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Procedure of Calculating the Parameters of the Inter-Pulse Period in Pulsed Arc Welding

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Abstract. The procedure of calculating the parameters of the inter-pulse period such as current strength, electrode supply speed and time length is presented in the paper. Their importance for the stable arc burning is demonstrated. The authors address to the inter-pulse period parameters, influencing on the temperature of the electrode in the device, where the inter-pulse current is used for heating the electrode. The data of calculations are confirmed in the process of experiments. The appropriate parameters of pulsed arc welding with preheated electrode extension are identified; the stability of the process is tested experimentally: impulse frequency, inter-pulse period, arc voltage during the inter-pulse period, speed of electrode supply, current of the inter-pulse period.

1. Introduction

Improving power efficiency of arc welding is still the urgent issue. As you know, arc welding is distinguished by considerable power consumption. Pulsed arc welding has an effect on power inputs into the welded item. However, the process of generating the modulated current requires power inputs, necessary for heating ballast resistances when decreasing welding current during the inter-pulse period.

As the results of using this process together with the robot the number of parameters is increased, their balance can hardly be detected practically; therefore, this problem requires application of mathematical modeling [1].

The researchers are currently focusing on modeling such processes as geometrical characteristics of the drop [2], modeling the origination of residual stresses [3]
when welding.

2. Description of the device

The authors have designed a device [4] (Figure 1), where a section of the electrode before the contact tip is used as a resistance, decreasing current up to 30-50A (inter-pulse period current) to improve the energy efficiency of pulsed arc welding. So it is possible to utilize the heat efficiently, which used to be emitted on the ballast resistance, causing, this way, power losses. When applying this device the amount of heat, emitted in the process of current decreasing during the inter-pulse period, is used for preheating the electrode [5] section between two contact tips. Therefore, less energy is required for melting and transfer of electrode metal drop in the pulse.

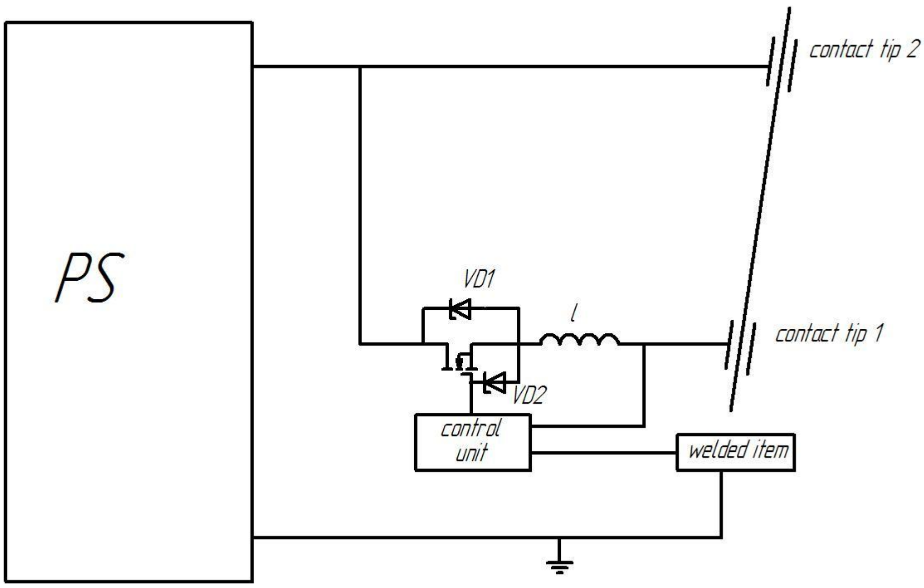

Figure 1 – Layout of the device
where: PS – power supply
VD1 – fuse diode of the overvoltage;
VD2 – protection from the input transient processes;
l – choke.

As there are more parameters in pulsed arc welding as against arc welding, it is quite difficult to identify the interrelation between these parameters. In the proposed device we use the electric circuit “contact tip – electrode extension”, which influences on the process of welding as well. Since overheating and rupture of the electrode are possible in the unstable process, it is absolutely necessary to assess importance of various parameters for the electrode section.

The stable arc burning is also an essential factor, because its behavior during the inter-pulse period (low current) depends on the arc voltage, which can’t be below the critical value.

This work is aimed at developing the procedure to calculate electrode preheating and assign on its base the parameters of inter-pulse current and length.

3. Methods of Research

The inter-pulse parameters in pulsed arc welding with preheating the electrode extension by the inter-pulse current were adjusted according to the following criteria:

- temperature of pre-heating;
- stable arc burning.

The adjustment of the inter-pulse parameters in pulsed arc welding with pre-heating the electrode extension by the inter-pulse current required revealing the importance of welding mode parameters for pre-heating the electrode and stable burning of the arc. The results of experiments demonstrated the process involving pre-heating the electrode up to 680°C is the most power efficient. The rise of the temperature results in high temperature tempering [6], being the cause of electrode jam before the second contact tip. At temperatures below 500°C there is decrease in the power efficiency. Stable arc burning is to be assessed as well. Burning fails to be stable at arc voltages below 20 V [7]. Let us assume arc voltage is 22 V. The experiments to find out appropriate inter-pulse parameters are carried out in these conditions.

A model for calculations, given in Figure 2, is proposed to carry out experiments. The following assumptions are made for this model:

- electrode supply is stopped when heating the electrode and during the inter-pulse period;

- electrode is moved during the pulse time only, passing the length equal that of the complete cycle time;

electrode is heated by the passing current only, thermal conductivity is not taken into account due to the quickness of the process.

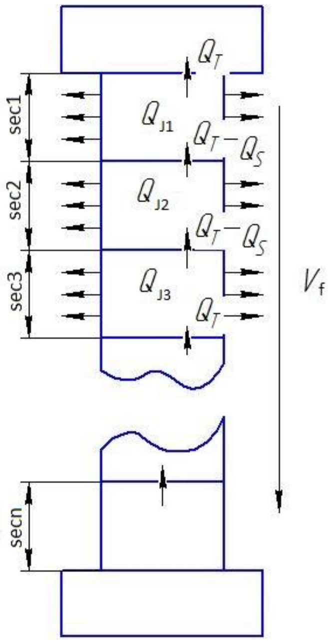

Figure 2 – A model to calculate pre-heating the electrode
Q_J – heat emitted by the passing current;
Q_T – heat consumed for thermal conductivity;
Q_S – heat consumed by surface heat emission;
vector V_f – electrode supply direction

The number of sections, the electrode between the contact tips is divided into, is dependent on the impulse frequency, electrode supply speed, and the length between two contact tips. The length between the contact tips is constant and assigned 0.4 m. Shortening the length deteriorates the effect of electrode extension pre-heating, while its elongation necessitates increasing the device dimensions. The impulse frequency is assigned 100 Hz for the purpose of calculations. Further calculations require variation of the inter-pulse period only. The electrode supply speed has a considerable effect on the temperature of pre-heating.

Physical and mechanical parameters (thermal capacity, hardness, and temperature of phase transformations) of the electrode 08Mn2Si with the diameter 1.2 mm are assigned constant for the purpose of calculations. The resistance of the electrode and its heat emission vary according to the changing temperature. All these parameters are calculated automatically in the model.

The authors do not take into consideration the gas-dynamic impact on the drop unless the model becomes more complicated [8].

The electrode is pre-heated according to Joule-Lenz law [9]. The pre-heating can be varied via changing the inter-pulse current.

Three key parameters influencing on the electrode pre-heating and its stability are ascertained.

Each parameter has a designation:

1. Inter-pulse current X
2. Electrode supply speed Y
3. Inter-pulse period Z

Table 1 provides the variability intervals with the pre-set step of parameters X, Y and Z.

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Table 1. Variability intervals of the parameters

Variability interval of the parameters	The step of parametric variation
30<X<40	ΔX=5
400<Y<650	ΔY=50
5<Z<10	ΔZ=1

When planning the experiments the complete factorial experiment is used [10]. Since it is difficult to measure the temperature on the moving section of the electrode when welding, the experiments were carried out relying on the mathematical model. This model makes it possible to assess resistance vs. changing temperature, thermal conductivity, and power losses for convective and radiant heat exchange. A fragment of the model cycle is presented in Figure 3 to calculate pre-heating of the electrode section.

$$
\begin{aligned}
&R1 \leftarrow \alpha \cdot Rv \cdot T \\
&R \leftarrow R + R1 \\
&Q1 \leftarrow I2^2 \cdot R \cdot t \\
&Q2 \leftarrow 1.5(T - 20) \cdot t \cdot s2 \quad \text{if} \quad T > 100 \\
&Q2 \leftarrow 0.5 \cdot [(T - 20) \cdot t \cdot s2] \quad \text{otherwise} \\
&Q4 \leftarrow Q1 - Q2 \\
&\Delta T \leftarrow \frac{Q4}{c \cdot m} \\
&Q3 \leftarrow k \cdot s \cdot \frac{\Delta T \cdot t}{lvileta} \\
&Q \leftarrow Q1 - Q2 - Q3 \\
&\Delta T \leftarrow \frac{Q}{c \cdot m} \\
&T \leftarrow T + \Delta T
\end{aligned}
$$

Figure 3 – A cycle to calculate the electrode pre-heating in the software MathCAD electrode

This model makes it possible to calculate the temperature on each section (Figure 4). However, for the purpose of experiment we use the temperature in the last point (400 mm). The temperature is always maximal in this point. As one can see, this is not a linear dependence because of the changing electrical resistance and heat emission when increasing the temperature.

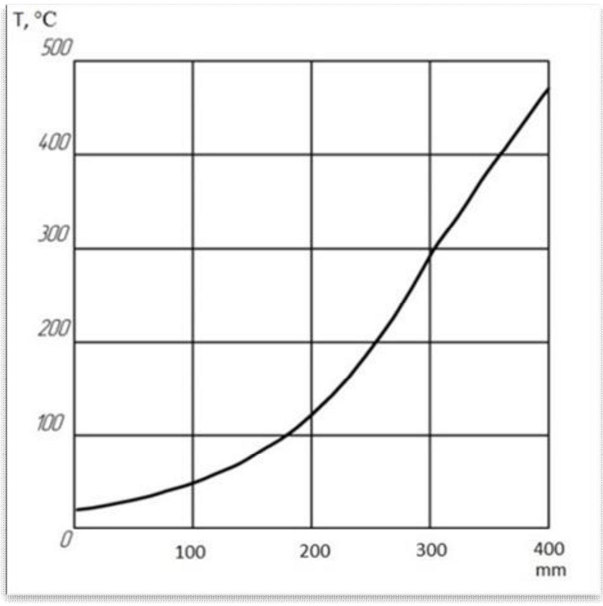

Figure 4 – The plot of temperature distribution when pre-heating the electrode wire between the contact tips 2 (point 0) and 1 (point 400 mm)

The results of numerical experiments involving the mathematical model obtained at various values of current strength, electrode supply speed and inter-pulse period are given in Figures 5, 6 and 7.

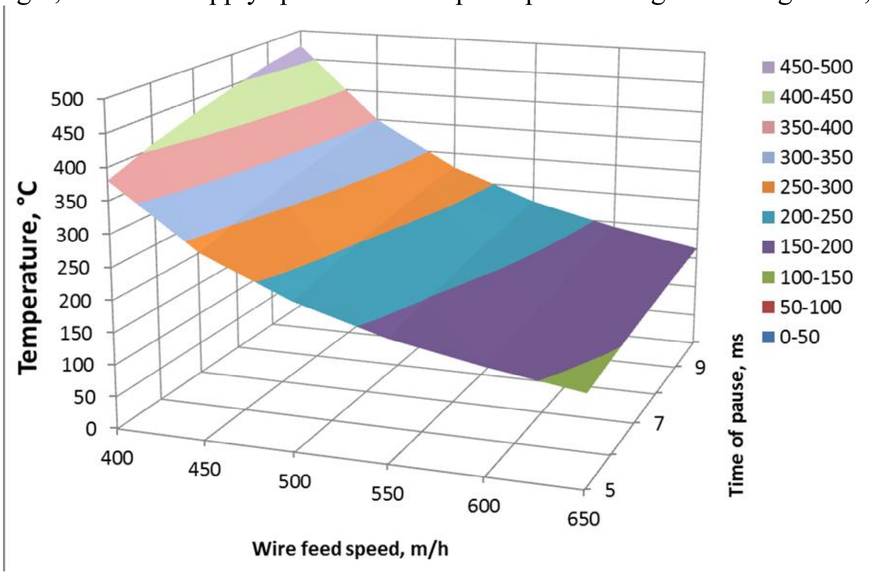

Figure 5 – The dependence of the electrode extension temperature on the supply speed and inter-pulse period, inter-pulse current 30 A

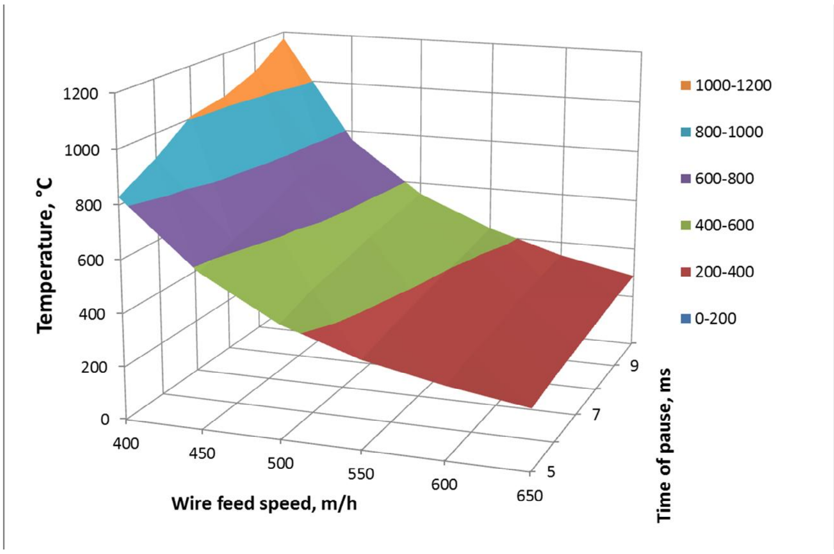

Figure 6 – The dependence of the electrode extension temperature on the supply speed and inter-pulse period, inter-pulse current 35 A

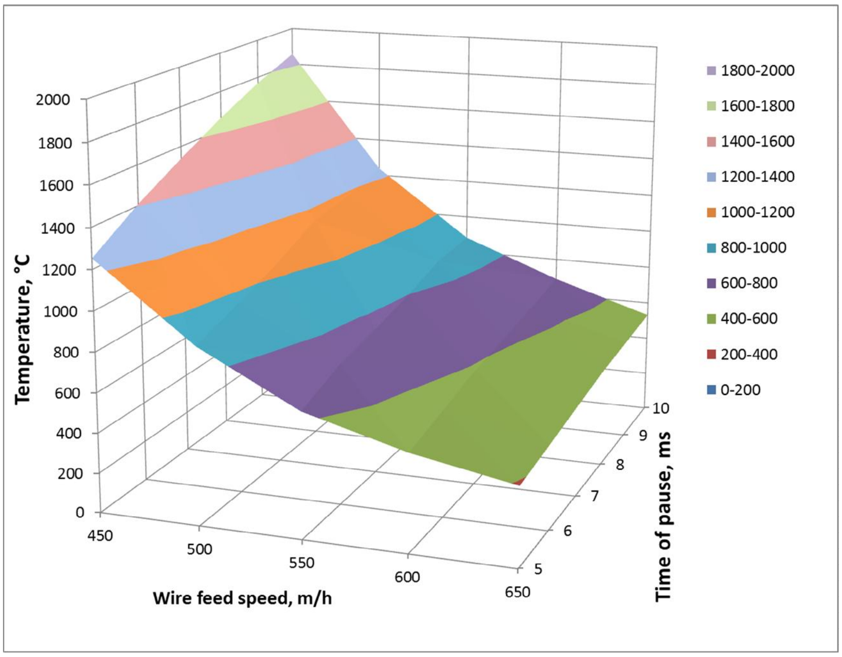

Figure 7 – The dependence of the electrode extension temperature on the supply speed and inter-pulse period, inter-pulse current 40 A

The authors have detected the influence of appropriate modes on the stable arc burning. The resistance drop is determined on the electrode extension and arc-drop voltage drop is measured.

The resistance of free running is assigned 80 V. Therefore, resistance drop on the electrode and on additional resistance can't exceed 58 V. Voltage drop is calculated as the product of current strength and resistance. The resistance of the full electrode extension between two contact tips is the sum of resistances on all its sections.

On the average, the resistance of 400 mm extension is 0.06 ohm at the temperature of 600°C before the second contact tip. The voltage drop of the electrode on the whole is 1.9 V.

The experimental research into pulsed-arc welding is carried out by the device described above. The appropriate parameters of welding are assigned: impulse frequency – 100 Hz; inter-pulse period – 7 ms; arc voltage during the inter-pulse period – 22 V; electrode supply speed – 600 m/h: inter-pulse current strength – 40 A.

Current and voltage oscillograms of pulsed-arc welding with electrode pre-heating by the inter-pulse current are given in Figure 8. Arc burning is stable over the whole range to be changed. The distinctive feature of the process is arc burning on the convex weld pool surface. Short impulses with the reduced amplitude can not cause the change in the arc length.

Figure 8 – Current (100 A/segment) and voltage oscillograms (20 V/segment) of pulsed-arc welding (contact tip distance l=400 mm)

Planning and carrying out the experiment on the base of the mathematical model helps to reduce its time and costs. Results assessment of the mathematical experiment provides the information for improvement of the device without causing its failure in case of wrongly adjusted parameters.

3. Conclusions

1. The appropriate modes of the inter-pulse are determined in the course of experiments and their influence on the process stability is determined. Three key parameters are identified which have an effect on electrode pre-heating and its stable behavior: speed of electrode supply, inter-pulse period and current.

2. The appropriate parameters of the inter-pulse current and time are assigned on the base of the proposed model for calculating the electrode pre-heating (impulse frequency – 100 Hz; inter-pulse period – 7 ms; arc voltage during the inter-pulse period – 22 V; electrode supply speed – 600 m/h: inter-pulse current strength – 40 A).

3. When pre-heating the electrode up to 600°C less power is required to melt the electrode and transfer the drop of electrode metal, this is made obvious by decreased amplitude and time of current pulses.

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