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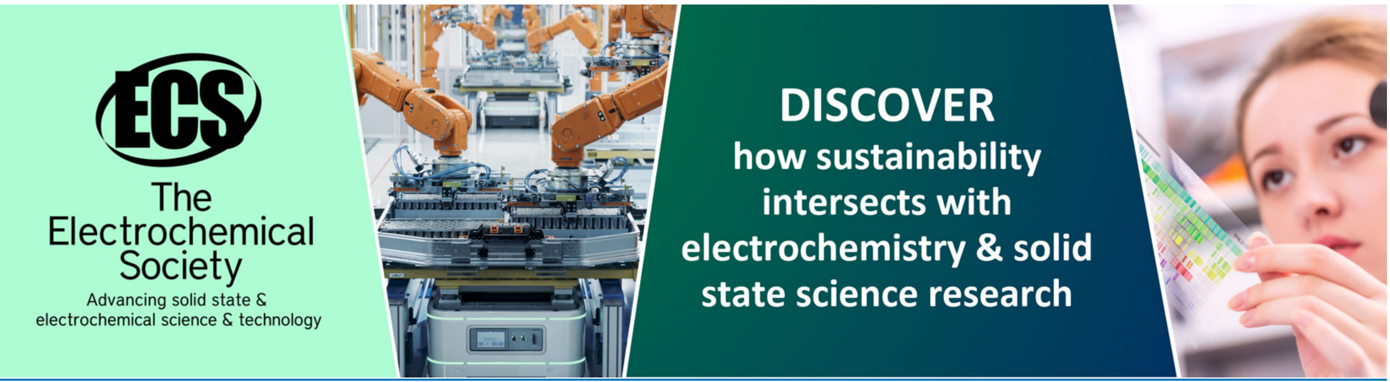

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Forecasting of the soil processing units working bodies resource

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Abstract. The necessity of developing a mathematical model of the calculation and theoretical forecasting of the resource of the working body of the tillage aggregate is substantiated. The formula as a mathematical model is proposed. The results of calculations using this formula made it possible to evaluate several options for hardening the processing of samples and establish preferable ones. These options were samples hardened by boration and surfacing of metal powders in a liquid coolant. The proposed formula allows predicting the value of the resource of the working bodies of tillage and sowing units during their hardening, restoration and manufacturing process.

1. Introduction

The research on the improvement of the technology of hardening machine parts, when restoring them, to improve the service properties of their working surfaces, involves the derivation of such a mathematical expression that would allow predicting the expected value of their resource [1, 3, 9, 13].

The resource assessment during the operation of the working bodies of the tillage unit is carried out taking into account the stochasticity of the process of their wear. The resource is estimated by the number of hectares processed by one working body until the limit state is reached. The factors determining their resource are the following: moisture, hardness, and soil texture; unit speed and processing depth; the shape of the working bodies, as well as the service and mechanical properties of materials [2, 7, 8, 15, 16].

2. The object and method of research

The solution to this problem, due to its multifactorial nature, causes some difficulties, but it can be implemented either by simulation or analytically [2, 3, 9, 12, 14]. For this, the criterion of the onset of the limit state is determined. This is the limit value of wear of cutting part of the working bodies. There is a need to analyze the conditions of the work and the wear process of the working bodies.

The calculated scheme of the cultivation process, carried out by the corresponding working bodies - paws, is reduced to the movement of a wedge with a flat surface in the soil. In this case, crumbling, chipping, and then moving the soil along the working surface of the wedge take place [9, 10, 11, 13, 16].

The pressure acting on the wedge depends on the following parameters: its shape and size, speed of movement, depth of cultivation, and physical and mechanical properties of the soil. Abrasive particles located in the soil, upon contact with the surface of the wedge, wear it out. The increase in the rate of movement of the abrasive along its surface and soil pressure on this surface leads to an increase in the amount of wear [9, 10, 11].

Physico-mechanical properties of the soil affect the intensity of abrasive wear of the working bodies of agricultural units. When the size of the abrasive is more than 10^{-6}m, the process of abrasive wear begins. The increase in the size of the abrasive promotes an increase in the intensity of abrasive wear [1, 2].

The intensification of the process of wear of the working body is facilitated by the presence in the soil of acid, alkali and salt in a certain amount [4, 5, 6, 9].

It is known that the part with high surface hardness and low core ductility has greater wear resistance. The presence of nitride, carbide, and boride phases in its internal structure has a significant effect on increasing the wear resistance of the surface of the part, since they increase the wear resistance by 3 ... 5 times more efficient than quenching [12, 14].

The aggressive effect of the abrasive on the surface of the part depends on its shape, fastening, as well as the ratio of mechanical properties (material of the part and abrasive) and the current load. Moreover, it is known that about 10% of abrasive wear is micro cutting [10, 11].

Upon contact of the abrasive with the surface of the part around this point adjacent to the contact spot, the action areas of internal tensile and compressive stresses are formed. The stress-strain state in these areas is not stable, and the following processes apparently occur there: adsorption, oxidation with destruction, and phase transitions with recrystallization. Microscopic volumes experience these effects with high repeatability, so internal stresses gradually accumulate and grow. At a certain stage, their stabilization begins, after which a catastrophic increase in these stresses is observed. As a result, an alternating cyclicity is formed when loading microscopic volumes of the surface and subsurface regions of the material of the part. Energy is generated and stored in these deformable microscopic regions. The accumulation of energy leads to a supersaturation of micro volumes with this energy, which leads to the appearance and summation of various defects that turn into damage, for example micro cracks. This also contributes to the heat during deformation, which soften these zones. The occurring fusion of damage contributes to the formation of submicroscopic wear particles. This is the result of friction-contact fatigue of the material of the part, but micro cuts can also occur if stresses or strains arising from a single interaction of these abrasive particles with a wear surface exceed the tensile strength of the material [15, 16].

For a mathematical description, taking into account the features of the processes, the calculation model should be based on some assumptions. Modeling the process of interaction between the soil and the working body is based on the assumption that a continuous flow of soil moves to a stationary working body. The soil flow contains the same abrasive particles of spherical shape, density and strength. The meeting of a moving continuous flow of soil with the surface of the part occurs at an angle (crumbling) and its speed is the same in magnitude and direction (speed of movement of the tillage unit) [12].

The same abrasive particles do not re-contact the surface of the part. Moreover, their size is much smaller than the average distance between adjacent moving particles. They are located in the soil flow randomly with a constant distribution density.

The interaction of the abrasive particles between each other in the flow is impossible. Therefore, the abrasive particle interacts exclusively with the wearing surface. This interaction is a random process as well as a stationary one.

Interacting with the surface of the part, the abrasive particle deforms it, with the formation of a sub-microwell and a hardening zone under it. Then it slides out of this hole and moves along the surface (in the design scheme it is half-space) without rolling.

The kinetic energy of a moving abrasive particle is transformed into work on plastic deformation of the surface of the part, dissipation and overcoming adhesion. One of the parameters of this energy is the coefficient of friction of the slip of the abrasive on the surface of the part. In this case, the tangential friction force (inhibitory motion) and the normal reaction (pushing) act on the particle.

The consideration of abrasive wear processes leads to the formulation of a mathematical problem to determine the resource using modeling methods and similarity theory.

The source data is information on the mechanical, frictional-fatigue, microgeometric and load characteristics of the operating tillage working bodies. Considering that the surface of the working body is affected by the distributed pressure created by the soil layer, the expression for determining the resource of the working body of the tillage aggregate can be obtained by integral summation of the dependences describing the destruction of the microscopic surface section [2, 13, 14].

At the heart of the calculation model for determining the resource of the working body of the tillage unit is a formalized description of the process of its abrasive wear. This description is based on the theory of fatigue, taking into account the theory of thermodynamics of irreversible processes, based on the use of methods for studying the mechanics of the stress-strain state and fracture of both continuous and inhomogeneous (coated) media [11, 12, 15].

Abrasive wear occurs during the stochastic interaction of particles with the surface of the part, while the frequency of contact of the abrasive with the same spot of the surface of the part, as well as the location of these sections and their number at an arbitrary point in time is random values. Like many real processes, abrasive wear is a spatio-temporal physical process. The time factor is the frequency of abrasive particles falling into the same microscopic region of the surface of the part until the moment of separation of the wear particle from it. The spatial factor is the interaction of neighboring microscopic regions undergoing elastoplastic deformation under the influence of an abrasive at an arbitrary point in time. Taking these factors into account allows more accurate and more full description of the process of abrasive wear [12].

Based on the theoretical and practical study of abrasive wear of the surfaces of the working bodies of tillage units [10, 11, 12, 16], taking into account the accumulation of damage, we can predict their service life as after manufacturing, and after recovery according to the following formula:

$$S^{(T)} = \frac{k^{(\beta)} \cdot k^{(\upsilon)} \cdot n^{(\delta)} \cdot k^{(\delta)} \cdot k^{(\tau)} \cdot k^{(\lambda)} \cdot HV^{2.5} \cdot V_{\mathrm{W}}^{\mathrm{T}} \cdot \delta_{\mathrm{V}} \cdot k^{(\varepsilon)}}{k^{(\mathrm{p})} \cdot k_{\mathrm{ab}}^{\rho} \cdot h_{\mathrm{d}}^{\rho} \cdot k^{(\mathrm{ha})} \cdot R_{\mathrm{ab}}^{\mathrm{av}} \cdot (\delta_{\mathrm{c}}^{\mathrm{ab}})^{2.5} \cdot v_{\mathrm{c}}^{\mathrm{t}} \cdot H_{\mathrm{h}}^{(\rho)}}, \tag{1}$$

where $S^{(T)}$ – source of the working body of the tillage unit (lancet paws of the cultivator), ha; $k^{(\upsilon)}$ – coefficient of influence of the magnitude of the speed of movement (0.1), m/s; $k^{(\delta)}$ – coefficient (of hardening) of resistance during the destruction of micro-volumes of the surface of a part exposed to abrasive particles (1...5); $k^{(\lambda)}$ – coefficient of the probability of falling into the same microzone (0.1); $n^{(\delta)}$ – number of loading cycles with low-cycle fatigue (140...160); $k^{(\tau)}$ – coefficient of microcutting; HV – hardness of the cutting part of the cultivator paws, MPa; $V_{\mathrm{W}}^{\mathrm{T}}$ – value of the maximum volumetric wear of the cultivator paws ($1{,}53 \cdot 10^{-5}$), m^3; δ_{V} – tensile strength of steel, MPa;

$k^{(\mathrm{p})}$ – coefficient depending on physical and mechanical properties of the soil (taking into account the fastening of abrasive particles and pressure on the working surface of the part) (20.0...21.0); $k^{(\mathrm{ha})}$ – coefficient of transfer of dimension (10^4), m^3/ha; $k^{(\beta)}$ – coefficient of the direction of movement of the abrasive:

$$k^{(\beta)} = \frac{\sin(\beta + \psi)}{\sin \beta},$$

where: β – angle of inclination of the working surface of the part (crumbling) to the horizon (25), deg.; ψ – angle of deviation of the trajectory of movement of abrasive particles from the normal (chipping), restored to the working surface, deg; k_{ab}^{ρ} – coefficient of abrasive composition of the soil ($(1.5...2)\cdot 10^8$), 1/m^3; h_{d}^{ρ} – depth of tillage during cultivation (0,08...0,15), m; $R_{\mathrm{ab}}^{\mathrm{av}}$ – average radius of abrasive particles of the soil ($(1.5...3.5)\cdot 10^{-4}$), m; $\delta_{\mathrm{c}}^{\mathrm{ab}}$ – ultimate compressive strength of an abrasive

(80 ... 145), MPa; $v_{\mathrm{c}}^{\mathrm{t}}$ – cultivator translational speed (1.7...3.3), m/s; $H_{\mathrm{h}}^{(\rho)}$ – soil hardness (1.0 ... 2.0), MPa; $k^{(\varepsilon)}$ – coefficient of kinetic energy of interaction:

$$k^{(\varepsilon)} = \frac{f_{\mathrm{fr}}^{\mathrm{s}} + f_{\mathrm{fr}}^{W}}{f_{\mathrm{fr}}^{\mathrm{s}}},$$

where $f_{\mathrm{fr}}^{\mathrm{s}}$ – coefficient of sliding friction of abrasive particles inside the soil formation (0,72...0,76); f_{fr}^{W} – coefficient of sliding friction of abrasive particles on the surface of the working body (0.64...0.67).

The calculations were carried out for parts made of steel 30 and steel 65G processed by various technologies supposedly working under the same conditions (Figure 1).

The calculations show that boration and surfacing in a liquid coolant should provide a higher resource of working bodies of tillage units.

The data obtained using the computational-mathematical model must be checked for compliance with the actual resource values determined experimentally. Under laboratory conditions, it is not possible to conduct resource studies of working bodies, and since the life of these parts is determined by their wear resistance, laboratory tests for abrasive wear of the corresponding samples will allow a preliminary assessment of the adequacy of the mathematical model.

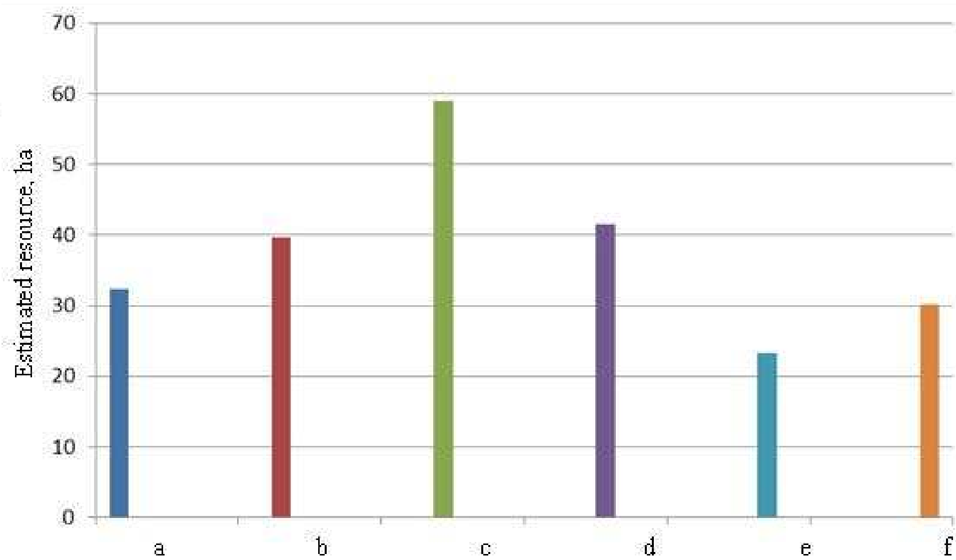


Figure 1. Prediction of the value of the resource of the working bodies of soil cultivating units reinforced (restored) by the following technologies: a - cementation; b - electrospark alloying; c - boration; d - surfacing in a liquid coolant; e - hardening of steel 30; f- hardening of steel 65G

The process of frictional interaction of the working body with the soil is simulated by the sliding friction of the sample over the abrasive mass. Laboratory studies were carried out on the installation (Figure 2) for testing for abrasive wear of materials [11, 12, 14].

A flat cylindrical sample *1*, mounted by means of a shaft *6* in the chuck of the spindle of a drilling machine, rotates under a certain pressure, and at the same time interacts with the lower part with an abrasive mass *2*, which is located in a cylindrical steel case *3* mounted on a thrust ball bearing *4*.

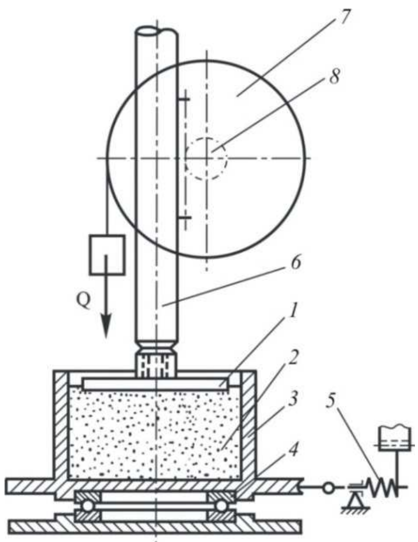
The bottom of the case is a disk larger than the case of diameter with a fixed rod going to the dynamometer *5*. This setup scheme allows tracking and recording the moment of friction during the test of the sample.

The specific load on the sample is determined by the following formula:

$$F_{sp} = M_1 \cdot L_{arm} / \pi \cdot R_s^2 \cdot r_m^g \quad (2)$$

where M_1 **–** load weight, kg; R_s – adius of the sample, cm; L_{arm} – shoulder length of the loading arm (7), cm; r_m^g – radius of the middle circumference of the gear (8), cm.

a



b

Figure 2. Installation for laboratory wear tests: a - general view; b - scheme: *1* - test sample; *2* –– abrasive mass; *3* - case; *4* - bearing support; *5* - dynamometer; *6* - shaft; *7* - load block; *8* - gear

Fractionated quartz sandblasted sand with a particle size of 0.25 ... 0.3 mm and a moisture content of 0 ... 2% served as an abrasive material. Most soils in their natural state contain the largest number of grains of sand of this size (18...20%) [9, 11, 13]. This method of movement of the investigated laboratory sample through the abrasive imitates the process of wear of the working body under operating conditions during soil-cultivating treatment [1, 3, 9, 10].

The samples under study, with one end surface hardened, were flat disks of the same shape and size.

The sample wore on the lower end surface, which was in direct contact with the abrasive mass.

In accordance with the working conditions of the paws during cultivation (speed of the unit, soil pressure on the working part), the conditions for testing the abrasive wear of hardened and reference samples were determined. The spindle speed was 700 rpm (~ 2.7 m/s), the specific load on the sample was ~ 22000 N/m^2 (axial force transmitted by the rod ~ 100 N). The duration of these tests was established on the basis of preliminary experiments. For one sample, 15 repetitions of 4 min each and after 5 repetitions, the abrasive mass was changed, since the sharp edges of these particles were rounded and the wear rate decreased. The tests were repeated for three samples for each hardening technology.

Before the experiments, the samples were run-in in the same abrasive mass as during the experiments in order to obtain a steady-state wear process.

The amount of wear of the tested and reference samples was determined by weighing before and after testing on an analytical balance VLA-200g-M with an error of not more than 0.1 mg. The time interval between weighing was chosen on the basis that the weight loss of the sample due to wear during the test should be at least 5 mg. Before weighing, the samples were washed with hot water and dried with heated air.

3. Results

The results of laboratory tests carried out in accordance with the above methodology showed that under conditions of abrasive wear, the borated layer significantly reduces the wear of the tested samples (2...3 times), compared to the samples of heat-treated steels of grades 30 and 65G (Figure 3). As the thickness of the borated layer decreases, the rate of further wear of the experimental samples gradually increases and becomes the same as that of samples made of 65G steel.

The high wear resistance of the borated sample is explained by the structure of the hardened layer, which is a matrix made of dyelide boride containing ~ 20% inclusions of iron monoboride, which helps to provide increased stability of mechanical properties and reduce the number of possible foci of destruction during wear.

If the layer hardened by boration contained iron monoboride in an amount of 25...50%, then it would be less wear-resistant, since it would become more brittle due to the increased content of the high-boron phase [2, 3, 16].

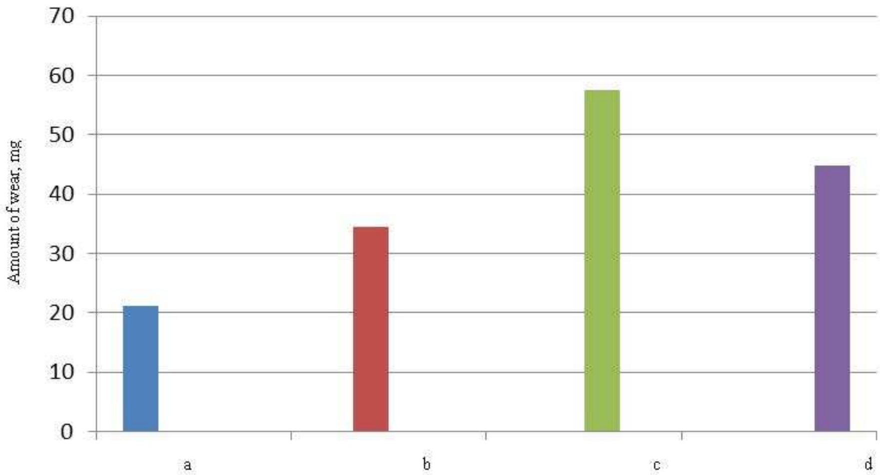


Figure 3. Results of comparative laboratory studies of hardened samples for wear: borated steel 30; b - steel 30 deposited in a liquid coolant; in - hardened steel 30; g - hardened steel 65G.

The results of laboratory tests (carried out in accordance with the above methodology) of samples with chromonickel powders deposited in a liquid coolant (PR-N67X18C5P5) coatings allow stating that they have high wear resistance. The amount of their wear is 35...70% lower than the hardened samples of steels 30 and 65G. The reason for this is the fine-grained structure and uniform distribution of carbide-boride constituents (hardness 16.5...18.6 GPa) in the layer. This ensures the stability of physico-mechanical properties and, accordingly, reduces the number of foci of destruction during friction. In this case, the ability of the coating to form secondary structures acting as protective films on the contact surface plays a positive role. Surfaced coatings have a porosity of 3...5%, which does not have a negative effect. If the coatings had a porosity of ~ 10...12%, as well as slag inclusions in the layer, then there would be a tendency to the formation of germinal microcracks. They can become centers of destruction that develop in the process of friction [15, 16].

4. Conclusion

The calculated data (Figure 1) for predicting the resource of the working bodies of soil cultivating units were verified by laboratory tests for abrasive wear, of samples hardened by similar technologies, which allows stating that the difference is in the range of 10 ... 12 %. Therefore, the presented calculation model can be used to predict the resource of the working bodies of tillage and sowing units, which will allow more accurate planning of repair and maintenance activities.

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