Pulsed welding plasma source

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Abstract. It is shown that in order to form the current pulse of a near rectangular shape, which provides conversion of the welding arc into a dynamic mode, it is rational to connect a forming element made on the basis of an artificial forming line in series to the welding DC circuit. The paper presents a diagram of a pulsed device for welding with a non-consumable electrode in argon which was developed using the forming element. The conversion of the arc into the dynamic mode is illustrated by the current and voltage oscillograms of the arc gap and the dynamic characteristic of the arc within the interval of one pulse generation time in the arc gap. The background current travels in the interpulse interval.

1. Introduction

Argon-arc welding with a non-consumable electrode provides a high weld quality when constructing metal structures for critical applications. One of the disadvantages of this method is low melting capacity. Various methods and means to eliminate this disadvantage can be found in literature. The dynamic mode of arc burning is among them. This method allows an increase in the melting capacity by 25…30 % [1] with a more concentrated heat input into the product, in comparison with the conventional welding mode. This improves weld formation and mechanical properties of the welded joint.

It is known [1, 2] that in the dynamic mode of arc burning the pulse duration is to be less than 450 μs. The resumption of the electric discharge occurs through gas molecule ionization in the arc gap. When the arc is powered by short-time current pulses with a steep front and edge, ionization processes leg behind the change in the current, and the arc discharge does not become steady. This process provides a contracted arc column and anode spots adjacent to the column. The arc discharge in the dynamic mode is characterized by a greater density of the energy input into the product and greater melting capacity if compared with those of the arc discharge by a stationary arc with the current equal to the average current of the dynamic mode. Since the concentration of the heat input in the product in the dynamic mode is greater due to the arc energy parameters without auxiliary structures and devices used, the study of this discharge for practical purposes is of great interest.

The lack of technical means for implementation of the dynamic mode of arc burning hinders its wide application.

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2. Theoretical analysis

The analysis of the scientific literature showed that the energy storage of the electrical network and its further conversion into the welding current pulses can be provided by chemical elements; a centrifugal mass; magnetic elements; coaxial cables and forming lines.

Electrochemical energy storage devices utilize the energy from chemical reactions for energy storage and regeneration [3]. When using an accumulator, the energy is accumulated due to the chemical reactions between the electrodes immersed in the electrolyte solution. The upper limit of the currents flowing through the accumulator is equal to 300 A. To use the accumulator as the energy storage device, for the dynamic mode of arc welding in particular, is not rational due to the increased heat losses and consequently low efficiency if compared to the stationary mode and other energy storage devices.

The rotating masses are most economical in comparison with capacitors and inductors. The accumulation of energy in the inductive load occurs in two stages: 1) the prime mover of small capacity accelerates the rotor of the impact-excited generator up to the nominal speed; 2) the impact-excited generator converts the stored kinetic energy into the electromagnetic one and transmits it to the inductive load. The losses of the rotating mass energy are insufficient if compared with the transmitted energy, i.e. the efficiency of the charging unit is high, and the weight-size parameters of the system are large.

A homogeneous artificial forming line (*AFL*) is of great importance in creation of the current pulse which provides the dynamic mode of arc burning [4, 5].

The line (Figure 1) consists of L_c and C_c cells with equal inductance values of chokes L_c and capacitances C_c. When analysing the processes occurring in this line, the resistance of the chokes is typically taken into account and the losses in the capacitors are neglected.

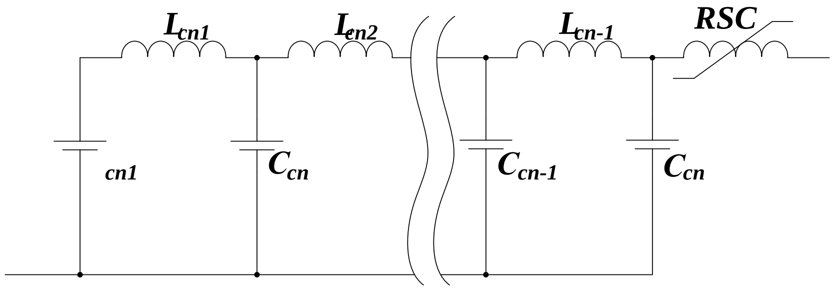

Figure 1. Equivalent circuit of the homogeneous artificial line.

In this system, the capacitor is charged through charging choke L_o and the charge thyristor, and discharging to the arc gap is carried out through the discharge thyristor. The discharge of this line produces rectangular pulses with a steep front and edge. The disadvantage of the system is a limited pulse formation frequency due to a sufficiently long phase of capacitor pre-charging and possible occurrence of the through current which causes failure.

In addition to the *AFL*, coaxial cables or stripline circuits can be used as a device for pulse formation and energy storage [7]. Such lines are used to generate pulses of nanosecond duration. However, their practical application is attended by structural difficulties; limited duration (from 20 ns to 0.5 μs); low operating voltage.

3. Practical implementation

To eliminate the identified shortcomings, the discharge of the forming element (*FE*) and its recharge are to be combined within the time of the pulse current travelling through the arc gap. For this purpose, the *FE* is included in the diagonal of the bridge converter, and the other diagonal of the

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bridge converter is connected in series with the welding arc to the external circuit of the constant current source.

A functional diagram of the developed experimental model of the power system is presented in Figure 2 [6].

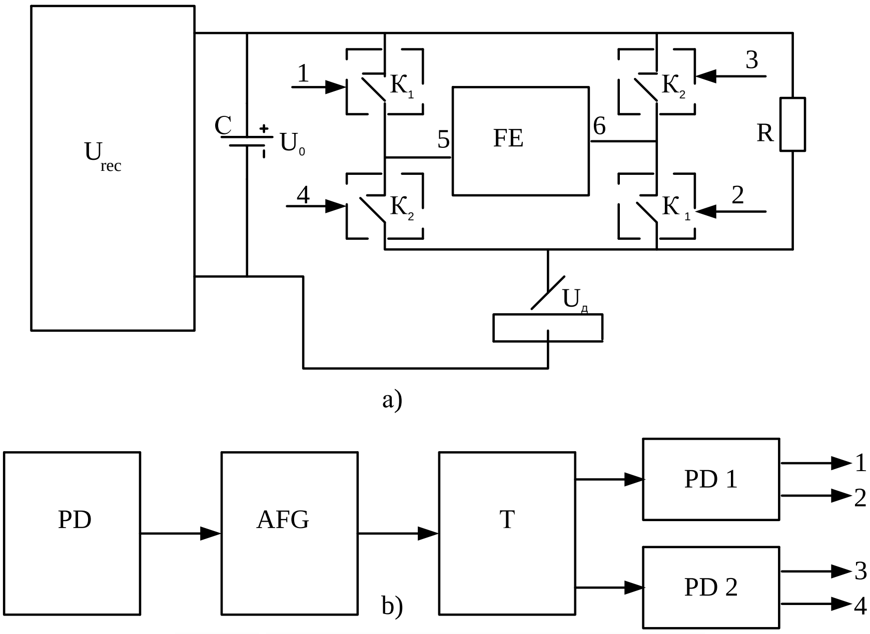

Figure 2. A functional scheme of the device.

The device consists of three-phase rectifier U_{rec} with a rigid external characteristic and regulated open circuit voltage. To reduce the internal resistance to output terminals U_{rec}, the capacitor bank of high capacitance *C* is connected.

The connection of the *FE* to the diagonal of the bridge and presence of capacitor bank C allows for *FE* recharging from the opposite polarity through the arc gap, in the sequential opening of key pairs $K_1 – K_1$and $K_2 – K_2$, without pre-charging from the power supply unit.

To ensure the arc continuity within the inter pulse interval, the interval is shunted by resistor *R* to provide the background current flow through the arc gap. The range of the background current values is limited by a minimum value (requirements for the arc physical stability and protection), and by a maximum value (technological requirements).

The power supply unit (*PSU*) supplies power to the control circuit. The frequency of the device operation is determined by the adjustable frequency generator (*AFG)* capable of varying frequency from a few hertz to several thousand hertz with a corresponding decrease in the welding current pulse width. The sequence of pulses from the generator is supplied to the input of the T-trigger to divide the frequency by two. The pulse sequence frequency is two times less than the adjustable generator frequency, and the pulses shifted relative to each other by the period of the generator pulse frequency are fed to keys $K_1 – K_1$ and $K_2 – K_2$from the two outputs of the T-trigger.

The *AFL* consisting of n-th number of cells is used as a forming element of the *FE* (Figure 3).In turn, each cell consists of series-connected capacitor C_c and choke L_c.

The last cell choke is designed as a rapidly saturated choke (*RSC)* with the core having are ctangular magnetization curve, and the inductance in a saturated state is equal to the inductance of the cell chokes.

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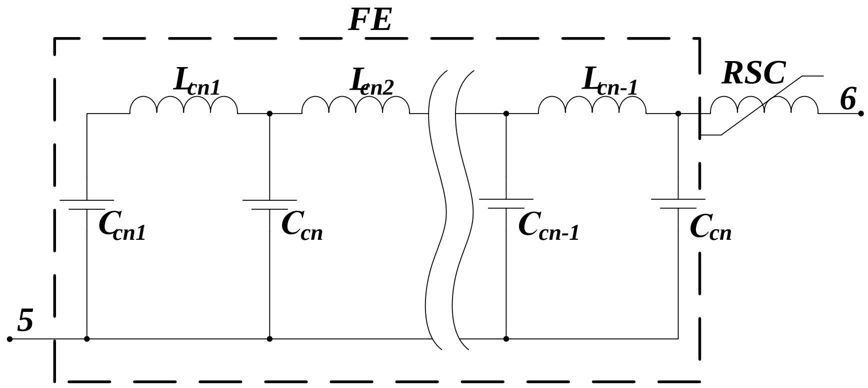


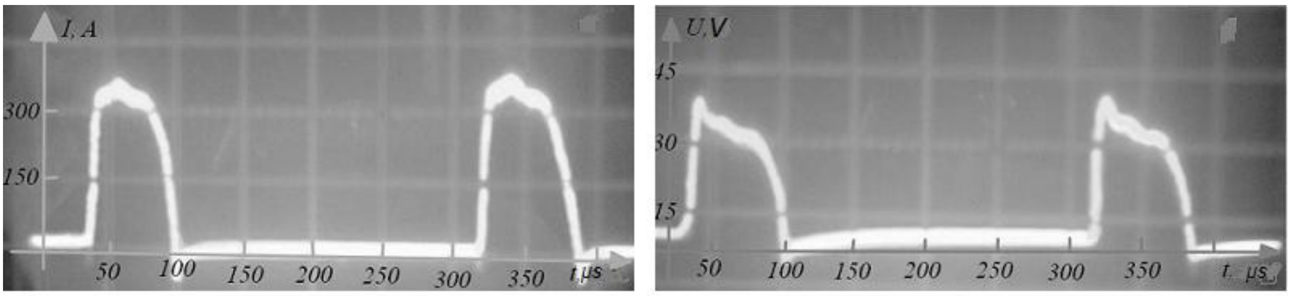
Figure 3.A forming element

The device operates as follows. When feeding the control pulses to keys K_1 – K_1 located in the opposite arms of the bridge, the lower plates of capacitors C_c are negatively charged and the upper plates of the *AFL* capacitor are positively charged. Capacitor bank *C* is always charged from rectifier U_{rec} with the upper plates being positive. When keys K_1 - K_1 are opened under total power supply voltage U_{rec} and the voltage of charged capacitors C_c, the *AFL* is recharged as follows: rectifier U_{rec} (plus) – key K_1 – *FE* – *RSC* – key K_1 – arc gap (between the product and the electrode) – rectifier (minus). When recharging is completed, capacitors C_c change their polarity: the lower plates become positive, and the upper plates become negative.

When keysK_2 – K_2 are opened, the recharging process of the *AFL* is similar to the recharging process with keysK_1 – K_1 opened. In this case, unipolar current pulses travel through the arc gap.

The energy is transferred from the device to the welding arc via the coaxial cable to reduce the welding circuit inductance. The oscillogram of the welding process was recorded by a non-inductive shunt.

Figure 4 shows typical oscillograms of one of the dynamic arc welding recorded under the following parameters: the arc length (distance from the electrode end to the plate surface) was maintained equal to 3.5 mm. The welding conditions were as follows: I_p = 320 A; *Iii* = 16 A; pulse duration was 70 μs; U_p = 32 V. The tungsten electrode had a spherical surface that enhances the operational life and did not violate the spatial stability of the arc column in the dynamic burning mode. The pulse frequency of the welding current was 3.3 kHz.



a b

Figure 4. Oscillograms of *a* – arc current pulse, and *b* – arc voltage.

The current pulse amplitude in the welding circuit was determined by [3]:

$$I_p = \frac{U + U_c - U_d}{2\rho};$$

Where U, U_c, U_d are voltages of power supply U_{rec}, the *AFL* charge, and the arc gap, respectively; $\rho=\sqrt{L_c/C_c}$ is the *AFL* impedance; L_c is the choke inductance of the *AFL* cell; C_c is the capacitance of the *AFL* cell capacitor.

The superimposed oscillations occur at the top of the current pulses; the number of oscillations depends on the number (n) of the *AFL* cells. The value of the first maximum spike of the current and voltage oscillations [3] is virtually independent of the number of the *AFL* elements and it is determined by the parameters of the first cell. However, due to severe requirements for the constancy of the pulse peak, the peak is to be corrected. [3]. A rapidly saturated choke is used for the first oscillation spike reduction and smooth transition from the background current to the pulse (at low currents). The active duration of the current pulse to be formed is [3]:

$$t_p = 2,2n\sqrt{L_c \cdot C_c}\ ;$$

where n is the number of cells in the forming line.

The high rate of the current rise and arc voltage assumes that the arc behaves like active resistance within the edge pulse interval. When the current of the pulse peak arc is conventional dc, the voltage drops smoothly due to the development of the ionization processes in the arc column. The properties of the arc column as nonlinear energy storage are observed at the pulse edge. A large number of charge carriers in the arc column facilitate the transition of the arc column voltage to the negative region. This owes to the fact that the number of charge carriers from the power supply required to provide the background current flow should be less than the number of carriers in the arc column volume.

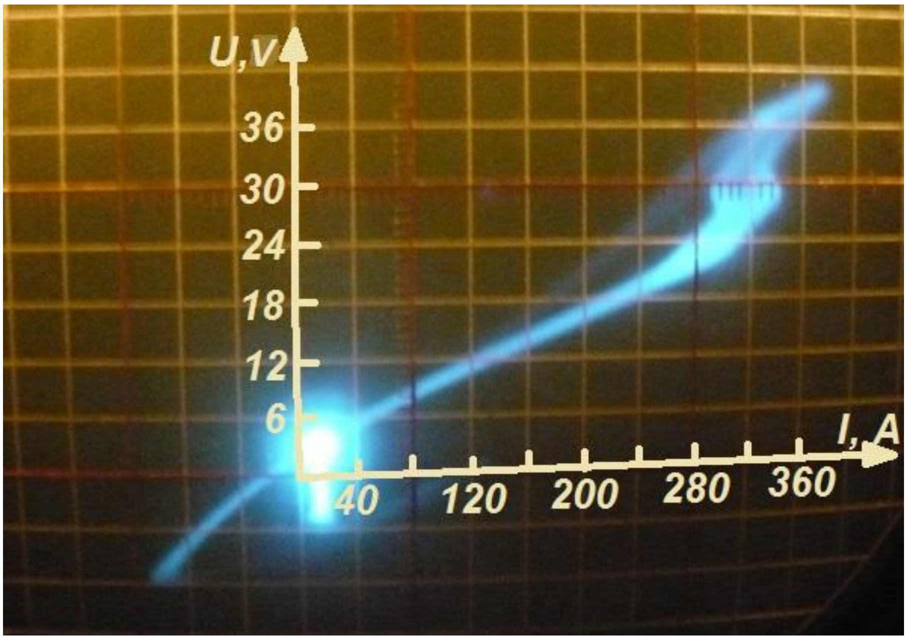


Figure 5. A dynamic volt-ampere characteristic of the arc.

The dynamicvolt-ampere characteristic(DVAC) of the arc presentedin Figure 5indicates a dynamic mode of arc burning, which causes the hysteresis. The upper branch of the DVAC correspondsto thepulse front edge, but the branch cannot be clearly seen on the oscilloscope screen because of the rapidrise of the currentandarc voltage. The lower branch of the DVAC corresponds to the pulse edge.

4. Conclusion

The pulsed device, consisting of a bridge converter with the *AFL*-based forming element connected to one of its diagonals, which is connected in series with the welding circuit, enables generating welding current pulses of a near rectangular shape, provides a dynamic mode of arc burning, and increases its reliability.

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The proposed circuit of the power unit increases the frequency of welding current pulse generation through combining the charging and recharging processes of the *AFL* during the welding current pulse.

The proposed circuit, if compared to known circuits, enhances the *AFL* efficiency with the same cell parameters through generating current pulses under the total effect of the power supply and pre-charged capacitors of the homogeneous artificial line to increase the current amplitude.

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