FEATURES OF CURRENT PROTECTION OF POWER SOURCES FOR EBW

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The purpose of investigations was elaboration of recommendations to reduce disturbances of weld formation during EBW, if current protection of accelerating voltage source has operated because of vacuum breakdown in the welding gun, or if specified value of beam current was exceeded because of short-circuiting in the control electrode–cathode circuit. In view of the random nature of development of the mentioned transient processes, normally-open shorting plug of control electrode–cathode circuit and discharger with adjustable interelectrode gap were temporarily built into the accelerating voltage source between the cable conductor connected to control electrode and ground. This allowed closing any of the circuits and recording load current and accelerating voltage directly during welding, which was followed by comparison of oscillograms with the occurring disturbance of weld formation. It is found that in order to reduce the disturbances of weld formation at breakdown in the gun, the high-voltage source should go into the mode of automatic re-starting during the time of about 0.1 ms. The current threshold of this transition should 3–4 times exceed the maximum load current of the source, allowing for starting current at asynchronous switching on of the power source, and charging currents of capacitances of high-voltage cable and output filter. At short-circuiting in the control electrode–cathode circuit, the accelerating voltage source should automatically go into the mode of beam current stabilization after exceeding its set value by 20–30 % for 3–5 ms. 3 Ref., 1 Table, 4 Figures.

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In welding gun emission system breakdowns can develop in vacuum insulation between control electrode and anode. Gap between control electrode and cathode is often bridged by drops of molten metal from the weld pool. Violation of electrical insulation between the high-voltage cable conductors connected to cathode and control electrode is also possible. In all these cases an uncontrolled beam current rise takes place, disturbing weld formation.

Abrupt switching off of accelerating voltage source at operation of maximum current protection is highly undesirable, as it causes a serious weld defect in the form of a through-thickness crater, unfilled with liquid metal. Therefore, it is first of all necessary to minimize disturbance of weld formation, and only after that disconnect accelerating voltage source. If the source was switched off, then in case of its asynchronous restarting current protection operation is inadmissible, because of power source starting current, which is much higher than the operating current, because of a surge of magnetization current of the power source [1], and charging current of capacitances of high-voltage cable and output filter. These are exactly the currents, which at automatic re-starting of the source, even in the mode of the so-called soft, i.e. delayed start, can cause false operation of current protection, if its time delay is absent and too low operation threshold is set.

This work is devoted to experimental study of algorithms and dynamics of current protection operation at breakdowns and current overload in the gun, in order to reduce disturbances of weld formation.

Investigation procedure. High-voltage inverter power source of 6 kW power with 60 kV accelerating voltage was used in the study. It was created as a result of cooperation of the teams of PWI and «Torsion» Company (Kharkov). At up to 0.1 A load currents the source operates in the mode of accelerating voltage stabilization. Because of the presence of current sensor in the load circuit, at short-circuiting the voltage stabilizer can go into current stabilization mode, thus limiting the load current. Connected at high-voltage filter output is a ballast resistor, limiting the maximum amplitude of current through output high-voltage rectifier at short-circuiting in the load and preventing development of parasitic resonance processes in output cable [2].

Random nature of vacuum breakdown development makes it difficult to record its electric and time parameters to compare them with weld formation disturbances. Therefore, normally-open shorting plug of control electrode–cathode circuit and discharger with adjustable interelectrode gap were temporarily built into the high-voltage power source between the cable conductor connected to control electrode and ground (Figure 1). This allows directly during welding of the sample closing any of the circuits, recording the oscillograms of load current and accelerating voltage at a selected moment, and comparing them with the occurring disturbance of weld formation. Used as a recorder was digital electronic oscillograph Tektronix TDS-2014 with the bandwidth of 100 MHz and sampling frequency of 1 Gsamp/s.

Results and their discussion. Experimental studies revealed the need for applying various approaches to operating algorithms of power source current protection, in order to enable performance of EBW at simulation of breakdowns in the gun and at short-circuiting of control electrode–cathode circuit (diode mode of gun operation).

Figure 2 gives oscillograms of beam current and accelerating voltage at simulation of electric breakdown between the control electrode and anode of the gun directly during welding. Accelerating voltage source is forcedly switched into the mode of automatic re-starting, in order to prevent any serious disturbance of weld formation or malfunction of the source [3]. Duration of fronts of accelerating voltage cutting off and respective load current surge is equal to about 0.1 ms. Accelerating voltage is absent for 7.5 ms, that allows recovering the electric strength of vacuum gap of gun emission system. Then accelerating voltage is recovered slowly enough — in 2.5 ms — by the linear law.

Recovery of accelerating voltage can be performed much faster, but then metal splashing out of the weld pool can take place, because of the respective increase of beam current rising speed. Moreover, a soft start of accelerating voltage lowers the source starting current, and also slows down charging of capacitances of the filter and high-voltage cable, that enables a certain lowering of requirements to power source maximum current. Nonetheless, as follows from Figure 2, the value of load current surge at the moment of accelerating voltage re-starting reaches 0.35 A, i.e. it exceeds the maximum operating current of the source (0.1 A), by at least 3–4 times. Naturally, if the threshold of exceeding the admissible current is lowered, then even if the electric strength of the vacuum gap has already been recovered, false operations of source protection will be occurring for an unlimited time, and the welding process will not be able to recover. Note that

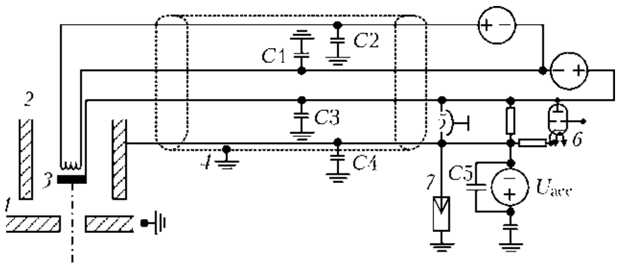

Figure 1. Schematic of experimental set-up: *1* — anode; *2* — control electrode; *3* — cathode; *4* — high-voltage cable; *5* — short-circuiting plug of control electrode–cathode circuit; *6* — beam current regulator; *7* — discharger with adjustable interelectrode distance; U_{acc} — accelerating voltage source; *C*1–*C*4 — distributed capacitances of cable conductors relative to the ground; *C*5 — filter capacitance

in the absence of accelerating voltage the oscillogram records running of a certain load current, in all probability, between the cathode, which is at residual negative potential, and control electrode. At increase of accelerating voltage the transient current rises, its value being affected by beam current stabilization circuit. In the absence of serious malfunctions of instrumentation, total duration of recovery of normal operation of equipment is not more than fractions of a second and in the worst case, a repair welding pass over the region of weld formation disturbance is required.

In the considered case, switching the accelerating voltage source into the mode of automatic re-starting is much more efficient that forced switching of the accelerating voltage source into the current source mode, as current flowing results in maintaining of ionization processes in the vacuum gap, which prevent recovery of its electric strength.

Contrarily, as will be shown below, at emission system transition into the diode mode, forced switching of accelerating voltage source into current source mode turns out to be beneficial because of short-circuiting of control electrode–cathode circuit. At closing of this circuit, current rises up to a level, corresponding to completely

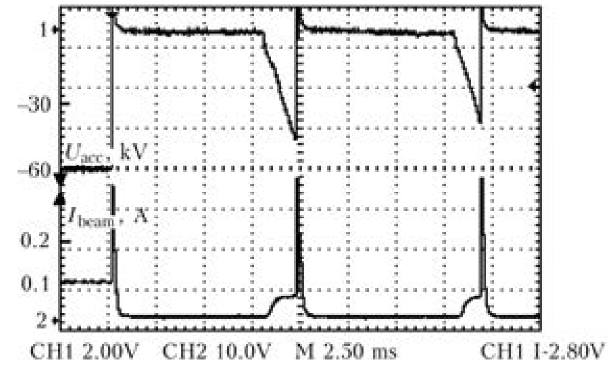

Figure 2. Dynamics of variation of beam current I_{beam} and accelerating voltage U_{acc} at simulation of electric breakdown in the gun in the vacuum gap of control electrode–cathode directly during EBW

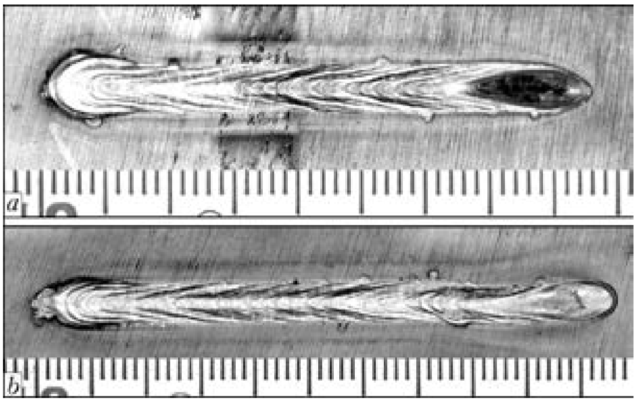

Figure 3. Appearance of welds interrupted at the moment of short-circuiting in control electrode–cathode circuit: *a* — formation of defect in the form of crater at cutting off of accelerating voltage by maximum current protection; *b* — defectfree completion of weld owing to source going from accelerating voltage stabilization mode into beam current stabilization mode

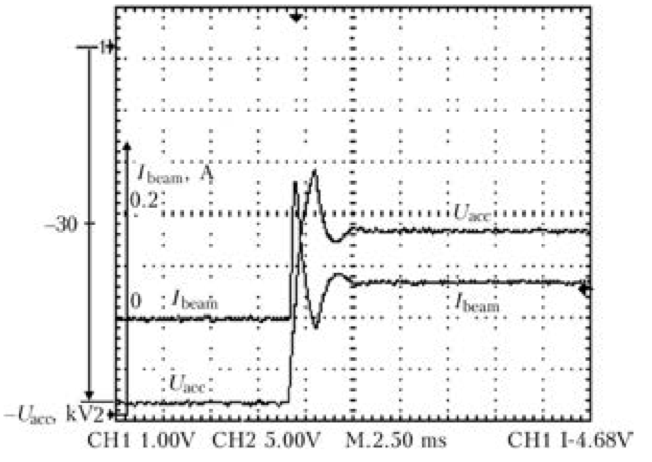

Figure 4. Dynamics of variation of beam current I_{beam} and accelerating voltage U_{acc} at simulation of short-circuiting of control electrode to cathode directly during EBW

Characteristics of current protection of power source for EBW

Welding mode disturbance	Cause for disturbance	Algorithm of current protection operation	Operating time, ms
Beam current 3–4 times exceeded maximum load current of the source	Electric breakdown between the control electrode and anode	Forced switching of accelerating voltage source into the mode of its automatic re-starting	~0.1
Beam current reached the value corresponding to diode mode of gun emission system	Short-circuiting in control electrode–cathode circuit	Forced switching of the source from voltage stabilization mode into current stabilization mode	2–5

unblocked emission system. Cutting off accelerating voltage at this moment leads to defect formation in the form of a deep crater unfilled with liquid metal and having numerous shrinkage cracks (Figure 3, *a*).

Switching accelerating voltage source into current source mode with respective lowering of accelerating voltage allows avoiding formation of this defect (Figure 3, *b*).

Figure 4 gives oscillograms of beam current and accelerating voltage at simulation of electric breakdown between control electrode and cathode of the gun. At the moment of short-circuiting of control electrode to the cathode, when the emission system goes into diode mode, beam current rises from the set value of 0.1 up to 0.25 A. After 3–5 ms current protection operates, in which programmed threshold is 0.13 A, i.e. is by 30 % higher than beam current level, and the voltage source goes into the mode of stabilization of this value. In order to maintain such current, the source generates a voltage of about 30 kV. Thus, beam power decreases from 6 to 3.9 kW, and, most importantly, at lowering of accelerating voltage the beam is refocused significantly (focal spot rises relative to item surface), that results in a considerable reduction of molten metal volume. A defect-free completion of weld formation without fixing of the crater takes place, after which the source can be switched off to perform the required reconditioning operations.

The Table gives optimum characteristics of current protection of accelerating voltage source.

Conclusions

1. At breakdown in welding gun emission system, the high-voltage source should within about 0.1 ms go into the mode of automatic re-starting. Current threshold of this transition should be 3–4 times higher than the maximum load current of the source, allowing for starting current at asynchronous starting of the power source and charging currents of capacitances of the high-voltage cable and output filter.

2. At short-circuiting of control electrode–cathode circuit, the accelerating voltage source should automatically go into the mode of beam current stabilization after 20–30 % exceeding of its set value for 3–5 ms.

1. Shabad, M.A. (2011) *Maximum current protection*. Leningrad: Energoatomizdat.
2. Nazarenko, O.K., Matvejchuk, V.A. (2011) Limitation of overvoltages in high-voltage circuits after discharges in welding gun. *The Paton Welding J.*, **10**, 32–35.
3. Lebedev, V.K., Nazarenko, O.K., Lokshin, V.E. et al. *Method and apparatus for electron beam welding*. Pat. 3042652 DE. Publ. 02.04.82.

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