determined using manometer (model 11202, GOST 6521–72) should not occur during 30 min;

11) assembly of four sets of measuring chambers in welding-assembly device with 0.2 mm lower thin plate of steel 12Kh18N10T (nipples and exhaust pipes are directed downwards), loading into vacuum chamber and making successively firstly four overlap welds along the long side and then four straight-line overlap welds along the short side (see items 4–6). Visual inspection of crossing of eight straight-line welds for absence of defects (Figure 3, *b*);

12) evacuation of vacuum chamber and performance of final testing of completely welded measuring chambers for vacuum-tightness using method of excessive pressure.

The conditions of EBW in general vacuum of measuring chamber of magnetic pneumatic gas analyzer, succession of performance of assemblies and welds, intermediate and final checking of formation of welded joints for lack of defects and vacuum-tightness allowed obtaining 100 % output of annual production. As is shown in Figure 5, the width of face bead of overlap weld was $B \cong 0.24$ mm at the depth of penetration of about 0.5 mm.

It was also established that values of residual deformations of structure of measuring chamber are in direct dependence on heat input of welding which in its turn is determined by welding conditions and depends on weld section. The measuring of postweld deformation was performed using method of comparison with the reference sample. Sagging and buckling of thin plate of foil of thickness 0.2 mm in the area of gas channel did not exceed 0.1 mm.

CONCLUSIONS

1. EBW technology and equipment as applied to precision welding of measuring chamber of magnetic pneumatic gas analyzer of stainless steel 12Kh18N10T meet all requirements for vacuum tightness and geometric sizes of the gas channel.

2. Minimal heat input of electron beam and minimal width of the weld are achieved at $v_w \geq 40$ mm/s.

3. The given conditions of EBW of overlap and circumferential joint, succession of making assembly and welds, stage-by-stage control of quality of welding and vacuum-tightness allowed obtaining 100 % output of annual production.

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LIMITATION OF OVERVOLTAGES IN HIGH-VOLTAGE CIRCUITS AFTER DISCHARGES IN WELDING GUN

O.K. NAZARENKO and **V.A. MATVEJCHUK**
E.O. Paton Electric Welding Institute, NASU, Kiev, Ukraine

Occurrence of overvoltages in output circuits of a high-voltage power source, cable and welding gun after its discharge was studied using computer modeling. Recommendations are given on optimal parameters of elements of the overvoltage limitation circuit for the powerful power sources.

Keywords: *electron beam welding, electron gun, source of accelerating voltage, limiting resistor, natural inductance, shunting diode, high-voltage cable, discharge in gun, modeling of transition processes*

The development of abnormal non-stationary processes in welding gun, to which electric discharges refer due to the loss of vacuum seal, can result not only in violation of weld formation but also cause damage of a number of assemblies of power unit, such as a high-voltage insulator of welding gun and cable (Figure 1), and also limiting resistor. As far as mentioned assemblies can withstand test voltage twice exceeding the operating one without fracture, it can be assumed that overvoltages exceeding operating voltage at least twice exist.

In welding gun the overvoltages were revealed after discharge as early as at the beginning of application of EBW, however the conductance of device measurements of rapidly flowing processes under high potential relatively to the earth is considerably complicated [1–4]. It partially explains the absence of publications on the problems of prevention of overvoltages after discharge in welding gun. It is managed experimentally to fix only the current overloads of sources of accelerating voltage.

The use of controlling electron pentode as a linear element prevents intense current surges in power source after discharge in welding gun. However, it

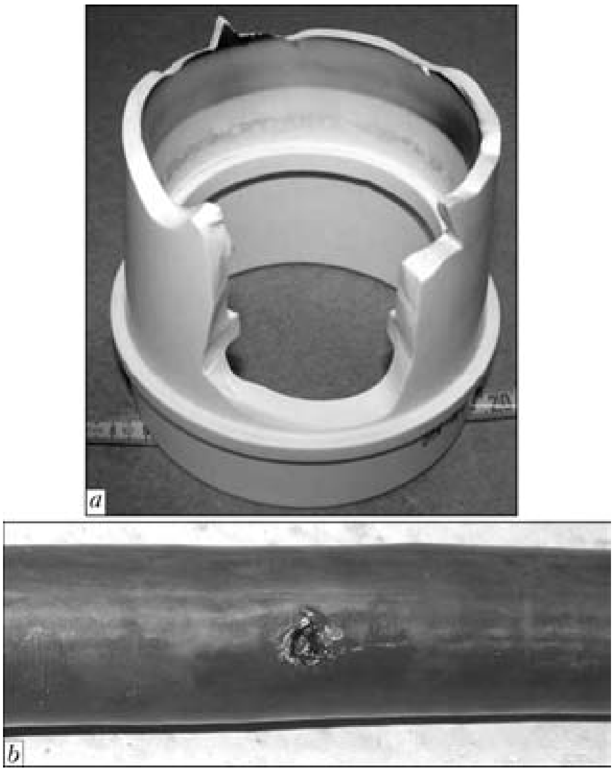

Figure 1. High-voltage insulator of high alumina ceramics (*a*) and high-voltage cable (*b*), withstood the test voltage of 120 kV but destroyed in the process of operation of standard power unit ELA-60 (rated voltage of 60 kV)

was stated that, for example, in equipment with accelerating voltage of 60 kV after discharge in the gun the voltage in controlling pentode can increase up to 130 kV which can cause almost simultaneously the discharge in controlling pentode. For this emergency case the source of accelerating voltage should be equipped with additional protective system except of maximal one. For this purpose the limiting resistors, connected in series to a load, are often used. The resistor resistance value is limited by the power, dissipated in it, and minimizing of loading characteristic of the source. Therefore, for example in work [2], it is offered in series with an output of high-voltage

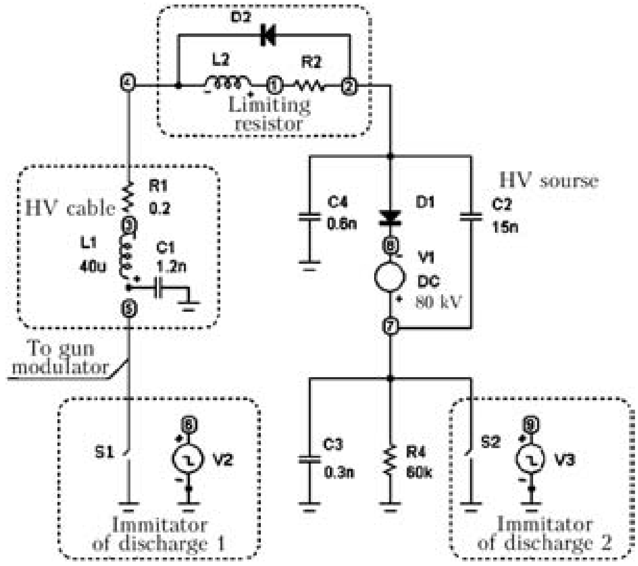

Figure 3. Diagram for modeling transition processes (for designations see the text)

power source to use high-voltage choke shunted by reverse biased diode or simply by resistor as a tool of its dynamic protection. Here, the overvoltages in the source–high-voltage cable–insulator system were not considered.

The limiting resistors as to their design can be bulk and wire-wounded. The latter are characterized by noticeable natural inductance which reduces speed of power source current increment during discharge, but causes the oscillatory process in high-voltage cable and resistor itself. Earlier the optimum correlation of resistance and natural inductance was not discussed as well. Therefore this work is devoted to modeling of non-stationary and emergency situations in the source of accelerating voltage–high-voltage cable–welding gun system for selection of optimal parameters of protection from overvoltages.

Object and investigation methods. For stationary power unit ELA-60 (Figure 2) at modeling of transition processes [5] after discharge in welding gun some simplifying assumptions can be made. From the mod-

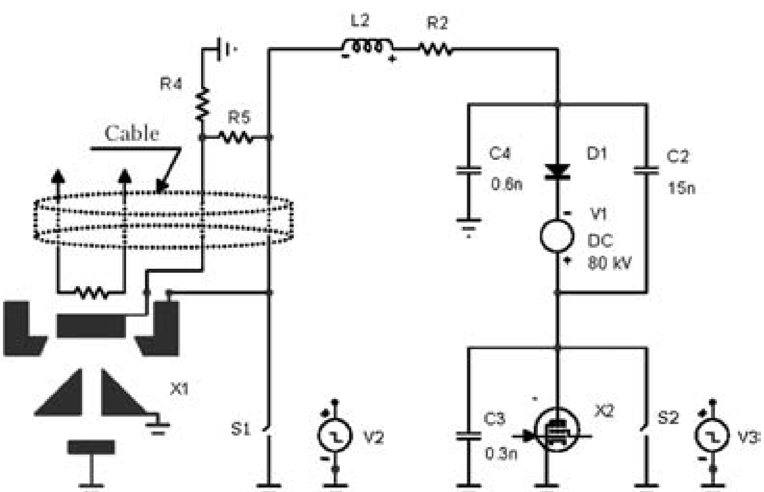

Figure 2. Simplified schematic diagram of standard power unit ELA-60 with elements for modeling transition processes (for explanations see the text)

eling scheme (Figure 3) the gun X1 itself and high-voltage cable, presented by an electric link with concentrated capacitance, inductance and resistance, are excluded. Some error of such representation affects only high-frequency components of the transition process. As was established that load current does not influence characteristics of transition processes appearing in gun discharge, it was preset arbitrary (300 mA). The source of accelerating voltage is represented by a voltage source V1 with diode D1 (capacitors C3 and C4 account for all capacitances relatively to the earth, connected to positive and negative terminals of the source). Resistor R4 = 60 kOhm, simulating the controlling electron pentode X2 in the mode of 300 mA current flow, is connected in series to the source of accelerating voltage V1 into its plus circuit. Discharges in welding gun and pentode are simulated respectively by switches S1 and S2 which are controlled by the sources of pulse voltage V2 and V3. The resistance of contacts of breakdown imitator S1 in open state is 200 kOhm, which corresponds to the flowing of stationary current of 300 mA, the resistance of close contact S1 at imitation of discharge is 0.01 Ohm and resistance of contacts of switch S2 in open state is 100 MOhm, in close one it is 0.01 Ohm. The duration of short-circuiting is preset by a longer time (5 μs) which corresponds to two stages of discharge: breakdown and spark [6]. As a protection the limiting resistor R2 with natural inductance L2 was used. The length of high-voltage cable is 10 m.

Results and their discussion. Time diagrams of transition processes are presented in Figure 4 where the following designations are given: $v(C1)$ — potential in the unit of cable connection to gun modulator; $v(4.2)$ — drop of voltage on the limiting resistor; $I(7.8)$ — current of accelerating voltage source;

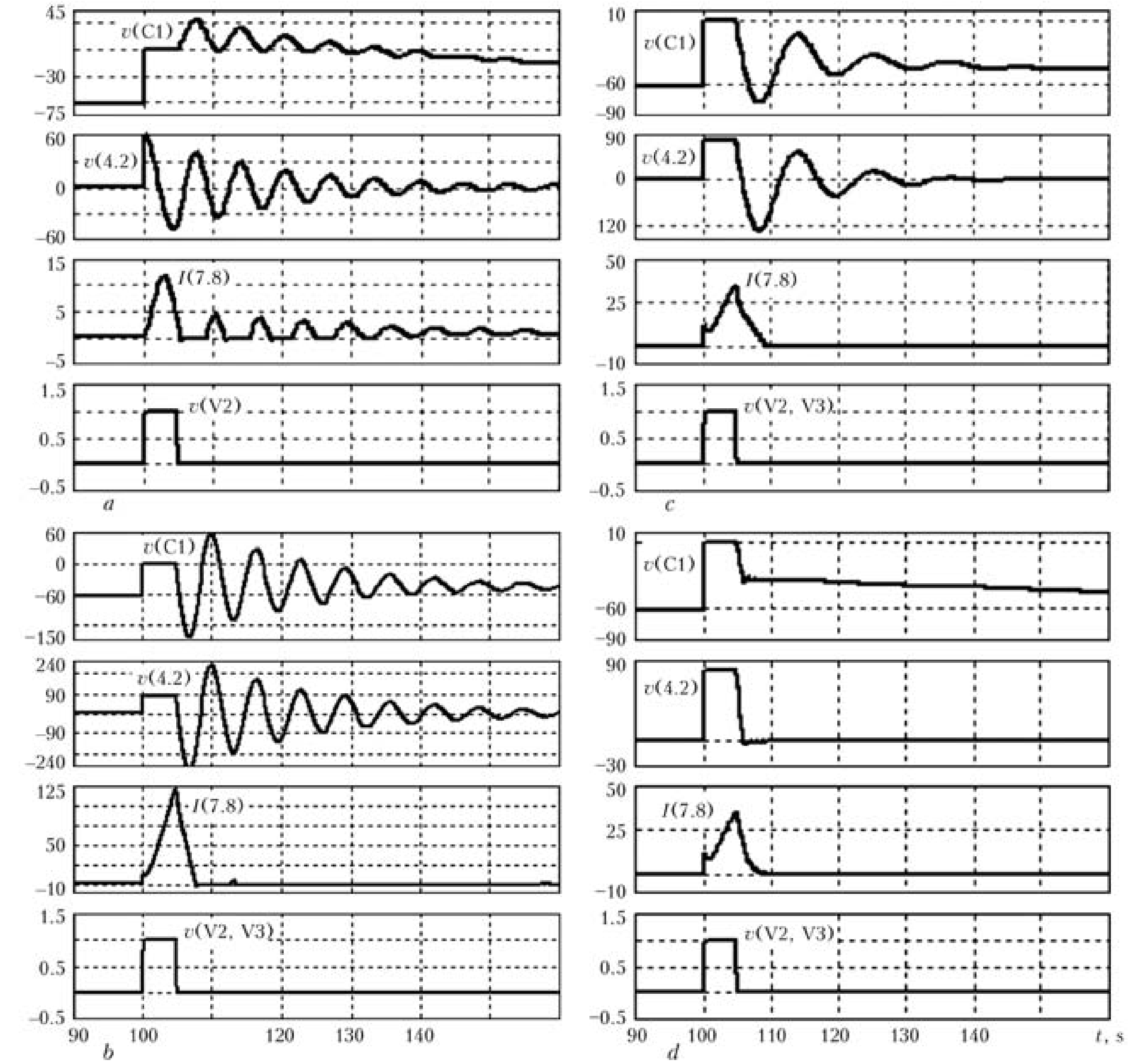

Figure 4. Time diagrams of transition processes: *a* — discharge only in gun, R_{limit} = 200 Ohm, L = 2 mH; *b* — successive discharge in gun and controlling pentode, R_{limit} = 200 Ohm, L = 2 mH; *c* — successive discharge in gun and controlling lamp, R_{limit} = 1200 Ohm, L = 6 mH; *d* — successive discharge in gun and controlling pentode, R_{limit} = 1200 Ohm, L = 6 mH, shunting diode is switched on

v(V2), v(V3) — presetting of time of discharge existence.

As it follows from time diagram given in Figure 4, *a*, during discharge the potential of modulator drops to zero only in the gun, and after termination of discharge the rated value of accelerating voltage is restored aperiodically without dangerous overvoltages. The amplitude of voltage oscillation in the limiting resistor is changed in the range of $\pm U_{acc}$, and amplitude of current flowing through the power source does not exceed 12 A. Such progress of events is quite acceptable and this is not an emergency situation.

However successive discharge in the gun and controlling pentode (Figure 4, *b*) has already created the emergency situation: the potential of modulator reaches −150 kV, amplitude of voltage oscillations on the limiting resistor is ±250 kV, current of power source at the time of discharge existence succeeds in growing up to 125 A.

Therefore, to prevent this emergency situation it is necessary to increase resistance of limiting resistor up to the value acceptable regarding minimizing of load characteristics of power source, dissipation of heat evolved in oil tank and losses of net power. Naturally, this value can change for each specified source. For example, for sources with load current of about 1 A the optimal resistance is 1000–1200 Ohm. As it follows from obtained time diagrams of transition processes at simultaneous discharges in welding gun and controlling pentode using R_{limit} = 1200 Ohm with natural inductance L = 6 mH (Figure 4, *c*), after termination of discharge the overvoltage in the point of cable connection to the gun modulator decreased down to −75 kV and amplitude of current flowing through power source did not exceed 30 A. However, oscillations of potential in the circuit of limiting resistor remain significant enough (from 90 to −120 kV).

The next step in overcoming the overvoltages is shunting of limiting resistor by a diode (practically by a circuit of diodes connected in series, withstanding the drop of voltage down to $1.5U_{acc}$), as it was expected, leads to a complete suppression of oscillating process. Due to that the overvoltage in the cable is absent, drop of voltage in limiting resistor is only 80 kV (Figure 4, *d*).

Though numerous values obtained during modeling of transition processes can not be completely valid, nevertheless the general regulations of influence of parameters of protection on character of these transition processes are seemed to be convincing. The confirmation of efficiency of increase in resistance of limiting resistor and its shunting by chain of reverse biased diodes is the fact that after application of all those recommendations the breakdowns of main insulation of high-voltage cables, destruction of limiting resistor and high-voltage insulators of welding guns did not occur in our practice.

The similar protection provides also an accident-free operation of powerful power units of inverter type with high-frequency transformation of mains frequency, where controlling pentode is not used. In power units of lower power the values of limiting resistor can be respectively increased, thus increasing the efficiency of protection system from overvoltages even more and decreasing the source current during gun discharge.

CONCLUSIONS

1. The system of limiting overvoltages and controlling pentode of standard power unit ELA-60 provides a safe level of overvoltages in the power source–cable–gun system after discharge in welding gun.

2. Successive discharge in gun and in controlling pentode has already created the emergency situation as the potential of modulator exceeds the level of accelerating voltage by 2.5 times and limiting resistor — by 4 times, that can lead to damage of insulator, cable and limiting resistor.

3. Maximum acceptable increase of resistance of limiting resistor by 6 times (from 200 to 1200 Ohm) does not prevent the oscillation process at successive discharge in gun and controlling pentode, but oscillation amplitude in the cable exceeds accelerating voltage only by 20 %. However the amplitude of maximal overvoltage in limiting resistor exceeds accelerating voltage twice.

4. Shunting of limiting resistor by a chain of reverse biased diodes excludes exciting of oscillating process at successive discharge in gun and controlling pentode. Due to this, the overvoltage in the cable is completely absent, drop of voltage in limiting resistor exceeds accelerating voltage only by 50 %.

5. Obtained results are acceptable for using both in sources without frequency transformation and also in inverter-type sources.

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