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Determination of Optimal Pulse Current for Arc Welding

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Introduction

It is known, that welding is used widespread in practice. The arc welding application is a leader compared to other methods of welding. It occurs in gas-shielded metal-arc welding used active gases (MAG process), inert gases (MIG process) or manual welding by the covered electrodes (MMA process). Now the fraction of metal, deposited by manual arc welding [1], is reduced because of more broad usage of the mechanized methods of welding. 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 surfaces 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 pulse current (pulsing arc) solves many of other problems and allows improvement of quality of weld joints [4-8].

Advantage of welding pulse current

Now pulse current (pulsing arc) is more frequently used in arc welding because it has a lot advantages in comparison with the usual arc. Main advantages are the following [4]:

- the opportunity to take control of carrying of electrode metal;
- the ability to control thermal cycle of 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 drops F=2-10 Hz. Using such pulse frequencies of a current 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 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 [4].

It is proved that the use pulse (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 [5].

Literature analysis revealed indisputable advantages and perspectives of the usage of modulated current for welding by pulsing arc. The determination of optimal parameters of the pulses current for different welding methods follow.

Calculations

For transition of high quality metal through an arc gap it is necessary to accomplish transfer of one drop of molten metal at the transport 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

$$F = \frac{\pi r_e^2 V_l}{\frac{4}{3}\pi r_d^3}, \qquad (1)$$

where r_e - electrode stick radius of; V_l – linear speed of electrode fusing (burn - off rate); r_d - 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 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 effect on molten metal of a welding bath. Therefore suppose, that $d_d = 0{,}8d_e$. Considering, that $r_e=0.5d_e$ and $r_d=0.4d_e$ the formula (1) receives a following expression

$$F = 2.93\frac{V_l}{d_e}. \qquad (2)$$

Electrode diameter d_e and mean magnitude of welding current I_w is selected depending on thickness S of welded metal from handbook data [3].

The wide scatter of welding currents is explained by the fact, that a welding in vertical and overhead positions the current magnitude 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

$$V_l = \frac{V_m}{S_e\rho} = \frac{4V_m}{\pi d_e^2\rho}, \qquad (3)$$

where V_m - mass (quantitative) speed of electrode fusing; S_e - cross-sectional area of an electrode stick; ρ - the density of the steel (7.8 g/cm^3).

Mass speed of electrode fusing

$$V_m = \alpha_d I_w, \qquad (4)$$

where α_d - deposition coefficient (for electrodes УОНИ-13/45 α_d= 9.0 g/Ah [9]).

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, get

$$V_l = \frac{0.408 I_w}{d_e^2}, \text{ mm/s}. \qquad (5)$$

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

$$F = \frac{1.2 I_w}{d_e^3}. \qquad (6)$$

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 [10]. The advisable pulse frequencies F vary from 1.7 Hz [4] up to 5 Hz [7]. 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

$$Q_{fus} + Q_{ev} + Q_{h.ch} + Q_{ov.h} = Q_e + Q_{h.dr} + Q_{chem}, \qquad (7)$$

where values outlay of power Q are: Q_{fus} – fusion of the electrode; Q_{ev} – evaporation of metal; $Q_{h.ch}$ – heat interchange with environment; $Q_{ov.h}$ – overheating of drop metal; Q_e – heat generated by arc and flowing current at the electrode stub; $Q_{h.dr}$ – heating of a drop by flowing current; Q_{chem} – 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 consumption energy [2,10], which can be taken into account accepting fusion process efficiency of a electrode to be η=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) [10]. 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 [10]), 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 [10]. It is obvious, that

$$Q_{fus} = Q_{arc} + Q_i. \qquad (8)$$

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

$$Q_{fus} = V\rho(ct+\lambda)\eta^{-1}, \qquad (9)$$

where V – the volume of molten metal drop ($r_d=0.4d_e$); ρ – the density of steel ($7.8\cdot10^{-3}$ g/mm^3); c - specific heat capacity (for weigh unit) of molten metal (0.724 J/(g·K) [10]); t - mean temperature of molten metal drop (2600 K [10]); λ - specific fusion heat of a steel (272 J/g); η - the heat efficiency of electrode fusion (0.6).

The outlay of power of fusion one drop metal Q_{fus} for manual arc welding (MMA) and different diameters of electrodes d_e are is presented in Table 2. This data is similar with fact counted A.Erochin [10].

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 – anodic voltage (4V [11]); φ – output potential of an electron from the anode (4.18 V); $i(t)$ – the function of current impulse change.

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

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

where r_s – 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 – the length of effective heating of the electrode stub (≈5 mm); ρ_s – mean specific resistance of the electrode stub (≈$3 \cdot 10^{-4}$ Ω·mm); πr^2_e – 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 (11) will be converted

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

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

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

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 a rectangular pulse current, according to the formula (14), 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 and amplitude I_i are determined at different manual arc welding regimes by the covered electrodes (MMA). This pulses current parameters was given in [12].

Analogously optimal pulse parameters determined for gas-shielded metal-arc welding used active gases (MAG) (Table 1).

Table 1. Parameters of the pulses (MAG process)

d_e, mm	I_s, A	$V_v \cdot 10^{-2}$, m/s	f_p, Hz	Q, J	I_i, A	τ, ms
1.0	100	6.0	90	6.7	360	1.81
1.0	150	10.0	150	7.5	360	2.05
1.0	200	15.0	225	7.5	360	2.04
1.2	150	7.5	94	12	420	2.88
1.2	200	11.3	141	12	420	2.87
1.2	250	15.8	198	11	420	2.74
1.4	200	8.5	91	17	500	3.66
1.4	250	11.5	123	18	500	3.61
1.4	300	15.0	161	17	500	3.46

The diapason of average frequency current‘s pulses must coincide the liquid metal drops traffic frequency (30-200 Hz). In this way every liquid metal drop gets one current pulse and this makes it easier to transfer. This way fully controlled liquid electrode metal transferring and pulse current welding is obtained [9]. Nowadays power sources may form the current having not only any frequency needed but can change the pulse pause τ_p, duration τ_i, amplitude I_i and basic current I_p quantities.

During the pauses of impulses τ_p usually will use a small base current (I_p≈50 A [5]) is used for the support arc burning. In this case average welding current I_{av} is equal

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

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

As the result pulsed current frequency f_m changed as shown in Table 2.

Table 2. Parameters of the pulses current (MMA process)

I_{av}, A	220	220	220	220	220
τ_i, s	0,01	0,01	0,01	0,01	0,01
I_p, A	50	50	50	50	50
τ_p, A	0,01	0,015	0,02	0,025	0,03
I_i, A	390	475	566	644	730
f_m,Hz	100	67	50	40	33

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

Conclusions

1. Reaching a pulsing arc by using of the pulse current. The accomplished literary analysis has shown indisputable advantages of application of the modulated current and topicality of estimation of its optimal parameters for welding by pulsing arc.

2. 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 arc and a flowing current. This allowed to assign optimal parameters of the modulated current for different welding methods and regimes.

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The manual and semi-automatic welding by pulse current (pulsing arc) is considered in the article. The advantages of welding by the pulsing arc are found out in comparison with welding by a constant arc. Using energetic calculation taking into account thermal balance at the electrode stub, optimal parameters of modulated current, such as frequency and duration of electrical pulses were established for different welding methods and regimes. By that stabilized heat, which needed for making melting drops, lower the level of metal splash and improve formation of the weld. Bibl. 12 (in English; summaries in English, Russian and Lithuanian).

Е. Щемелёвас. Определение оптимальных импульсов сварочного тока при дуговой сварке // Электроника и электротехника. – Каунас: Технология, 2009. – № 7(95). – С. 87–90.

Рассматриваются ручная и полуавтоматическая сварка импульсами тока (пульсирующей дугой). Выявлены преимущества сварки пульсирующей дугой по сравнению со сваркой постоянным током. При помощи энергетического расчета и баланса теплоты на торце электрода определены оптимальные параметры модулированного тока: частоты следования и длительности электрических импульсов для различных сварочных способов и режимов. Это стабилизирует тепло, необходимое для создания жидких капель, уменьшает разбрызгивание металла и повышает качество формирования шва. Библ. 12 (на английском языке; рефераты на английском, русском и литовском яз.).

J. Ščemeliovas. Lankinio suvirinimo optimalių srovės impulsų nustatymas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2009. – Nr. 7(95). – P. 87–90.

Straipsnyje nagrinėjamas rankinis ir pusiau automatinis suvirinimas srovės impulsais (pulsuojančiu lanku). Nustatyti suvirinimo pulsuojančiu lanku pranašumai, palyginti su pastoviu lanku. Naudojant energetinę skaičiuotę bei šilumos balansą elektrodo gale, nustatyti optimalūs moduliutos srovės parametrai: impulsų dažniai ir trukmės, suvirinant įvairiais būdais ir režimais. Tai stabilizuoja šilumos kiekius, būtinus skystiems lašams sudaryti, mažina metalo ištaškymo lygį ir gerina siūlės formavimą. Bibl. 12 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).