All the basic conclusions obtained for an ac arc in a transverse gas flow are also valid for a dc arc; all that is required is to set $\partial h/\partial t = 0$ in Eq. (1).

NOTATION

h, enthalpy; ρ, density; t, time; v, velocity; ϰ, σ, thermal conductivity and electrical conductivity; E, electric field strength; U, potential at the arc; Q, radiant flux; T, period of oscillation of the current; r, radius; l, length of electric arc; d, L, diameter and length of electrode; Θ, temperature; ν, kinematic viscosity; Pr, Prandtl number; φ, current function. Indices: 0, gas parameters far from arc; 1, parameters at arc boundary; x, projection on the axis Ox; y, projection on the axis Oy; E, effective value; e, characteristic value.

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OPTIMIZATION OF METAL HEATING IN PLASMA-MECHANICAL TREATMENT

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Results are presented of an experimental investigation of the process of energy transfer to the anode of an arc in application to plasma-mechanical treatment of components.

The process of cutting ultrastrong brands of steel is characterized by large thermal and force loads on the cutting instrument. Consequently, its sturdiness is reduced, the time occupied in treating one component is increased, and the power, size, and weight of the tools grow.

The recently proposed process of plasma-mechanical treatment (PMT) permits raising the weight productivity of the cutting process, i.e., the mass of the chips removed from the workpiece in unit time. PMT is a combination method of molding the component that includes heating the layer to be cut by a high-current stabilized arc (HSA) and its subsequent removal by the cutting instrument [1]. As a rule the component to be treated is the anode. In certain cases it is expedient to submelt part of the metal and blow it off by plasma jets.

Utilization of the HSA has the following advantages over other kinds of heating: the high space—time stability of the arc column and the near-anode domain, the high energy flux concentration on the surface of the material being treated, the convenience of regulating the power of the plasma flux.

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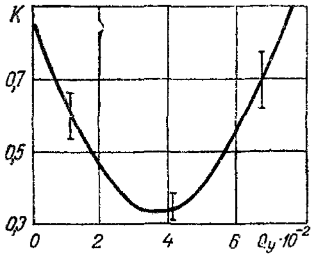

Fig. 1

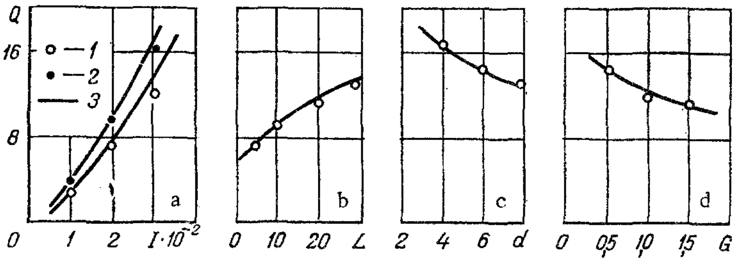

Fig. 2

Fig. 1. Dependence of cutter lifetime on the magnitude of the specific energy contribution to the layer being cut. K, pieces per h; $Q_y \cdot 10^{-2}$, kJ/kg.

Fig. 2. Dependence of the energy flux in the anode on the governing parameters: a) current; L = 10 mm, d = 6 mm, G = 0.5 g/sec; 1 and 2 correspond to h = 4.5 and 8.0 mm; b) distance between plasmotron nozzle edge and anode: I = 200 A, h = 4.5 mm, d = 4 mm, G = 0.5 g/sec; c) plasmotron nozzle diameter: I = 200 A, L = 20 mm, h = 8 mm, G = 0.5 g/sec; d) gas consumption: I = 200 A, L = 20 mm, h = 8 mm, d = 6 mm (1 and 2 are experiment, and 3 is a computation), Q, kW.

In the general case, the efficiency of using PMT is determined independently of how the questions of optimizing the material heating and cutting modes, the noise level reduction, the light and ultraviolet radiation, the dangerous gas, oxide and dust concentrations, as well as raising the technicoeconomic indices.

Diverse, sometimes contradictory, requirements are imposed on the PMT process for optimization in all the parameters, consequently, it is difficult to obtain the solution that would be best for each of them. In this connection, it is first expedient to find the solution for one or several optimization problems. Up to now, such a question has not come up in the literature.

One of the most important factors affecting the improvement of the PMT process indices is heating of the layer to be cut. Hence, the purpose of this paper is optimization of heating the metal under PMT, by which we shall understand optimal energy flux to the anode. We examine this question in application to a nitrogen arc.

Preliminary experiments showed that optimization of the heating process for PMT depends on the kind of cooling of the cutters which can be forced or natural. The life of a cutter cooled by force, as well as the productivity of removing the metal, rise monotonically as the specific energy contribution increases [2]. Furthermore, the life of the cutter is understood to be their quantity expended in treating the component for 1 h on the tool, while the quantity of specific energy contribution is understood to be the magnitude of the energy introducible from the arc per unit mass of the layer to be cut. However, for the PMT of components by a cutter with natural cooling, the nature of the dependence of their stability on the magnitude of the specific energy contribution is different. For example, an investigation of the dependence of cutter life on the magnitude of the specific energy contribution showed that the curve obtained has a minimum (Fig. 1). Analogous results were obtained in [1]. This permits making the deduction that the governing factor in instrument wear is the specific energy contribution. Its optimal magnitude corresponding to minimal cutter wear is different for each metal-cutter pair. The existence of such a minimum can be explained as follows. As the energy whose magnitude is yet lower than the optimal insertion into the layer to be cut increases, the work expended in deformation of the chips and overcoming the friction at the rear surface of the cutting surface is reduced. The result is a rise in the life of the cutting tool, which is observed just so long as the heat from the cutting edge succeeds in being eliminated, i.e., no substantial rise in temperature occurs in the cutting zone. As the energy contribution increases above the optimal, a situation is produced as when temperature growth in the cutting zone results in magnification of the wear and shortening of the life of the cutting instrument in the long run.

The integral energy flux in the anode, its distribution in the anode spot, the thermophysical properties of the material, and the heat propagation time therein up to the time of removal of the layer being cut must evidently be determined to compute the specific energy contribution. This must be known in order to find the total quantity of heat being

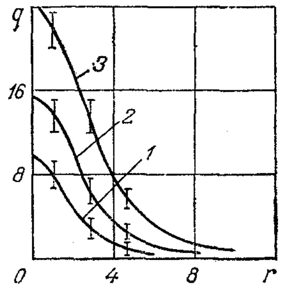

Fig. 3. Experiment energy flux density distributions on the anode for different currents: 1, 2, 3 correspond to I = 100, 200, 300 A; L = 10 mm, h = 4.5 mm, d = 6 mm; G = 0.5 g/sec; q in kW/cm^2, and r in mm.

transmitted to the component, and also the fraction of heat remaining in the layer being cut must be taken into account.

The generalized equation of the integral energy flux in the anode of a nitrogen arc, obtained by the method developed earlier, is written thus [3]:

$$Q = 1.42\,\frac{I^{1.36}L^{0.36}(1+82h)}{d^{0.3}G^{0.17}}. \tag{1}$$

Comparing computed and experimental results shows that the error in a computation by using (1) is 20%. The limits of variation of the governing parameters are here the following: I = 100-400 A, L = 10-40 mm, h = 4.5-12.0 mm, d = 4-8 mm, and G = 0.5-3 g/sec. Figure 2 illustrates the nature of the dependence of the energy flux in the anode on the governing parameters.

The exponent for each of the parameters in (1) characterizes its relative effect on the process of energy transmission to the anode (Fig. 2). Let us note that the variations of the parameters mentioned have both upper and lower bounds. For example, the selection of the arc current is constrained by the limits of output parameter regulation of the specialized supply source. Moreover, the minimal values of the current are determined by the stability of arc combustion, while the upper are determined by the abrupt rise in the erosion of the plasmotron cathode and nozzle. The maximal spacing between the cathode and the nozzle exit is limited by the double arc-formation [4], the spacing from the plasmotron nozzle exit to the anode and the plasmotron nozzle diameter by the stability of arc combustion, and the consumption of the plasma-forming gas by the noise level. Therefore, when using cutters with forced cooling, the current, the spacing between the plasmotron nozzle exit to the cathode and anode must be increased to raise Q, while the nozzle diameter and the gas consumption must be diminished. When using cutters with natural cooling, the optimal magnitude of the energy contribution to the layer being cut must be found for each material-cutter pair, and then the requisite energy flux must be delivered to the workpiece, depending on the cutting mode.

For instance, according to the results of our investigations, the magnitude of the specific energy contribution to the layer being cut is 350 kJ/kg for the pair steel 110G13L-cutter with a VK8 plate during PMT on a model 1540 boring and turning lathe. This corresponds to a layer mean-mass temperature of 550°C.

The generalized equation for the energy flux distribution on the nitrogen arc anode, obtained by the method developed earlier [5, 6], has the form

$$q = 3.4\cdot 10^{-3}\,\frac{I^{0.9}G^{0.4}(1+120h)}{d^{1.8}L^{0.9}}\exp\left[-2.8\cdot 10^{-4}\,\frac{G^{0.61}(1+20h)}{I^{0.46}L^{1.9}d^{1.7}}\,r^2\right]. \tag{2}$$

The deviation of the computed values of q for the experimental results is 35%. The limits of variation of the governing parameters are the same as for (1). Experimental energy flux density distributions on the nitrogen arc anode are shown in Fig. 3 as a function of the current. It is seen from (2) and Fig. 3 that the energy flux density distribution in the anode spot is subject to the normal distribution law $q = q_m \exp[-k_q r^2]$, where the values of q_m and k_q are computed for each arc combustion mode.

Let us show that the characteristic dimension of the energy flux density distribution on the anode can be taken as the width of the domain to be heated for PMT under heating conditions by a high-current stabilized arc. Indeed, to avoid overheating the component the degree of heat propagation, estimated by the formula $S_0 = (3\text{-}4)\sqrt{a\tau}$ in [7], should be less than or equal to the chip thickness. In practice, the chip thickness in PMT does not exceed 2.0-2.5 mm. Then, for instance, $a = 4 \cdot 10^{-6}$ m²/sec for steel mark 110G13L and the time τ is 0.15 sec. The spot size we chose at the $0.1q_m$ level [6] is greater than 2.0-2.5 mm and can be selected as the heating width, i.e., heat spread over the steel surface can be neglected. Starting from the estimates obtained, the spacing between the plasmotron and the cutter can be selected by means of the formula $k = v\tau$.

Computations utilizing (2) show that for conditions when the chip width exceeds the dimension of the spot at the $0.1q_m$ level while its thickness is greater than 2.5 mm, then up to 90% of the heat transmitted to the material through the anode spot will remain in a layer lying under the exit.

Taking into account the considerable power of the arc, it is expedient to select its combustion mode such that the coefficient of energy transmission (CET) to the anode would be maximal for an unchanged value. The equation to compute the electrical power of the arc, obtained by multiplying the current by the left and right sides of the CVC formula [8], is written thus

$$N = 0.176\,\frac{I^{0,1}h^{0,8}}{G^{50d-0.44}d^{1.18-50d}L^{0,36}} + 45{,}8\,\frac{210^{4,7L-65G+0,035}L^{0,28}}{d^{0,34}I^{4,7L-65G+0.39}(1+82h)}\,. \tag{3}$$

Analysis of the relationships obtained in exactly this manner for argon and air arcs shows that the energy flux to the anode and the electrical power of a nitrogen arc are 1.8-2.2 times greater than the argon, while those for the air arc are 1.1-1.2 times greater than for the nitrogen arc.

For convenience in writing the CET in terms of the governing parameters, we divide (3) by (1) and obtain

$$\frac{1}{\eta} = 0{,}176\,\frac{I^{0,1}h^{0.8}}{G^{50d-0.44}d^{1,18-50d}L^{0,36}} + 4{,}58\,\frac{210^{4,7L-65G+0,035}L^{0.28}}{d^{0.34}I^{4,7L-65G+0,39}(1+82h)}\,. \tag{4}$$

Analysis of (4) and the experimental data shows that the CET does not become less than 0.3. This is due primarily to the fact that the plasma flux generated in the arc is directed to the anode surface.

According to tests, an increase in the efficient of the energy transmission process is achieved because of the rise in arc current and in the spacing between the cathode and the nozzle exit. The strong dependence of the CET to the anode on the current is explained by the substantial connection between the plasma flux parameters and the arc current. In particular, as the current increases the flux temperature, its enthalpy, dynamic head, and velocity all increase [9]. The radial temperature profiles in the arc column become broader, which results in diminution of the relative fraction of the energy losses through the side surface. We also found that the CET diminishes as the gas consumption and the spacing between the plasmotron nozzle exit and the anode increase.

NOTATION

Q_y, energy introduced per unit mass of the layer being cut, W/kg; Q, integral energy flux in the anode, W; I, arc current, A; L, spacing between the plasmotron nozzle exit and the component, m; h, spacing between the plasmotron nozzle exist and the cathode, m; d, plasmotron nozzle diameter, m; G, gas consumption, kg/sec; q, energy flux density in the anode spot, W/cm²; r, spacing from the center of the anode spot to the point at which the energy flux density is calculated, cm; q_m, energy flux density at the center of the anode spot, W/cm²; k_q, concentration coefficient, cm⁻²; S_0, degree of heat propagation, m; a, thermal diffusivity factor, m²/sec; τ, time, sec; k, spacing between the plasmotron and the cutter, m; v, cutting rate, m/sec; η, coefficient of energy transmission to the anode; N, electrical power of the arc, W.

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STOCHASTIC SELF-OSCILLATIONS IN THE PRESENCE OF DRY FRICTION

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We propose and investigate a mathematical model of a one-dimensional mechanical system which executes stochastic self-oscillations for certain values of the parameters.

Many mechanical systems involve the relative motion of bodies in the presence of dry friction. It is known [1, 2] that self-oscillations are possible in such systems, and a number of papers have been devoted to their study. There are two characteristics of the laws of dry friction, either of which can lead to the initiation of self-oscillations in an elastic system. The first is the decrease of the frictional force with increasing relative velocity [3], and the second is the increase of the static frictional force with an increase in the time of stationary contact [4, 5].

In the present article we propose a simple model of a mechanical system in which stochastic self-oscillations occur for certain values of the parameters.

We consider a body moving on a plane under the action of a spring of stiffness c whose end is displaced with a constant velocity v. We assume that the force of sliding friction has the constant value F_0, and that the maximum force of static friction $F(\tau)$ depends on the time τ of stationary contact between the body and the plane in the following way: $F(0) = F_0$, and $F(\tau)$ increases monotonically with increasing τ and approaches a finite value F_1 as $\tau \to \infty$.

The behavior of such a system was investigated in [4, 5] for

$$F(\tau) = F_1 - (F_1 - F_0)e^{-\delta\tau}, \tag{1}$$

but the parameters F_1, F_0, and δ were assumed variable over rather narrow limits. We show below that the whole (F_1, δ) plane is divided into a number of nonintersecting domains, one

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