Pulse Plasma Surface Thermostrengthening of Machine Parts

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Abstract. The paper presents a pulse plasma generator for surface hardening of parts. The given equations allow to calculate the parameters of the pulse plasma generator to ensure the specified quality indicators of the hardened zone.

1. Introduction
Thermal processing of metals leads to modification of their structure, which affects the operational characteristics of products. In many cases, the local heat treatment is technically and economically justified. Thus reinforce the most loaded working surface, at a constant microhardness of the matrix. The concentrated streams of energy are widely spread for surface hardening of details in industry. Surface heat treatment of the parts with the use of concentrated energy flux is a substantial reserve of saving material and energy costs [1; 2; 3].

Experience shows that the plasmatron as a source of energy for surface heating can be applied in many cases along with such sources as laser and electron-beam, providing more high technical-economic indicators of the technological process [4; 5; 6; 7, 8, 9].

In this paper an effective method of plasma hardening of the surface layer due to the cumulative effects of pulsed-plasma stream is proposed: elastic strain interaction with a shock wave and pulsed plasma jets.

2. Basic part
Pulse plasma generator consists of a water-cooled frame, two electrodes of the same size and shape located in parallel to each other. Plasmatron works the following way: electric arc, moving on the surface of the electrodes in the field of their own current (railotron effect), heats the plasma gas, arc separates from the electrode surface between electrodes, then compressed plasma arc along with the flow of heated gas comes out of the nozzles and gets on the workpiece.

The hardening process is carried out due to rapid heating of the surface layer with the subsequent cooling by heat in the amount of metal as well as in the environment. High speed of heating and cooling of the surface layer of metal (>106 K/s) contributes to the formation of fine crystalline structure with a high dislocation density. By regulating the energy parameters and the duration of the cycles of heating and cooling, as well as the application of various plasma-forming gases, it is possible to change the structural-phase state of the surface layer of metal, creating the optimal structure for required operating characteristics [10].

The main parameter affecting the quality indicators of the hardened area is the temperature zone plasma impact. It should be noted that a reliable way to check the temperature changes in the areas of
plasma heating does not currently exist. Therefore, the analysis of thermal processes is analytically on the basis of solutions of the heat equation with the boundary and initial conditions and certain assumptions. In this context, the study and modeling of distribution of temperature in pulse plasma heat treatment is of great importance.

For the determination of temperature fields at pulse plasma action it is accepted that there is no internal heat source in the sample, because of the low energy not only penetration of charged particles doesn’t happen, but even of neutral particles into the depths of the material and the thermal wave propagates at a distance of more than 100 microns; pulse plasma flow is axisymmetric, and the radius of heating spot is significantly more than termoline zones; there are no radiation losses from the surface; the temperature of the irradiated material at the initial moment of time and beyond the zone of thermocline equals 0 degree in Celsius.

For calculations we have the equation describing the process of propagation of heat in metal from distributed instant source density $Q_j/m^2$, on the adiabatic surface of the half-space [11] (1).

$$T(x, z, \tau) = n \cdot \left( -\frac{Q \cdot \eta \cdot \sqrt{a}}{2 \cdot \lambda \cdot \pi \cdot \tau_M} \right) \cdot \exp \left( -\frac{z}{4 \cdot a \cdot \tau_M} \right) \cdot \left( \left[ \text{erf} \left( \frac{x}{\sqrt{4 \cdot a \cdot \tau_M}} \right) - \text{erf} \left( \frac{x - 2 \cdot r_p}{\sqrt{4 \cdot a \cdot \tau_M}} \right) \right] + \frac{Q \cdot \eta}{2 \cdot \lambda \cdot \sqrt{\pi \tau_{O6}}} \cdot \exp \left( -\frac{z}{4 \cdot a \cdot \tau_{O6}} \right) \cdot \left( \left[ \text{erf} \left( \frac{x}{\sqrt{4 \cdot a \cdot \tau_{O6}}} \right) - \text{erf} \left( \frac{x - 2 \cdot r_p}{\sqrt{4 \cdot a \cdot \tau_{O6}}} \right) \right] - \frac{\sqrt{a}}{\tau_M} \cdot \exp \left( -\frac{z}{4 \cdot a \cdot \tau_M} \right) \cdot \left[ \text{erf} \left( \frac{x}{\sqrt{4 \cdot a \cdot \tau_M}} \right) - \text{erf} \left( \frac{x - 2 \cdot r_p}{\sqrt{4 \cdot a \cdot \tau_M}} \right) \right] \right) + T_0 \right)$$

where $n$ is the number of pulses, $Q$ is the amount of energy per pulse Joule/m²2, $\eta$-plant efficiency factor, $a$ is the thermal diffusivity coefficient m²/s, $\lambda$ - thermal conductivity coefficient W/m⋅K is a function of temperature [12], $\tau_I$ - the duration of the plasma effect on the sample sec, $\tau_P$ - pause time sec, $\tau_{O6}=\tau_I+\tau_P$, $l_E$ - length of electrodes m, $V$ - velocity of the arc m/s, $\tau_{O6}$ is the period sec, $z$ - depth impact m, $x$ is coordinate $z\perp m$, $r_p$ – is a spot radius of influence m.

The temperature fields in the sample after exposure to $n$ calculated plasma flux pulses are presented on fig. 1.

The proposed model (1) is a solution of a nonlinear of the first kind which takes into account the change of the thermophysical properties of the material ($\lambda(T)$) depending on the temperature. The model allows to calculate the number of pulses of the given energy and thermal parameters of pulse plasma generator to achieve the required temperature in the zone of influence of plasma with the detail and depth thermostrengthening.
Fig. 1. The calculated temperature field in a sample of steel 45 after 15 pulses; a) without regard to cooling between pulses; b) including cooling between pulses; c) including cooling between pulses and change in $\lambda$ temperature.

To verify the model, experimental studies of pulsed plasma flow on the surface of metals were conducted. Various alloy tool steels and steels with different content of carbon were selected as the samples. The purpose of metallographic was a determination of the depth and structure of the hardened zone. Figure 2 presents a sample of steel 45 processed with impulse plasma generator.

![Image](image1.png)

Fig. 2. The sample of steel 45 processed with impulse plasma generator, the power $P=6$ kW, air flow $G=124$ l/min.

Metallographic investigations of different steels in the field of plasma hardening showed that the zone of thermal influence of the plasma jet is the shape of the segment. When metal surface by plasma jet is heated, surface layer is being heated up to different temperatures, as a result it has a layered structure (Fig. 1.) which corresponds to the selected model.

Change of hardness depth of the hardened zone is represented in Fig. 3.

![Image](image2.png)

Fig. 3. Change of hardness depth of the hardened zone of the sample of steel 45.

Research has shown that the successful solution of problems of formation of high-strength state of the surface layers of carbon steels is conducting plasma surface hardening. This creates a dislocation structure formed at high temperature thermomechanical treatment and providing high strength and plasticity of the matrix.

The calculations allow to define the necessary parameters of pulse plasma generator to ensure the set of quality indicators of the hardened zone.

3. References

[1] Klebanov Y D, Grigoriev S. The physical basis for the use of concentrated energy flows in materials processing technologies. / Second edition. Textbook. 2005 M.: IC MSTU "STANKIN, Janus-to." 220c.
[2] Hasanov I S The plasma and beam technology 2007 Baku: Elm - 171 p
[3] Israfilov IH, Rakhimov RR, Khaibullin II, Saubanov RR Prospective application of highly concentrated energy for surface heat treatment product 2011 The socio-economic and technical systems: research, design, optimization. T. 58, № 1 - P. 25-30.
[4] Encyclopedia of Low Temperature Plasma: Introductory volume to 9 kN. Proc. 4 2000 Ed. Academician VE Fortova. - M.: Nauka, 516 p.

[5] Shakirov YI, Valiev RI, Hafiz A., GY Shakirov The multi-channel system with plasma electrolytic cathode 2011 Automotive 2, - pp 36-38.

[6] Low-temperature plasma: T.18. High energy processes materials processing 2000 / Exec. Ed. MF Zhukov; Ros. Acad. Sciences, Sib. Dep- tion, Institute of Thermophysics. - Novosibirsk: Nauka, 425 p

[7] Taran V M, Lisowski S M, Lyasnikova A V Designing elektroplazmennyh technology and automated equipment 2005 M.: MSTU. NE Bauman, - 250p

[8] Zvezdin V V, Galiakbarov A T, Saubanov R R, Gabdrakhmanov A T, Nugumanova A I The influence of parameters of pulsed plasma generator on quality Process 2010Vestn. KSTU. Tupolev. 2 - p. 50-52.

[9] Parkin AA Processing Technology concentrated energy flows 2004 Samara: Samara State Technical University, 497 p.

[10] Davydov S V, Gulyaev Y V, Simochkin V V Effect of thermal properties of carbon steels at eutectoid transformation of austenite 2008 Bulletin of the Bryansk State Technical University, 1. S. 4-9.