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 acceleration 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.
the formula for pulse frequency calculation of the modulated current is

$$f = \frac{1.2I_w}{d_e^2}$$  \hspace{1cm} (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 YOHHI-13/45 ($d_e=4$ mm) the duration of drops transitions is $\tau=187-350$ 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, $\tau=267$ ms ($\tau=1/f$), 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 $\tau$ of the modulated current we shall take an advantage of power calculation using thermal balance at the electrode stub

$$Q_{fus} + Q_{ev} + Q_{h.ch} + Q_{ov.h} = Q_{e} + Q_{h.dr} + Q_{chem}$$  \hspace{1cm} (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 $Q_{h.dr}$ 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 $Q_{f}$ [12]. It is obvious, that

$$Q_{fus} = Q_{arc} + Q_{f}$$  \hspace{1cm} (8)

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

$$Q_{fus} = V \rho (cT + \lambda) \eta^{-1}$$  \hspace{1cm} (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
The fusion power of one metal drop \( Q_{fus} \) for different diameters of electrodes \( d_e \) are presented in Table 2. This data is similar to the one attained by A. Erochin [13].

The quantity of heat \( Q_i \), exuded on the stub of an electrode by the current of one impulse, is equal

\[
Q_i = \int_0^\tau i^2(t) r_e (t) dt
\]  

(11)

where \( r_e \) is electric resistance of the electrode stub.

It is known, that

\[
r_e = \frac{l_r \rho_s}{\pi r_e^2}
\]

(12)

where \( l_r \) is the length of effective heating of the electrode stub (≤5 mm); \( \rho_s \) is mean specific resistance of the electrode stub (≤3·10\(^{-5}\) Ω·mm); \( \pi r_e^2 \) is cross-sectional area of the electrode.

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

\[
Q_i = \frac{l_r \rho_s}{\pi r_e^2} \int_0^\tau i^2(t) dt
\]

(13)

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

\[
Q_{fus} = 8.18 \int_0^\tau i(t) dt + \frac{l_r \rho_s}{\pi r_e^2} \int_0^\tau i^2(t) dt
\]

(14)

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

\[
\tau_i = \frac{Q_{fus}}{I_p \left( 8.18 + \frac{l_r \rho_s}{\pi r_e^2} \right)}
\]

(15)

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

### Table 2

<table>
<thead>
<tr>
<th>( d_e ), mm</th>
<th>( Q_{fus} ), J</th>
<th>( I_v ), A</th>
<th>( f ), Hz</th>
<th>( I_c ), A</th>
<th>( \tau_p ), ms</th>
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During the pauses of impulses \( \tau_p \) usually a small current \( I_p \approx 50 \text{ A} \) [9, 10]) is used for the support arc burning. In this case average welding current \( I_v \) is equal [5]

\[
I_v = \frac{I_p \tau_p + I \tau_i}{\tau_i}
\]

(16)

where \( \tau_i \) 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 \( f = 1.2I_p/(d_e^2) \).

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.

### References


3. Акулов А.И., Белячук Г.А., Демьянов В.П. Технология и оборудование сварки плавлением.-Моск-
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.