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The Influence of a Welding Current Modulation on Weld Seam Formation

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Introduction

Pulse current is widely used in welding with semi-automatic and automatic welding equipment [1,2]. Lately, the pulse current is more frequently used in manual welding because it has a lot of advantages in comparison to direct current. The main advantages are the following:

- 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 parts being welded;
- to avoid cracks;
- to lower the level of residual stresses and deformation [3,4,9,10].

It is proven that the use of modulated current improves the hygienic part of welding process. In this way the overflow energy of the arc and melting electrode‘s materials evaporation diminishes. The experiments indicate that the intensity of aerosol evaporation is diminished when welding is being carried out on modulated current [6]. The amount of harmful for health hard welding aerosol fraction containing manganese can be considerably diminished.

The pulse current used for welding is produced by upgrading the older arc power sources (ex: ВДУ-504, [5]) or using the newer inverter sources with high-frequency energy exchangers [7,8]. Nowadays arc's power sources form practically any frequency pulse current with needed modulation. For this reason recently the new term is used – welding with modulated current. It is most important to estimate such modulated current‘s parameters influence on weld forming being welded.

Current pulse‘s parameters influence on weld‘s formation

The welding experiments were performed using 10 mm width steel plates; welding was processed using 3.25 mm wide УОНИ-13/45 electrodes, using direct and pulse modulated currents.

High frequency modulated current pulsations (invertors frequency) were taken 20-30 kHz. The lower limit was taken because frequencies higher than 20 kHz are silent and welding transformer and arch practically doesn't cause any noise. The higher limit was taken because above 30 kHz the current‘s flow in wires surface effects and losses increase.

At an initial arc excitation development of a torch of plasma occurs to speed about 10 km/s [12]. Such speed is comparable to speed of a sound in metal. It specifies explosive character of electrons issue. After the beginning of an arc starting speed of development of plasma decreases up to 200m/s, according of Institute of Physics(Lithuania).

The average length of an arc is ~3mm and its width is approximately equal to a diameter of the electrode which is 2.5mm. Proceeding from these datas we conclude, that it is enough 10µs for development of a welding arc. At such and greater pulse duration of a current there is a stable arc excitation.

The partition law of a current density *J* (Fig. 1) is known at a termination of action of a pulse (at disintegration of plasma) [13]:

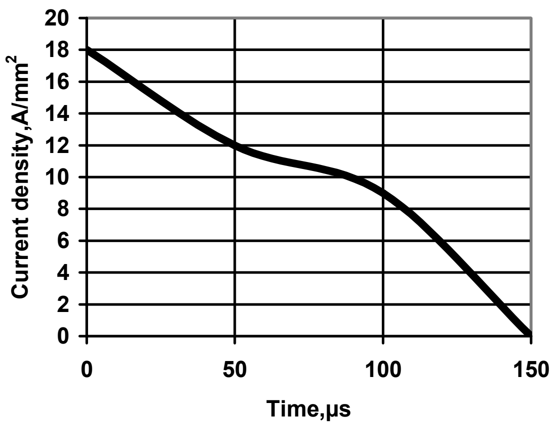

Fig.1. A current density at disintegration of plasma

Apparently from figure 1 after a termination of a pulse residual plasma exists about 150µs. If the pause between the pulses t_p is equal less time of disintegration of plasma the arc does not have time to fade. In this case disappears the need of a repeated arc excitation and there is a stable and steady burning a high-frequency arc. To such criteria satisfies an impulse high-frequency current

(F=20-30 kHz). The pulse ratio Q (relative pulse duration) is equal

$$Q = \frac{T}{t_i};\qquad (1)$$

where T - period of pulses;
t_i - duration of pulses.

Proceeding from a condition of sufficiency of time of development of a torch of plasma (arc excitation) equal 10μs the pulse ratio Q should not exceed 3 at F=30kHz and 4.5 at F=20kHz. Amplitudes of pulses I_i depend on an stated regime of welding i.e. from average welding current I_{ave} (Fig. 2).

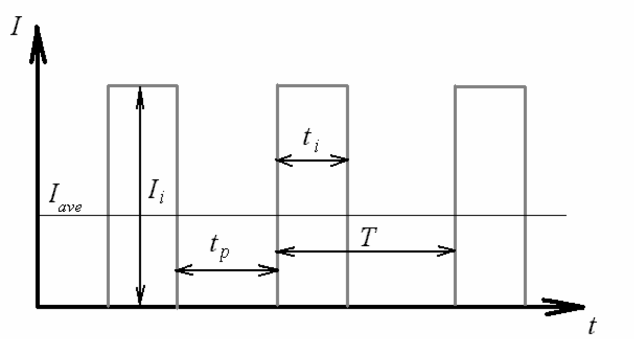

Fig. 2 Graph of pulse current

These parameters of high-frequency pulses are defined and submitted in Table 1.

Table 1. Parameters of high-frequency pulses

F, kHz	20	22	24	26	28	30
T, μs	50	45	42	38	36	33
t_i, μs	11	11	11	11	11	11
t_p, μs	39	34	31	27	25	22
I_{ave}, A	130	130	130	130	130	130
Q	4.5	4.1	3.8	3.5	3.2	3.0
I_i, A	591	537	492	455	422	394

Size of pressure of an arc under the electrode's central part is equal

$$P_C = \frac{I_{eff}^2}{S} = JI_{eff};\qquad (2)$$

where I_{eff} - size of an effective current;
S - the area of an anode stain;
$J = I/S$ - a current density in an anode spot.

At welding by a direct current (DC) an effective value of current I_{eff} is equal to average mean of welding current I_{ave}. Using of an impulse current, I^2_{eff} is equal to product of amplitude of an impulse current on an average current:

$$I_{eff}^2 = I_i I_{ave}.\qquad (3)$$

From here the ratio follows:

$$P_{hi} = P_{lo}\frac{I_i}{I_{ave}};\qquad (4)$$

where P_{hi} - pressure of a high-frequency impulse arc;
P_{lo} - pressure of a DC arc.

Amplitude of pulses I_i is always higher than average current I_{ave}. Therefore pressure of a high-frequency impulse arc is more than pressure of a DC arc at the same size of an effective current. It is possible to conclude, that at increase of a pulse ratio (at corresponding increase of amplitude) pressure of a welding arc will be increased, the pool interlayer under an arc will decrease and depth of penetration will increase.

Explained theoretical premises have proved to be true experimental researches. By help of the hydrometer pressure measuring method (Fig. 3) show that using the mentioned pulsation frequencies arch's pressure increases by ~ 10–15 % as well as arch stability.

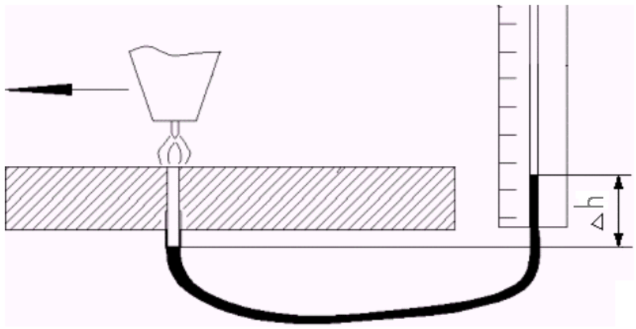

Fig. 3. The current‘s hydrometrical pressure measuring

This was proven by increased welding depth in the middle of weld (~ 10%) as well as arch's disconnection length (~ 50%) using average current of 100-150 A.

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 [2]. 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. The average welding current‘s quantity may be calculated according known equation:

$$I_{ave} = \frac{I_i\tau_i + I_p\tau_p}{\tau_i + \tau_p}.\qquad (5)$$

During the experiments the speeds of welding were changed when welding down using the constant average welding current I_{ave}=130 A. Modulated current‘s pulses duration were taken τ_i=0.005 s and basic pulse current in the moments of pauses I_p=50 A. Pauses of pulses durations were changed from 0.005 s up to 0.025 s. To maintain the constant welding current‘s quantity (I_{ave}=130 A) the pulse current (amplitude) was changes from 210 A up to 520 A. As the result modulated current frequency F changed as shown in Table 2.

Table 2. Parameters of pulse current

I_{ave}, A	130	130	130	130	130
τ_i, s	0,005	0,005	0,005	0,005	0,005
I_p, A	50	50	50	50	50
τ_p, A	0,005	0,01	0,015	0,02	0,025
I_i, A	210	290	370	450	530
F, Hz	100	66,7	50	40	33,3

During the experiments it was established that when using modulated current with such parameters the liquid metal‘s sputtering diminishes from 6-7% to 5%. This is explained by pulses of current helps drops of liquid metal to transfer directly into welding bath. Also, changing the pulse current pauses durations and pulses amplitudes the critical minimum welding speed V_{cr} was established, welding with which the electrode‘s slag does not flow under the arch and enables smooth stable welding process (Fig. 4).

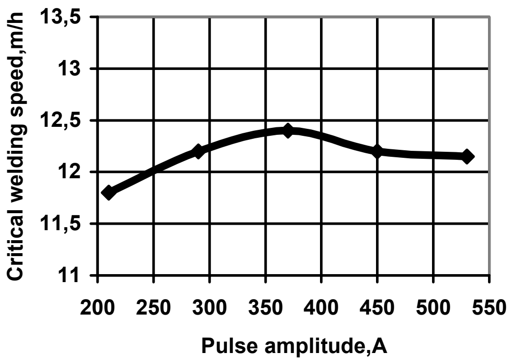

Fig. 4 Critical welding speeds

By increasing the modulated current amplitudes the critical welding speed a little increases although the increase of quality of weld formation was not noticed. Looks like these compared high frequency pulses do not have enough power to hydro dynamically act on liquid metal‘s bath. In general, while welding in vertical or ceiling positions it is very important to keep the liquid metal inside the bath. It is known that static bath‘s equilibrium is acted by forces of gravity and surface tensile stresses. Although it is necessary to take into account the arch pressure force and speed of liquid metal pouring out of welding bath. The metals pouring out of the bath properties are influenced by all of these forces. This controls the bath‘s pouring properties which may be controlled by more powerful modulated current pulses. The power of pulses may be increased by increasing their amplitudes, but at this moment the voltage increases which is limited for safety reasons. For acting on the liquid metal bath the longer duration pulses must be used. These pulses duration may be up to 1 s with frequency F= 1-10 Hz. The welding with such powerful current‘s pulses is called the welding by pulsing arch [1]. At the moment of pulse current pulse the power of arch increases, the amount of melting electrode and main metal increases too and in the moment of pause the partial metal crystallization occurs. Because of that it is possible to control and manage the specimens being welded thermal cycles, to improve the metal structure of weld and metal zone being thermally affected as well as to lower the level of residual stresses and deformations.

Double modulation pulse welding

Double modulation pulse welding source structural scheme is shown in Fig. 5.

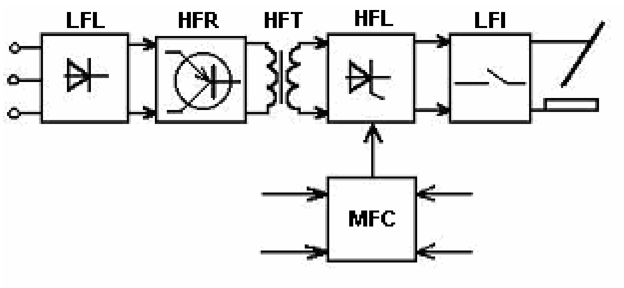

Fig. 5. Power source structural scheme

The voltage is levelled by low-frequency converter LFL and is supplied to the high-frequency converter HFR. The high-frequency alternate current (f=20-30 kHz) is formed here which will be transformed up to welding needed properties. The welding transformer HFT is high-frequency device, therefore it‘s mass and size diminishes more than ten times. High-frequency current is levelled in the block HFL and is supplied to low-frequency interrupter LFI where low-frequency current‘s modulation is formed (F_L=1-10 Hz). Middle-frequency current’s modulation is established in pulse formation control block MFC. Depending on welding’s regime in the part HFL the pulse pauses τ_p and amplitudes I_i quantities are being changed while the steady pulse durations τ_i and basic current I_p remain constant. In this way the steady, fully controlled welding using double modulation current with high-frequency pulsations is obtained.

Conclusions

1. High-frequency modulated current’s pulses f=20-30 kHz increase the pressure in the middle of the arch and upgrade it’s stability and penetration.

2. Middle-frequency current’s pulses F=30-200 Hz control the liquid metal’s transferring lower the level of metal splash from 6-7 % to 5 %.

3. Low-frequency modulated frequency’s pulses F_L=1-10 Hz (the ache’s pulses) influence on the liquid metal’s bath and weld formation, improve its metal structure, lower the level of deformations and possibility of appearance of cracks.

4. When welding with modulated current in up-down direction it is possible to use the common electrodes with basic cover. It increasing welding speed.

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J. Ščemeliovas. Suvirinimo srovės moduliacijos įtakos siūlės formavimui tyrimas // Elektronika ir elektrotechnika.- Kaunas: Technologija, 2004. - Nr. 2(51). –P. 33-36.

Straipsnyje nagrinėjama impulsinės srovės įtaka siūlės formavimui. Nustatyti impulsinės srovės pranašumai, palyginti su pastovia nuolatine srove.

Nustatyta, kad aukštadažniai srovės impulsai padidina lanko slėgį, jo stabilimą ir pralydymą. Vidutinio dažnio srovės impulsais galima valdyti elektrodinio metalo pernešimą, sumažinti jo ištaškymą. Žemadažniai srovės impulsai (pulsacijos) veikia skysto metalo vonelę, pagerina siūlės formavimą ir struktūrą. Il. 5, bibl. 13 (anglų kalba; santraukos lietuvių, anglų ir rusų k.).

J. Ščemeliovas. Reasearch of Welding Current Modulation Influence on Weld Seam Formation // Electronics and Electrical Engineering.- Kaunas: Technologija, 2004. – No. 2(51). –P.33-36.

The influence of a welding current on formation of weld is considered in the article. The advantages of welding by the modulated current are found out in comparison with welding by a direct current.

It is determined that the high-frequency pulses of a current increase pressure of an arch, its stability and penetration. The pulses of a current of average frequency operate carrying of electrode metal and reduce sputtering. The low-frequency pulses of a current (pulsation) influence liquid welding bath, improve formation of the seam and its structure. Ill. 5, bibl. 13 (in English; summaries in Lithuanian, English and Russian).

Е. Щемелевас. Исследование влияния модуляции сварочного тока на формирование шва // Электроника и електротехника.- Каунас: Технология.- 2004. -№ 2(51). –С. 33-36.

Рассматривается влияние модуляции сварочного тока на формирование шва. Выяснены преимущества сварки импульсным током по сравнению со сваркой постоянным током.

Определено, что высокочастотные импульсы тока увеличивают давление дуги, ее стабильность и проплавление. Импульсы тока средней частоты управляют переносом электродного металла и уменьшают его разбрызгивание.

Низкочастотные импульсы тока (пульсации) действуют на жидкую сварочную ванну, улучшают формирование шва и его структуру. Ил. 5, библ. 13 (на английском языке; рефераты на литовском, английском и русском яз.).