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PLASMA RESTORATION AND HARDENING OF ELEMENTS OF TILLAGE TOOLS

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Abstract: The solution of the problem of creating competitive technologies of elements restoration and hardening considerably depends on impartial assessment of their technical level. This assessment is especially necessary at the stage of new technological processes development. Particularly at this stage of technological processes designing of elements restoration and hardening the right assessment of its technical level will influence the economic results during serial assimilation.

Key words: *plasma-jet surfacing, elements restoration and hardening, powered alloys, tillage tools.*

INTRODUCTION

At worn elements restoration the number of manufacturing operations is reduced in 5-8 times in comparison with manufacturing new ones. At that durability of restored elements can reach the level of new, but their cost corresponds to 40-70 % from new elements prize [1-3]. To use this reserve is necessary to develop efficient and accessible for wide application of innovative technologies. It follows therefore that the problem of extension of operating life of tillage tools elements is of vital importance in economic as well as resource saving aspect.

Promising direction of this problem solution is restoration of elements working surfaces by wide-layered plasma-jet surfacing of coatings (up to 1,3 mm on the side)

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with wear resistant powered hard alloys. At the same time is important to choose the surfacing mode that allows surfacing coatings with minimum penetration depth of base material. In this case thin layer of coating retains its original physical and mechanical properties.

RESULTS AND DISCUSSION

At plasma-jet surfacing there are many factors that to a variable degree influence the depth of penetration. Effort to sum up the results of single-factor experiments and to give general analysis and numerical estimate to the phenomenon sometime is problematic because of the considerable number of dependences having a particular value. Single-factor experiments do not allow taking into consideration synergy of several factors.

We turn our attention to technological parameters and peculiarities of plasma-jet surfacing technology; one should pay attention to some of them at restoration of quick wear elements of tillage tools and equipment. In general, coating obtained by plasma-jet surfacing is characterized with technological parameters presented in Tab. 1.

Table 1. Technological parameters of plasma-jet surfacing

Technological parameters	*Designation*
Current rate of plasmotron arc	$J_к$
Plasmotron arc voltage	U
Plasma-jet hard-surfacing rate	$V_н$
Amplitude of plasmotron oscillations	A
Frequency of plasmotron oscillations	f
Powder granulation	d
Powder application rate	$G_п$
Consumption of plasma supporting gas	$q_{пл}$
Consumption of carrier gas	$q_{тр}$
Consumption of protective gas	$q_з$
Distance from plasmotron to an element	h
Diameter of internal plasma nozzle	$d_{вн}$
Diameter of external plasma nozzle	$d_н$
Preheat temperature of an element being surfaced	$T_{под}$

The spheres of application of plasma methods of hardening and restoration of elements are defined with the following characteristics:

- Application of powders as filler; this gives the opportunity to mechanize the surfacing of wear resistant, heat resistant and other high alloys from which is difficult or practically impossible to produce electrode wire;
- Small penetration depth of base metal, which allows obtaining the required content of the deposited metal even at the first layer in spite of its thickness, and refuse from multiple layer deposition in many cases; as a result, consumption of surfacing materials and time of surfacing;
- Excellent formation of deposited beads, stability and good reproducibility of their dimensions, as a result the expenditures for machining of the deposited

elements are reduced; small allowances for machining is also one of the ways of economy of surfacing materials;

- Possibility to change in a wide range of technological parameters of modes, many of them are independent from each other, it gives great flexibility to the plasma-jet surfacing process and allows depositing small elements that require several grams of alloy, as well as large items on which the deposited metal mass can correspond to tens of kilograms;
- Easiness of deposition process automation.

One of the main advantages of plasma-jet surfacing with hard powder alloys is the possibility to provide a fairly small penetration of base metal [4-6], and also it is acknowledged with the results of experimental tests [7].

Besides the applied meaning, these tests allow understanding the formation mechanism of the deposited coating at plasma-jet surfacing.

Current rate of plasmotron arc of direct action J_n produces maximum effect on the base metal in the deposited metal, which is most noticeable at surfacing with powder application rate to 2 $kg \cdot h^{-1}$. At increase of powder application rate it is ma manifested in a less degree and a range of current rate providing admitted penetration of base metal is extended.

Current rate of plasmotron indirect arc J_k practically does not influence to base metal penetration that corresponds well to the results of calorimetric tests. But it is marked that at too low J_k *the plasmotron operation stability decreases*. At high values of J_k thermal loading on plasma-forming nozzle is increased greatly. From this point of view there is some optimal value of current rate of indirect arc which is equal to J_k = 70 - 100 A, it should be taken into consideration in production activity.

The influence of *consumption of plasma supporting gas* $q_{пл}$ on penetration of base metal is mainly connected with plasma arc pressure on the molten metal zone, because arc heat input at the change of $q_{пл}$ in the investigated limits is changing only by 10 - 15%. At the same time plasma flow rate in an arc increases more than twofold. Obviously, consumption of plasma supporting gas at surfacing must be supported low as far as possible. Its value should be selected according to the conditions of providing arc stability and stability of the surfacing process (according to the experimental data $q_{пл}$ = 1 - 2 $l \cdot min^{-1}$).

Consumption of carrier gas $q_{тр}$ in the limits of 4 - 9 $l \cdot min^{-1}$ influences on the part of the base metal in the deposited bead γ_0 similar to plasma supporting gas but obviously weaker. Further increase of $q_{тр}$ does not result in penetration increase. Comparing these data with the results of measurements of plasma flow rate in an arc at different consumptions of carrier gas it is easy to prove that in this case also there is full correspondence between the influence of consumption of plasma supporting gas on plasma rate and value γ_o.

With increase of consumptions of carrier gas the powder consumptions grow as the result of increase of particles initial rate and worsening of the conditions of their heating in the arc. At consumptions of carrier gas 3 - 4 $l \cdot min^{-1}$ plasma-jet surfacing is failed often because of plasmotron channels obstruction with powder. Consumptions of carrier gas is considered as optimal in the limits of 6 - 9 $l \cdot min^{-1}$. In the field or other specific conditions at the failure of supplies of protective gases, application of hot hydrocarbons of internal combustion engine with consumption of 10 - 14 $l \cdot min^{-1}$ is allowed for powder carriage and protection of coating being deposited.

Amplitude and frequency of plasmotron oscillations in the studied range (A = 2,5 - 16 mm, f = 8 - 87 min^{-1}) influence on base metal penetration insufficiently. Thus, at oscillations amplitude changes in the range of 2 - 16 mm value γ_o changes in the range of 12 - 17%. For this reason oscillations amplitude of plasmotron should be selected according to the required width of deposited bead, taking into consideration that bead width exceeds value A by 5 - 8 mm. Oscillations frequency must be coordinated with deposition rate so that oscillations interval will correspond to 2 - 5 mm.

When *distance from plasmotron to an element h* changes in the range of 7 - 22 mm base metal penetration remains practically constant that is the important advantage of plasma jet-surfacing.

Taking into consideration that with the increase of distance h molten metal protection is getting worse and powder losses are increasing it is recommended to support it equal to 8 - 15 mm.

The portion of base metal in deposited bead γ_o depends significantly on *powder consumption* G_n (at constant values of the rest of the technological process parameters). In practice powder application is selected simultaneously with surfacing rate $V_н$ that is why it is advisable to examine the influence of these two factors simultaneously.

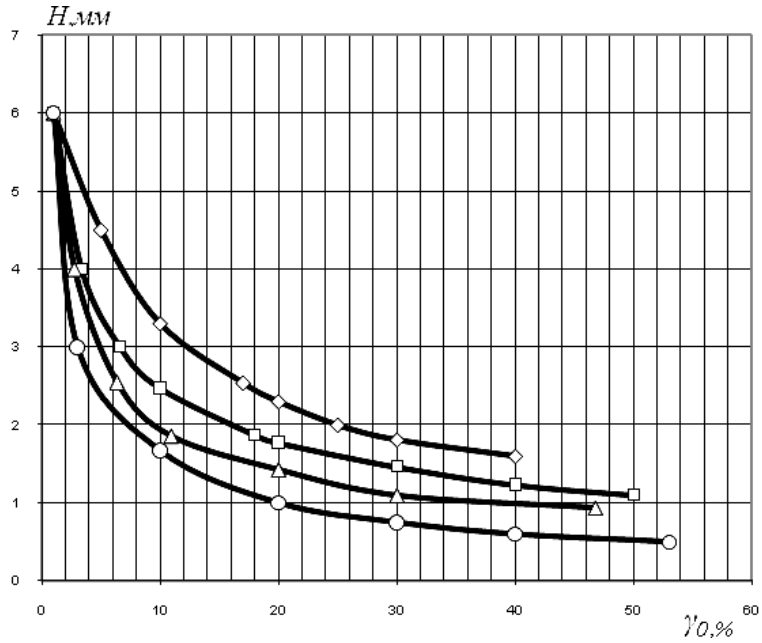

Figure 1. Dependance of coating being deposited from the base metal portion:
○ – productivity of plasma-jet surfacing 1 kg·h^{-1}; Δ – productivity of plasma-jet surfacing 2 kg·h^{-1};
□ – productivity of plasma-jet surfacing 4 kg·h^{-1};
◊ – productivity of plasma-jet surfacing 6 kg·h^{-1}

At increase of *surfacing rate* $V_н$ in the interval 1,7 - 32 m·h^{-1}, which value depends on current rate of plasmotron, powder application rate and amplitude of oscillations, the portion of base metal remains almost constant, and then decreases. At increase of

surfacing rate $V_н$ to keep thickness of deposited coating constant is necessary to increase powder application rate G_n. In this case to provide melting of more powder is necessary also to increase current rate of plasmotron arc of direct action J_n. As a result of simultaneous increase of $V_н$, G_n and J_n (at the condition of keeping deposited coating thickness), value γ_o increases too. Thus implies that the productivity of surfacing of a certain thickness is limited with permissible value γ_o.

The connection between deposited coating thickness, portion of base metal in the deposited one and surfacing productivity is illustrated with Fig. 1.

The analysis results show that the surfacing with thickness of 1,0 - 1,5 mm can be done with the productivity of 1,0 - 1,5 kg·h^{-1}, if value γ_o should not exceed 15%. The depositing of beads with the thickness more 3 mm can be done with the productivity more than 6 kg·h^{-1} at γ_o < 10%.

From the given data it follows that the choice of optimal modes of plasma-jet surfacing at restoration of quick wear elements of tillage machines results in general determining of current rate of arc of direct action J_n, powder application rate G_n and surfacing rate $V_н$. The values of the rest parameters of mode (J_k, $q_{пл}$, $q_{тр}$, h) should be supported constant in the mentioned above limits. Amplitude of plasmotron transverse oscillations A is maintained depending on the required width of bead being deposited, and oscillations frequency f is defined depending on surfacing rate $V_н$.

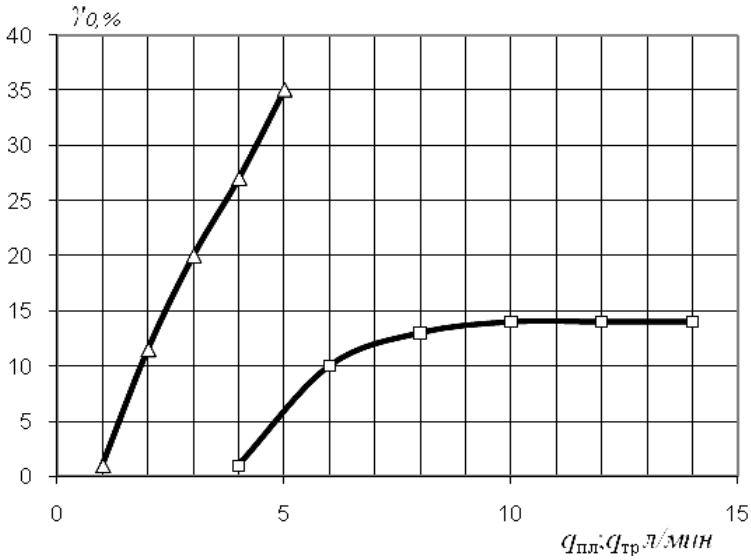

Figure 2. Dependence of the base metal portion in the deposited metal from consumption of plasma-supporting and carrier gases: Δ – plasma-supporting gas; □ – carrier gas

For selection of values $V_н$, G_n и J_n the following method is recommended. Depending on the preset thickness of the deposited coating and permissible value γ_o surfacing productivity is defined, it means that powder application rate value G_n, and then according to graphics $J_n = f(G_n)$ or $\gamma_o = f(J_n)$ at $G_n = const$ (Figs 2 and 3) the required current rate value is defined. The obtained value J_n is true for depositing of

beads with width up to 20 mm.

In case of depositing of beads with large width current rate of plasmotron is defined according to the following equation:

$$J_n = J_{20} + k\,(B - 20) \tag{1}$$

Where:

B [mm] - width of the deposited bead,
J_{20} [A] - current rate value, found graphically (for B = 20 mm);
k [A·mm^{-1}] - empirical factor (k = 3,5 - 4,0 A·mm^{-1}).

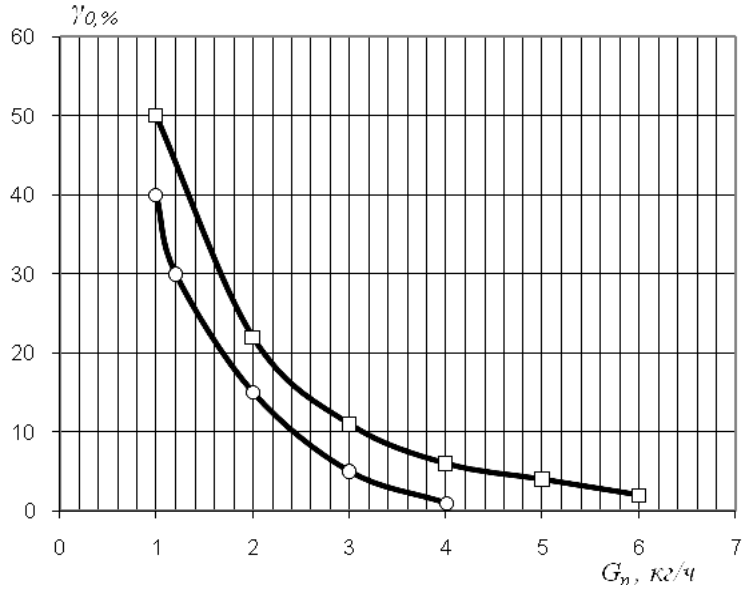

Figure 3. Dependence of the base metal portion in the deposited metal from powder application rate: ○ – at current rate of plasmotron arc J_n = 150 A; □ – at current rate of plasmotron arc J_n = 170 A

At the known productivity and preset bead dimensions surfacing rate can be defined by the following dependence:

$$V_H = \frac{G_n}{\rho \cdot \mu \cdot B \cdot H} \tag{2}$$

Where:

G_n [g·s^{-1}] - mass rate of powder application,
ρ [g·cm^{-3}] - density of the deposited metal,
μ [-] - bead completeness ratio (at plasma-jet surfacing μ = 0,8 - 0,85);
B [cm] - width of deposited bead,
H [cm] - height of deposited bead.

The observed method of surfacing modes selection is based on usage of empirical

dependences between current rate, powder application and a portion of base metal in the deposited coating from power hard alloys on nickel and iron base. These empirical dependences are defined by the heat and physical characteristics of the deposited material. At surfacing modes selection for other alloys it is necessary to take into consideration their heat and physical characteristics [7, 8].

Typical modes of plasma-jet surfacing of elements of different dimensions and form are given in Tab. 2.

If form and dimensions of the deposited element do not limit current rate of plasma-jet surfacing then productivity of plasma-jet surfacing of coatings with the width more than 3 mm is limited only with maximum permissible working value of current rate of plasmotron and maximum possible powder application, it means such application during which the plasmotron channels and nozzles are not obstructed. For example, for plasmotron of co-design with CJSC Scientific Production Association "Technoplasma" these values correspond to 350 A and 6,5 $kg \cdot h^{-1}$.

Thin coatings deposition productivity considerably depends on the permissible dilution of molten metal with base metal. At that, the thinner the coating and the less the preset value γ_o, the lower the productivity defined with the deposited metal mass per unit time.

Table 2. Plasma-jet surfacing modes for hardening and restoration of elements of tillage tools

Parameters	*Unit*	*Tillage tools elements*			
		Cutter ЭТЦ-1609	*Auger ПБУ-50М*	*Moldboard blade ДЗ-122А*	*Moldboard blade ДЗ-27*
Current rate	*[A]*	*80-110*	*120-140*	*140-180*	*140-180*
Consumption of plasma supporting gas (argon)	*[$l \cdot min^{-1}$]*	*2-3*	*1,5-2*	*1,5-2*	*1,5-2*
Consumption of carrier gas (argon)	*[$l \cdot min^{-1}$]*	*7-8*	*5-6*	*5-6*	*5-6*
Consumption of protective gas	*[$l \cdot min^{-1}$]*	*18*	*15*	*15*	*18*
Amplitude of oscillations	*[mm]*	*7*	*3*	*10*	*15*
Deposition rate	*[$mm \cdot min^{-1}$]*	*30-50*	*280*	*200*	*350*
Deposition productivity	*[$kg \cdot h^{-1}$]*	*1,4*	*2,2*	*3,0*	*5,0*

Powder losses. Not all powder particles moving peripherally of plasmotron arc column get into the zone of metal melting. Those of them which get on the deposited surface in front or sidewise of the metal melting zone, as a result of elastic recoil from this surface, are lost permanently. Powder losses will be less if the metal melting zone "leaks" under arc. This is observed at good moistening of base material with metal of the molten coating at low deposition rate, at deposition on down grade, at large thickness of deposited bead and etc.

It is necessary to stress that powder losses increase, if plasmotron is located or periodically approaches close to the edge of deposited element, if base width is smaller that plasmotron nozzle diameter and etc. Thus, powder losses depend on many mode parameters (J_n, $V_н$, G_n, $q_{пл}$, $q_{тр}$, $d_{вн}$, $d_н$, etc.), determining movement character and intensity of powder melting in plasma arc, dimensions of the metal melting zone and the

presence of molten metal layer under arc. But from the above mentioned parameters, current rate J_n and consumption of carrier gas q_{mp} mostly influence on powder losses. At optimal modes of plasma-jet surfacing they do not exceed 5 - 8%.

Dimensions and form of deposited beads are defined mainly by powder consumption, amplitude of plasmotron transverse oscillations, deposition rate and arc current of direct effect. The rest parameters influence is inconsiderable

According to the investigations bead thickness at one layer deposition does not exceed 5 - 6 mm, otherwise flanges and incomplete fusions along its edges appear. Minimum thickness of the deposited coating at $\gamma_o \leq 10\%$ corresponds to 0,5 mm about. If relatively large penetration of base metal is permitted then plasma-jet surfacing with small reinforcement of bead is not a problem.

Plasma-jet surfacing is done with plasmotron transverse oscillations, that is why bead width is determined by oscillation amplitude and reaches 55 - 60 mm. At deposition without oscillations bead width corresponds to 3 - 6 mm depending on the diameter focusing nozzles and plasmotron current rate.

CONCLUSIONS

1. The suggested rational modes of plasma-jet surfacing establish interaction between factors influencing the coating process. This allows defining optimization criterion value according to the selected factors or factors according to other selected parameters and the preset optimization criterion, and also providing wear resistant coatings deposition with necessary and sufficient strength of coating adhesion with base and minimum depth of penetration.

2. On the ground of the obtained results considering economic, ecological and resource saving peculiarities the technological processes of hardening and restoration of tillage tools with plasma methods providing high wear resistance and increase of deposited coatings resources of elements with the preset quality parameters are developed and implemented into production. Implementation of resource saving plasma technologies allows to decrease labor, material and energy costs and also to increase labor productivity and technique repair efficiency.

BIBLIOGRAPHY

[1] Kravchenko, I.N., Puzryakov, A.F., Bobryashov, E.M. 2013. *Plasma methods of hardening and hardening of working bodies of road-building and tillage machines*. Monograph. Publishing house «Eco-Press». 328 p.

[2] Kuznetsov, Y.A. 2013. Investigation of internal stresses in thin layer oxide ceramic coatings. *Traktori i pogonske masine*, Vol. 18, No. 2, Novi Sad, Srbija, p.p. 42-49.

[3] Mileusnić, I.Z., Petrović, V.D., Miodragović, M.R., Dimitrijević, Aleksandra. 2010. Uticaj uslova eksploatacije traktora na njegovu pouzdanost i radni vek. *Poljoprivredna tehnika*, vol. XXXV, No. 1, 2010, p.p. 59-67.

[4] Steklov, O.E., Alekseev, V.A. 1988. High efficiency process of plasma arc surfacing using heated filler wire. *Welding industry*, No. 8. p.p. 5-6.

[5] Bobryashov, E.M. 2010. Increase of resource of quick wear elements of tillage machines working bodies and technological equipment by plasma methods of hardening and restoration. *Technology of machine building*, No. 12. p.p. 27-33.

[6] Ašonja, N.A., Pastuhov, G.A. 2014. Uticaj dijagnostike stanja na pouzdanost dvostrukih poljoprivrednih kardanskih vrtaila. *Poljoprivredna tehnika*, vol. XXXIX, No. 1. p.p. 21-30.

[7] Kravchenko, I.N. 2011. Selection of optimal technological modes of plasma-jet surfacing by powder hard alloys. *Mechanization of construction*. 2011, No. 1. p.p. 4-5.

[8] Kravchenko, I.N. 2005. Influence of flowing on the structure formation and properties of plasma sprayed coatings. *Mechanization of construction.* 2005, No. 12. p.p. 14-17.

PLAZMA ZA OBNAVLJANJE I OTVRDNJAVANJE ELEMENATA ORUĐA ZA OBRADU ZEMLJE

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Sažetak: Rešenje problema određivanja kompetitivnih tehnologija za obnavljanje i otvrdnjavanje elemenata značajno zavisi od nezavisne procene njihovog tehničkog nivoa. Ova procena je posebno potrebna pri razvoju novih tehnoloških procesa. Na ovom nivou postavljanja tehnoloških procesa obnavljanja i otvrdnjavanja posebno je važna pravilna procena njihovog tehničkog stanja i uticaja na ekonomske rezultate u serijskoj primeni.

Ključne reči: *nanos mlazom plazme, obnavljanje i otvrdnjavanje elemenata, pogonske legure, oruđa za obradu.*

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