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Determination of pulse current optimal parameters for manual arc welding

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1. Introduction

The application of arc welding takes a leading position among other methods of welding. Now the fraction of metal, deposited by manual arc welding, is reduced for the score of more broad usage of the mechanized methods of welding. However, the manual welding by covered electrodes remains one of the most widespread types and is widely applied at assembly constructions. Under the forecasts, in near future the percentage of metal deposited by manual arc welding in industrially of the developed countries will be within the limits of 15-20%, and in construction will make 85-90% of total amount of welding work [1].

It is known, that manual arc welding by covered electrodes is accompanied by rather large losses of metal on splashing, evaporation and stubs ends (15-20%), and considerable proportion of entire losses is made by splashing molten metal (9-15%) [2]. It is followed not only by loss, but also by the surface pollution of the welded metal (adhesion of drops). Stiffened sparks aggravate the exterior of a hardware product, and in some cases magnify the probability of defects appearing [3]. Therefore it is necessary to carry out surface clearing of the welded hardware products, for what special tools, padding work breakdowns and energy are necessary. One of the most effective methods of splashing reduction at arc welding is using of the pulse (modulated) current for reaching pulsing arc. Welding by pulsing arc solves many of other problems and allows improvement the quality of welded joints [4-11].

2. Advantage of welding by the modulated current

Now pulse current is more frequently used in manual welding because it has a lot advantages in comparison with the direct current. Main advantages are the following [4]:

- the possibility to get stable welding process in vertical and overhead positions;
- the opportunity to take control of carrying of electrode metal;
- the ability to control thermal cycle of the parts being welded;
- to avoid cracks;
- to lower the level of residual stresses and deformations.

It is known, that in the case of arc welding by covered electrodes the time between transitions of the drops of metal can be 0.05-1.0 s and usually makes 0.1-0.5 s [1], i.e. real transition frequency of the drops *f*=2-10 Hz. Using such pulse of a current frequencies it is possible to receive small but powerful enough pulsations of the arc comparable with welding bath inertia. In the case of large volume of the welding bath (large currents) for of power increase of the pulsing arc it is necessary to lower pulse frequency of the current up to 1 Hz or even less. Arc pulsations of sufficient power effect on crystallization (callosity) of the weld material and there is a capability to operate process of formation of the weld. At a current pulse the arc power increases, the quantity of molten electrode and base metal is magnified. At impulse pause the power of an arc is sharply reduced. This promotes accelerate of crystallization of the molten metal of welding bath with lowering of the quantity of molten metal. By changing parameters of the modulated current it is possible to operate crystallization speed of the weld metal, to change the volume and fluidity of the bath, to provide necessary penetration ability of the arc without perils to burn holes and the capability of welding in different spatial positions [4].

The application of modulated current for welding of low carbon high-strength steels allowed improvement the formation of structure and properties [5] of welded joints, and their resistance hardness to delayed destruction:

- contents of injurious diffusive hydrogen has decreased by 25%;
- primary structure of the weld metal (up to 40%) was crushed;
- service characteristics were increased up to 30%;
- crack initiation was slowed considerably.

It is proved that the use of modulated current improves partly the environment safety factor of the welding process. In this case the overflow energy of the arc and the evaporation of melting electrode materials diminished. The experiments show that the intensity of aerosol evaporation is diminished when the welding is being carried out on modulated current [6]. The amount of health harmful hard welding aerosol fraction containing noxious manganese can be considerably diminished.

Literature analysis revealed indisputable advantages and perspectives of the usage of modulated current for welding by a pulsating arc. The calculation methods of optimal parameters of the modulated current for different welding schedules follow.

3. Calculations

For the transition of high quality metal through an arc gap it is necessary to accomplish the transfer of one drop of molten metal at the action time of one current pulse, i. e. the frequency of transfer of drops should be equal to the frequency of the modulated (pulse) current. Therefore pulse frequency *f* should be equal to the quotient from division of the consume volume of an electrode stick to the drop volume

$$f = \frac{\pi r_e^2 v_l}{\frac{4}{3}\pi r_d^3} \tag{1}$$

where r_e is an electrode stick radius; v_l is linear speed of electrode fusing (burn - off rate); r_d is the radius of molten metal drop.

For good welding process with small splashing it is desirable to receive small drops transfer of electrode metal, i. e. diameter of the drops d_d must be less than the diameter of electrode rod d_e. On the other hand too small drops will increase the frequency of their transition, the demand adequate frequency of current pulse, and the power of arc pulsations will be insufficient for the effect on molten metal of welding bath. Therefore we suppose $d_d = 0.8d_e$. Considering, that $r_e=0.5d_e$ and $r_d=0.4d_e$ the formula (1) receives the following expression

$$f = 2.93\frac{v_l}{d_e} \tag{2}$$

Electrode diameter d_e and the mean magnitude of welding current I_w is selected depending on thickness S of welded metal from handbook data (Table 1).

Table 1

Data of welding schedules

S, mm	0.5-2.5	1.0-3	1.5-5	3-10	6-20	10-30
d_e, mm	2	2.5	3	4	5	6
I_w, A	40-70	50-100	80-130	120-200	180-300	220-400

The wide scatter of welding currents is explained by the fact, that a welding in vertical and overhead positions the current magnitude is smaller, and for welding of lap and tee joints is possible to apply the greater current, since in this case the hazard of leaky penetrations is smaller.

Linear speed of electrode fusing is equal

$$v_l = \frac{v_m}{A_e \rho} = \frac{4v_m}{\pi d_e^2 \rho} \tag{3}$$

here v_m is mass (quantitative) speed of electrode fusing; A_e is cross-sectional area of an electrode stick; ρ is the density of the steel (7.8 g/cm^3).

Mass speed of electrode fusing

$$v_m = \alpha_d I_w \tag{4}$$

where α_d is deposition coefficient (for electrodes УОНИ-13/45 $\alpha_d = 9.0$ g/Ah [12]).

Inserting expression (4) into the equation (3) and taking into account, that $\rho = 7.8\cdot10^{-3}$ g/mm^3 and $\alpha_d=2.5\cdot10^{-3}$ g/As, we get

$$v_l = \frac{0.408 I_w}{d_e^2}, \text{mm/s} \tag{5}$$

Inserting expression (5) in the equation (2) the formula for pulse frequency calculation of the modulated current is

$$f = \frac{1.2 I_w}{d_e^3} \tag{6}$$

Here the coefficient can vary slightly depending on the sizes of given drops of molten metal. The accomplished analysis showed good correlation with the literary data. For example, at welding current I_w=200 A (reverse polarity) for an electrode УОНИ-13/45 (d_e=4 mm) the duration of drops transitions is τ =187-350 ms, and their masses are within the limits of 88-136 mg [11]. The advisable pulse frequencies f vary from 1.7 Hz [5] up to 5 Hz [8]. According this methodology f=3.75 Hz, τ =267 ms (τ=1/f), and mass of a drop (r_d=0.4d_e=1.6 mm) is equal 134 mg (actually smaller because of the losses on splashing and evaporation).

For the definition of the necessary durations of impulses τ_i of the modulated current we shall take an advantage of power calculation using thermal balance at the electrode stub

$$Q_{fus} + Q_{ev} + Q_{h.ch} + Q_{ov.h} = Q_e + Q_{h.dr} + Q_{chem} \tag{7}$$

where values of power are: Q_{fus} is fusion of the electrode; Q_{ev} is evaporation of metal; $Q_{h.ch}$ is heat interchange with environment; $Q_{ov.h}$ is overheating of a drop metal; Q_e is heat generated by arc and flowing current at the electrode stub; $Q_{h.dr}$ is heating of a drop by flowing current; Q_{chem} is proceeding of chemical reactions.

The outlay metal evaporation power Q_{ev} and overheating of the drop metal of a $Q_{ov.h}$ together make about 40% from all used energy [2, 13], which can be taken into account accepting fusion process efficiency of a electrode to be $\eta = 0.6$.

The outlay of power of interchange ($Q_{h.ch}$=2.5-4.1% from all used energy) practically is equal to incoming power of proceeding chemical reactions (Q_{chem}=3.5-3.8 % from all coming energy) [13]. These outlays of powers counterbalance one another and they can be eliminated.

The outlay of power of drop heating by flowing current is rather small ($Q_{h.dr}$= 0.2-0.5 % from all coming energy [13]), and it can be eliminated.

At such assumptions it is possible to consider, that $Q_{fus}=Q_e$. During passing of one current pulse the outlay of power Q_e is the sum of heats, exuded on the electrode stub by the arc Q_{arc} and a flowing current Q_i [12]. It is obvious, that

$$Q_{fus} = Q_{arc} + Q_i \tag{8}$$

Energy for heating and fusion of one molten metal drop with considering of losses on evaporation and overheating of the drop is determined

$$Q_{fus} = V\rho\left(cT + \lambda\right)\eta^{-1} \tag{9}$$

where V is the volume of molten metal drop (r_d=0.4d_e); c is specific heat capacity (for weigh unit) of molten metal (0.724 J/(g·K) [12]); T is mean temperature of molten metal drop (2600 K [12]); λ is specific fusion heat of a steel (272 J/g); η is heat efficiency of electrode fusion (0.6).

The fusion power of one metal drop Q_{fus} for different diameters of electrodes d_e are is presented in Table 2. This data is similar to the one attained by A. Erochin [13].

The quantity of heat provide up to the stub of an electrode by an arc Q_{arc} (reverse polarity) as concerns the effect of one current impulse practically is equal to exuded heat on anode in time τ

$$Q_{arc} = \int_0^{\tau} (U_a + \varphi) i(t) dt \qquad (10)$$

where U_a is anodic voltage (4V [14]); φ is output potential of an electron from the anode. (4.18 V); $i(t)$ is the function of current impulse change.

The quantity of heat Qi, exuded on the stub of an electrode by the current of one impulse, is equal

$$Q_i = \int_0^{\tau} i^2(t) r_s(t) dt \qquad (11)$$

where r_s is electric resistance of the electrode stub.

It is known, that

$$r_s = \frac{l_s \rho_s}{\pi r_e^2} \qquad (12)$$

where l_s is the length of effective heating of the electrode stub (≈5 mm); ρ_s is mean specific resistance of the electrode stub ($\approx 3 \cdot 10^{-4}$ Ω·mm); πr^2_e is cross - sectional area of the electrode.

Considering, that the length of effective heating l_s and mean specific resistance ρ_s of stub the electrode are constants, the expression (13) will be converted

$$Q_i = \frac{l_s \rho_s}{\pi r_e^2} \int_0^{\tau} i^2(t) dt \qquad (13)$$

Inserting magnitudes Q_{arc} and Q_i into the equation of thermal balance (8), attain

$$Q_{fus} = 8.18 \int_0^{\tau} i(t) dt + \frac{l_s \rho_s}{\pi r_e^2} \int_0^{\tau} i^2(t) dt \qquad (14)$$

In the obtained expression unknown magnitudes are pulse duration τ_i and the function current pulse $i(t)$ change. However, it is possible to assign the form and amplitude of the pulse current I_i subjected to a particular welding schedule. In the case of rectangular pulse current, according to the formula (11), the necessary pulse duration τ_i it is possible to determine by the expression

$$\tau_i = \frac{Q_{fus}}{I_i \left(8.18 + \frac{I_i l_s \rho_s}{\pi r_e^2} \right)} \qquad (15)$$

Using the last expression optimal pulse durations τ_i are determined at different welding schedules (Table 2).

Table 2

Parameters of the modulated current

d_e, mm	Q_{fus}, J	I_w, A	f, Hz	I_i, A	τ_i, ms
2	60.1	50	7.50	100	73
		70	10.50	140	52
2.5	117	60	4.61	120	119
		90	6.91	180	79
3	203	90	4.00	180	137
		120	5.33	240	103
4	480	130	2.44	260	224
		180	3.38	360	162
5	938	190	1.82	380	300
		260	2.50	520	219
6	1622	260	1.44	520	379
		350	1.94	700	281

During the pauses of impulses τ_p usually a small current ($I_p \approx 50$ A [9, 10]) is used for the support arc burning. In this case average welding current I_{av} is equal [5]

$$I_{av} = \frac{I_p \tau_p + I_i \tau_i}{T_i} \qquad (16)$$

where T_i is the period of impulses ($T_i = \tau_i + \tau_p$).

The use of the calculated parameters of modulated current will allow stabilization optimal heat quantities, necessary for making liquid drops, reducing splashing of the metal and improving the quality of weld formation.

4. Conclusions

1. The performed literature analysis has shown indisputable advantages of the application of modulated current and estimation principles of its optimal parameters for the welding by pulsing arc.

2. The frequencies of modulated current pulses are estimated. They are directly proportional to the average magnitude of arc current and are inversely proportional to the third power of the used electrode diameter ($f = 1.2 I_w / d^3_e$).

3. The analysis of heat at the electrode stub at one current impulse gives: the indispensable energies for fusion of drops of metal are considered as heats, exuded on the electrode stub by flowing current arc. This allowed to assign optimal pulses durations of the modulated current for different welding schedules.

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OPTIMALIŲ RANKINIO LANKINIO SUVIRINIMO IMPULSINĖS SROVĖS PARAMETRŲ NUSTATYMAS

Reziumė

Straipsnyje nagrinėjamas rankinis suvirinimas pulsuojančiu lanku (impulsine srove). Nustatyti suvirinimo impulsine srove pranašumai, palyginti su nuolatine srove.

Naudojant šiluminę skaičiuotę bei terminės energijos balansą ant elektrodo galo, nustatyti optimalūs moduliuotos srovės parametrai: impulsų dažniai ir trukmės, esant įvairiems suvirinimo režimams. Tai stabilizuoja šilumos kiekius, būtinus skystiems lašams sudaryti, mažina metalo ištaškymą ir gerina siūlės formavimą.

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DETERMINATION OF PULSE CURRENT OPTIMAL PARAMETERS FOR MANUAL ARC WELDING

Summary

Manual welding by pulsing arc (pulse current) is researched in the article. The advantages of welding by pulse current are found out in comparison with the welding by direct current.

While using energy calculation and taking into account thermal balance at the electrode stub, optimal parameters of the modulated current, such as frequency and duration of electrical pulses were established for different welding regimes. This stabilizes heat, which is necessary for making melting drops, by lowering the level of metal splash and improves of the weld formation.

Е. Щемелевас

ОПРЕДЕЛЕНИЕ ОПТИМАЛЬНЫХ ПАРАМЕТРОВ ИМПУЛЬСНОГО ТОКА ДЛЯ РУЧНОЙ ДУГОВОЙ СВАРКИ

Резюме

В статье анализируется процесс ручной сварки пульсирующей дугой (импульсным током). Выявлены преимущества сварки импульсным током по сравнению со сваркой постоянным током.

При помощи энергетического расчета, с использованием баланса теплоты на торце электрода, определены оптимальные параметры модулированного тока: частоты следования и длительности электрических импульсов при различных сварочных режимах. Это стабилизирует количество теплоты, необходимое для образования жидкой капли, уменьшает рабрызгивание металла и улучшает формирование шва.

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