,45	195	
Variation Interval	20	0,35	25	
Top level	80	0,7	220	
Top level	40	0,1	62	
Lower level				
Experiments	Coded and Natural Factor Values			
0	0; 60	0; 0,45	0;195	1,46
1	+1; 80	-1; 0,1	-1; 62	1,48
2	-1; 40	+1; 0,45	-1;62	1,50
3	+1; 80	-1; 0,1	-1; 62	1,62
4	-1; 40	+1; 0,45	-1; 62	1,64
5	+1; 80	-1; 0,1	+1; 220	1,66
6	-1; 40	+1; 0,45	+1; 220	1,62
7	+1; 80	-1; 0,1	+1; 220	1,59
8	-1; 40	+1; 0,45	+1; 220	1,57
b_i	2,5	20	25	
$b_i I_i$	5	7	6,25	
New variation interval	2,35	0,33	29	
Experiments				
9	82,35	1,03	249	
10	84,70	1,36	278	1,67
11	85,05	1,69	307	1,72

Reducing the optimization parameter in the 12th experiment shows that the result of the 11th experiment is the most profitable or extreme.

On the basis of the obtained results, it can be concluded that when surfacing under flux of worn-out parts for obtaining metal coatings with maximum hardness, the factors (similarity criteria) should have the following values:: $X_1 = \frac{\upsilon \mathcal{J}}{QV^2} = 85.10^8$ $X_2 = \frac{V_1}{V} = 1,69$ $X_3 = \frac{\rho}{\rho_1} = 307$

The following welding modes correspond to these factors:

Amperage - $\mathcal{J} = 225$ A,Deposition Rate - $V_1 = 0,0015 \frac{м}{сек}$, Radius of the Electrode – $e = 12\, мм$, Voltage - $\upsilon = 25\, в$, Electrode Feed Speed-$V = 0,03 \frac{м}{сек}$.When restoring details under these modes with the micro hardness of metal coatings$H_\mu = 10800$Mega Pascal.

Production tests of ploughshares restored through these regimes have shown that their resource is increased by 1.4 ... 1.5 times, and the technical-economic efficiency under the program of 800 parts amounts to 1462 Euro.

As a result of the theoretical and experimental studies carried out, the following conclusions can be drawn:

- The economic aspect of reliability is justified, the patterns of change in the efficiency of the use of agricultural machinery in time are established, and economic indicators of reliability are determined.
- Using the theories of similarity, dimensions and planning of extreme experiments, optimization of the surfacing process under flux has been carried out and the best modes for obtaining metal coatings with maximum hardness have been established.
- Operational tests of the restored parts were carried out, which showed that their resource was increased by 1.4 ... 1.5 times.

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