

# Control of the electrode metal transfer by means of the welding current pulse generator

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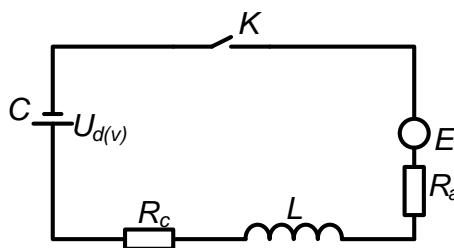
**Abstract.** The paper presents a generator of welding current pulses to transfer an electrode metal into the molten pool. A homogeneous artificial line is used to produce near rectangular pulses. The homogeneous artificial line provides the minimum heat input with in the pulse to transfer the electrode metal, and it significantly decreases the impact of disturbances affecting this transfer. The pulse frequency does not exceed 300 Hz, and the duration is  $0.6 \div 0.9$  ms.

## 1. Introduction

A number of power supplies have been developed for pulsed arc welding with a consumable electrode. They are made as separate pulse generators, which operate in aggregate with standard power supplies or in combination with a normal power supply [1, 2].

The easiest way to form welding current pulses is by means of direct or transformed discharging current or a capacitor bank of charging current through the arc space.

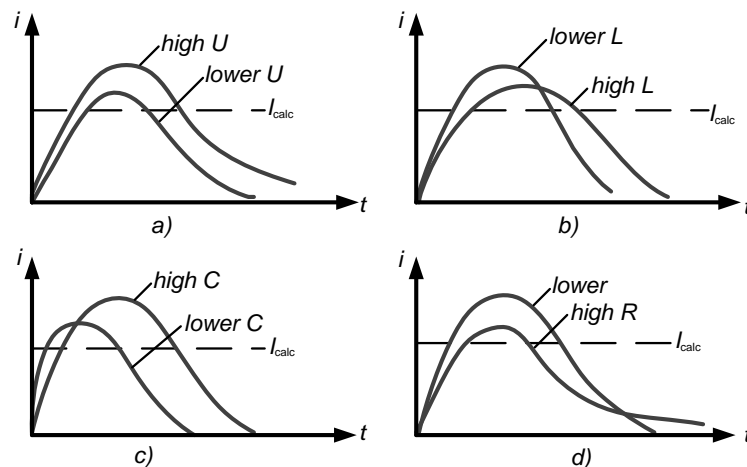
Figure 1 shows an equivalent circuit to form welding current pulses in this type of devices.



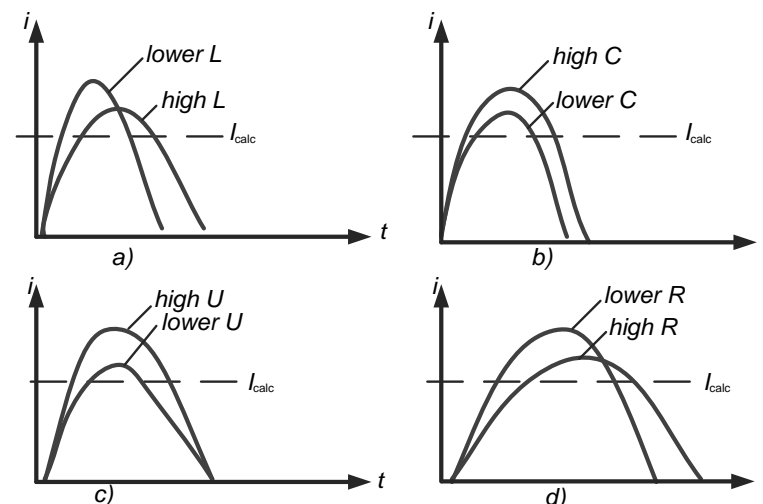
**Figure 1.** An equivalent welding current pulse-forming circuit, where  $L$  is the total inductance of the circuit;  $C$  is a capacitor bank;  $K$  is a half-controlled switching device;  $U_{d(v)}$  is capacitor charge voltage;  $R_c$  is circuit resistance,  $R_a$  is arc resistance.

When welding with a consumable electrode in shielding gas environment, the arc static characteristic is of a restoring character. In the working area, it may be represented in the form of emf and arc resistance  $R_a$  connected in series.

The process occurs in a decaying oscillatory or aperiodic manner, which depends on the circuit parameters. The pulse amplitude in these devices is adjusted by changing the capacitor charge voltage, and the pulse length is adjusted by changing the capacitance value or inductance that simultaneously affects the current pulse amplitude [3].



**Figure 2.** Dependence of the aperiodic discharge current waveform on adjustable parameters; a) capacitor voltage, b) inductance, c) capacitance, d) real resistance.



**Figure 3.** Dependence of the current waveform on adjustable parameters under decaying oscillatory discharge; a) inductance, b) capacitance, c) capacitor voltage, d) real resistance.

Figures 2 and 3 show the curves of the current change over time and the impact of the change in one of the variables on the current curve for aperiodic and oscillatory processes, respectively.

The required pulse amplitude of the welding current, which detaches a droplet from the electrode, is determined by equation

$$I \geq 2\pi \cdot \sqrt{\frac{4.2(T_{cr} - T_e) \cdot R_e}{\left(\frac{M}{\gamma}\right)^{\frac{2}{3}} \mu_0 \cdot \ln\left(\frac{R_c}{R_e}\right)}}$$

where  $T_{cr}$  is critical temperature of the metal electrode wire, °K;  $T_e$  is a melting point of the metal electrode wire, °K;  $R_e$  is an electrode wire radius, m;  $M$  is molecular weight of the metal electrode;  $\gamma$  is specific weight g/cm<sup>3</sup>;  $R_c$  is an arc column radius, m.

To enhance the stability of the electrode material transfer, the current pulse amplitude value should have a 1.2 ... 1.3 time increase (1), i.e.

$$I = (1.2 \div 1.3) I_{calc}$$

In case of large disturbances in the arc voltage, the pulse amplitude is to be increased.

Figures 2 and 3 show a conventionally plotted horizontal line corresponding to the calculated value of the desired pulse amplitude value. The time during which the current pulse has an effective impact on the molten metal at the end of the electrode is determined as the time during which the pulse current exceeds the calculated current value.

Figures 2 and 3 demonstrate that the total pulse duration measured at the base does not provide data on the time of the effective impact on a droplet. This may explain a wide spread of the values of pulse duration required for droplet detachment in the published data, as it is determined as the total duration of the pulse at the base.

As can be seen in Figures 2 and 3, a change of a single parameter causes a change in both amplitude and duration of the welding current pulses, therefore, the amplitude and duration of the current pulses cannot be controlled independently.

To obtain a uniform criterion when assessing the current pulse duration required for detachment of a droplet, it is recommended to use the concept of the active current pulse duration for any pulse shape. It is to be formed for the current value equal to the calculated current value.

According to the suggested criterion, the active duration of a sinusoidal current pulse is 0.378 ... 0.445  $I$  of the total duration. Due to the pulse, undesirable heat input into the product occurs within the rest of the time, which deteriorates the quality and energy data of welding.

A major shortcoming of sine and aperiodic current pulses is insignificant front and edge steepness. Under the impact of external disturbances, such kind of steepness disturbs the transfer stability as the active duration changes significantly (this pulse shape is not optimal).

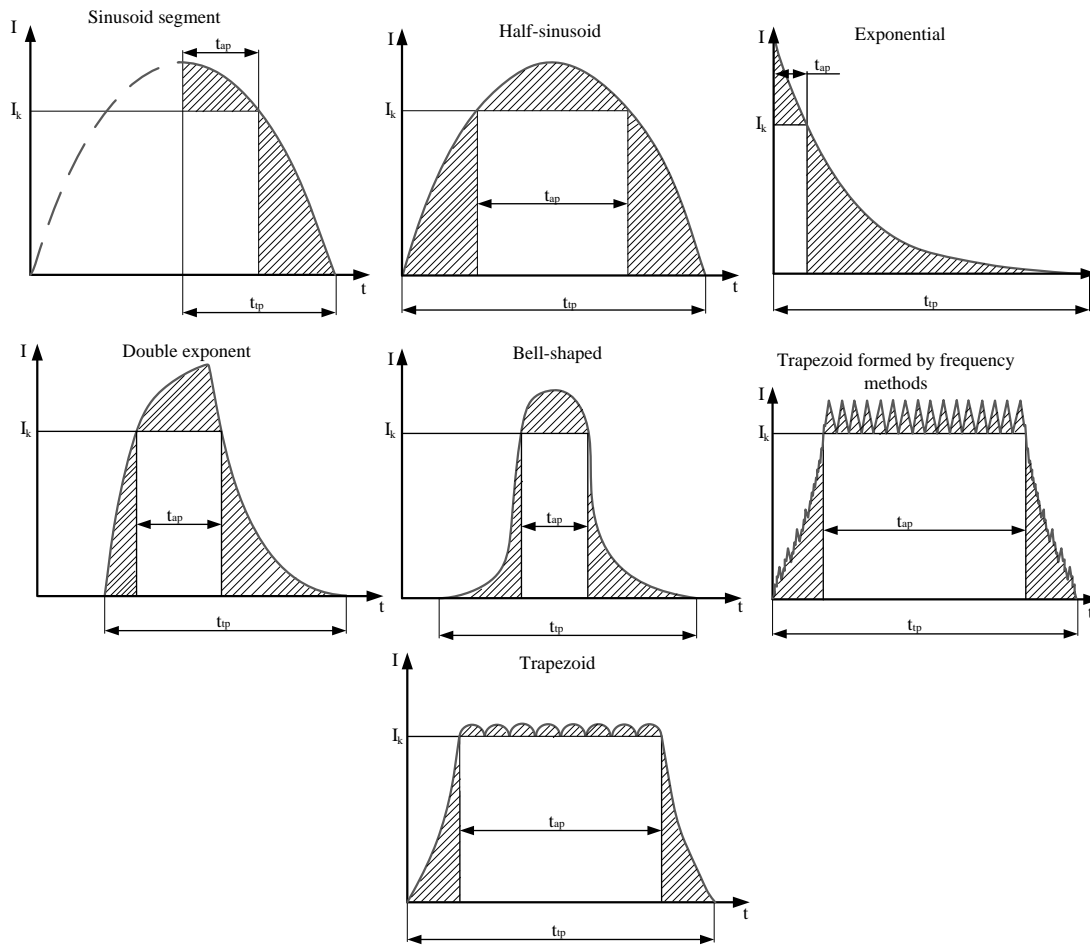
Figure 4 shows the shapes of the welding current pulse, which can be formed depending on the principles and techniques used.

A horizontal line plotted in Figure 4 corresponds to the calculated value of the current pulse amplitude.

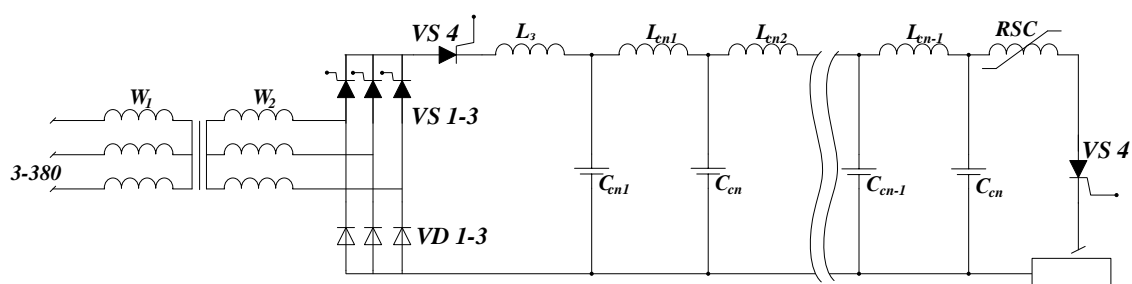
The analysis of the presented pulse shape shows that virtually all of the pulses introduce the energy in the arc space, which exceeds the energy required to detach a droplet and accelerate its transfer to the molten pool. In Figure 4, it is shown in shaded areas. Trapezoidal pulses are the most preferable to this effect. The active duration of these pulses  $t_{ap}$  under the calculated pulse amplitude of the welding current pulse significantly differs from total pulse duration  $t_{tp}$ . Hence, it can be concluded that for energy reasons near rectangular or at least near trapezoidal pulses are most preferable.

The energy of the pulse of this shape is minimal if compared to other pulse shapes, which is advantageous in terms of both quality and energy. The stability of the electrode metal transfer is considerably higher, since the active pulse duration during welding under arc voltage disturbance changes insignificantly.

A near trapezoidal current pulse shape can be formed using the artificial forming line [4, 5]. Figure 5 shows an electrical schematic of the pulse generator power unit based on a homogeneous artificial line.



**Figure 4.** Shapes of the welding current pulse.



**Figure 5.** An electrical schematic of the generator power unit.

Artificial line is a three-phase step-down transformer, primary windings, secondary windings, a discharge thyristor, a charging choke coil, cell choke coils, cell capacitors, a rapidly saturated choke coil.

The artificial forming line consists of homogeneous elements with lumped parameters. Each of the elements is a cell consisting of choke coil  $L_c$  and capacitor  $C_c$  connected in series.

Rectangular-shaped pulses are generated due to the discharge of the pre-charged line to the welding arc. A rectifier with stepped regulation of the idling mode for varying the line charge voltage is used to charge the forming line, and, hence, the amplitude of current pulses. The inductance value of charging choke coil  $L_3$  is chosen such that the minimum duration of the pulse repetition could exceed the half-

period of the charging circuit natural oscillations, since small value  $L_c$  has no significant effect on the process of capacitor charging.

The discharge of the forming line to the arc space is carried out when thyristor VS4 is open. The shape of the current pulse is near trapezoidal with the amount of ripples at the top equal to the number of cells  $n$ . At first, the direct wave of the forming line discharge travels causing the discharge of cell capacitors  $C_c$  by one half. Then, a backward wave travels causing the complete discharge of the capacitors and the overcharge of the capacitors with an opposite polarity up to the voltage sufficient to turn off thyristor VS4 by reverse voltage.

For a larger number of cells ( $n > 8$ ), the depth of ripples at the top of the pulse is insignificant, but this causes a high rate of the current rise both at the beginning of the pulse front and during the current edge decrease. This can cause failure in the arc zone shielding, electrode metal spattering and weld deterioration.

Theoretical and experimental studies [6, 7] proved that a rapidly saturated choke coil used as the last cell choke coil with a rectangular hysteresis loop results in a bell-shaped pulse. The inductance of this type of the choke coil is comparable with the inductance of cell  $L_c$  in a saturated state. The rapidly saturated choke coil at the beginning of the pulse front is unsaturated and its inductance is greater than that of cell  $L_c$ . This ensures a smooth current change at the beginning of the front and at the end of the pulse edge.

The combination of the parameters of the device, such as a forming line and a rapidly saturated choke coil, which is the choke coil of the last cell of the forming line, results in a bell-shaped pulse with a cut and almost flat top. This fact provides the optimum pulse shape, minimum energy input during a pulse, an increase in the electrode metal transfer stability, and improvement of the welded joint quality.

The experimental test has shown that in Al-based alloy welding using a 1.2 mm diameter wire, the developed pulse shapes provide the total duration of 0.6...0.9 ms, and the duration of sinusoidal-shaped pulses is 1.5...2.3 ms. In addition, the stability of the electrode metal transfer into the molten pool is provided.

The parameters of  $L_c$ – $C_c$  cells should be fulfilled according to the following relation:

$$\sqrt{\frac{L_c}{C_c}} = \rho > R_c ,$$

where  $L_c$  is cell choke inductance;  $C_c$  is cell capacitance;  $\rho$  is cell wave resistance;  $R_c$  is welding circuit resistance.

The current pulse amplitude is determined by

$$I = \frac{U_c - U_a}{2\rho} ,$$

where  $U_c$  is capacitor charge voltage in the artificial forming line;  $U_a$  is arc space voltage.

The pulse duration is determined by

$$t_p = 2n\sqrt{L_c - C_c} .$$

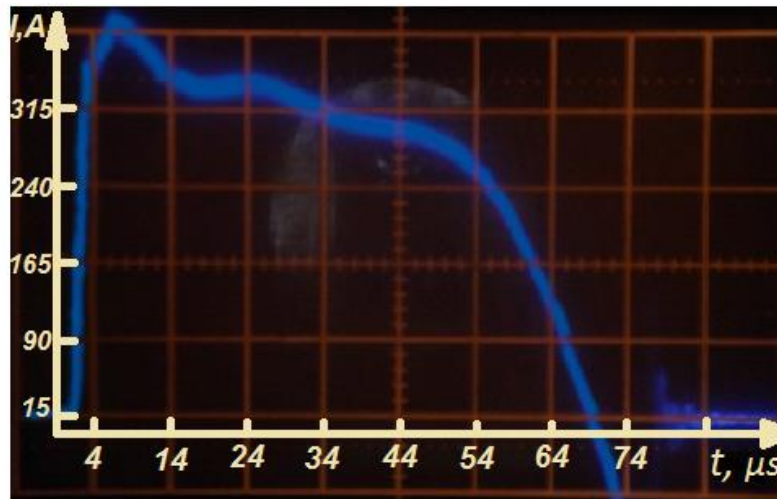
The maximum current pulse frequency is 300 Hz.

It can be smoothly varied within the range of 0...300 Hz.

The advantages of the device are as follows:

- the possibility to smoothly adjust the current pulse frequency;
- input of the minimum energy required to transfer a droplet within the pulse duration;
- independence of the active pulse duration of the welding current on the arc space voltage disturbances.

The experimental studies have shown that application of the considered pulse shape formed by means of an artificial forming line can be extended. In particular, the considered pulse shape can be used to control electrode metal transfer for gas mixtures and self-shielded flux-cored wires in a straight polarity manner. The pulse actual shape is shown in Figure 6.



**Figure 6.** The actual shape of the pulse

The discharge of the artificial forming line to the arc space is a near trapezoidal pulse with a number of pulses at the top equal to the number of cells  $n$ .

### Conclusion

A homogeneous artificial line is the most prospective for the development of a welding current pulse generator with energy storage.

According to the pulse shape estimated by the criterial parameter, the trapezoidal shape is optimal, and the edge duration is about 3 times greater than the pulse front duration.

Presence of the rapidly saturated choke coil in the welding circuit allows reducing both the rate of the pulse current rise at the initial stage and the rate of the decrease in the pulse edge current at the final stage. This fact has a beneficial effect on the welding process.

Active duration of the current pulse does not change significantly under the arc voltage disturbances. It is possible to adjust the welding current pulse frequency smoothly. The input of the minimum pulse energy required to transfer a droplet is provided.

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