Automatic Pulsed Power Supplies for Electron Beam Surface Thermal Treatment Equipment

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Abstract – The paper describes automatic power supplies included into the power and control system of the setup intended for thermal treatment of material surfaces by a pulsed electron beam.

The electric-power system includes two magnetic coil pulsed power supplies, power supplies of ignition and main discharges, and a high-voltage accelerating power supply. All above-mentioned electric-power supplies are controlled synchronically from the unified control panel based on a microprocessor.

The advantage of the developed complex is enlargement of technological possibilities for material treatment with a pulsed electron beam. This was achieved by introducing an independent control of the pulse length (50÷200 μs), beam current amplitude (20÷250 A), pulse repetition rate (1÷20 Hz), magnetic coil currents (2÷10 A), number of pulses (0÷999), and accelerating voltage value (5÷25 kV).

The developed complex of power supplies is made on the modern element base providing its stable operation under conditions of heavy electromagnetic interferences. The complex has an informative and convenient operator interface, possibility of remote control from a personal computer. Possibility of program assignment for parameters of the material thermal treatment process is envisaged.

1. Introduction

At present, the process of material surface modifica-tion with application of pulsed electron beams attracts special attention explained by a number of essential advantages in comparison with other thermal treatment methods [1]. These advantages are as follows: high thermal Q-factor, metal refining and degassing when treated in vacuum, absence of necessity to use expensive shielding or quenching media, ecological purity of the process, possibility to control parameters of electron-beam treatment in a wide range.

Moreover, the process of material thermal treatment with an electron beam allows essentially intensifying a modification process decreasing the buckling of component parts, sharply decreasing power inputs and automating the process completely [1].

Fig. 1 presents the structural diagram of the electron gun [2] as well as its electric power supply system. A plasma emitter consists of two gas-discharge systems, and namely: the initiating system and the main arc discharge one.

The ignition discharge is excited between the anode 1 and cathode at a 12-kV amplitude voltage pulse application from the pulsed power supply (trigger). The main high-current arc discharge is excited between the cathode and anode 2 at application of the voltage pulse with the amplitude up to 800 V from the ARC power supply.

Electrons are extracted from the main discharge plasma through a mesh electrode under the high pres-sure U=5–25 кВ applied from a high-voltage DC power supply HV to the gap between the mesh and accelerating electrode made in the form of a diaphragm. The diaphragm is fastened at a grounded drift tube inside which the electrons are transported to a collector. The beam transport system is placed into a longitudinal magnetic field initiated by two magnetic coils (Coil1 and Coil2). Pulse supply of the coils is provided by two identical power supplies (COIL1, COIL2). After passing the transport system the formed beam enters the treated surface.

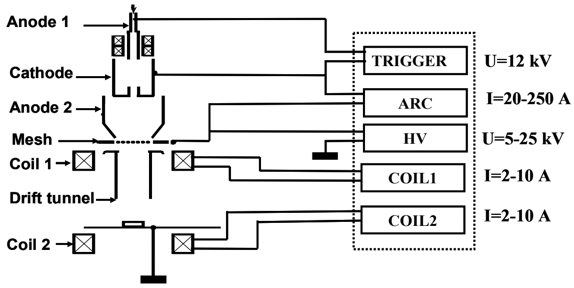

Fig. 1. Setup structural diagram

2. Description

Thanks to development of a semiconductor element base and, specifically, appearance of high-power IGBT-modules it is possible to develop a modern complex of electric power supplies allowing eliminating series of drawbacks inherent to the previously developed electric power supply systems and substantially enlarging the range of operating parameters of the device. The main requirements to the power supply system under development were the following:

- Independent control of the length ad amplitude of the electron beam current;
- Efficient ignition of the main discharge in the whole range of operation pressures;
- Automation of the technological process control;
- Decrease in magnetic coil energy consumption;
- Control system interference immunity.

Resulting from the work that was carried out, the electron gun electric power supply and control complex has been developed and fabricated. Technical characteristics and operation principles of this complex are presented below.

Fig. 2 presents the time diagram explaining the principle of operation synchronization of the power supplies relative to each other.

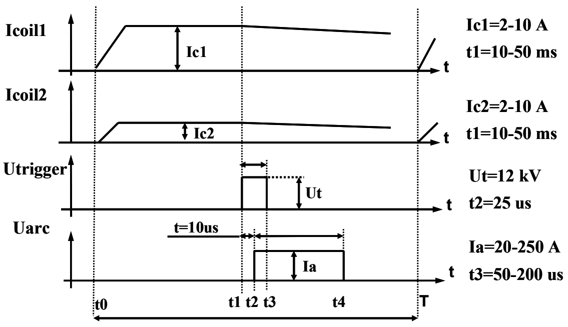

Fig. 2. Time diagram of operation

At the initial moment of time t_0, the magnetic coil power supplies are turned on and smooth current acceleration and stabilization at a fixed level (t_0–t_1 interval) takes place in them. The power supplies allow controlling the length of the interval t_0–t_1 in order to provide a possibility to connect magnetic coils of dif-ferent inductances.

At the moment of time t_1 the IGBT-module commutation occurs in the initiating discharge feed circuit and a 12-kV amplitude, 40-μs length (t_1–t_3 interval) voltage pulse is applied to the cathode – anode gap 1 of the initiating discharge.

15 μs before the initiating pulse finish, at the moment t_2, a voltage pulse is applied for the main arc discharge (t_2–t_4 interval). During pulses of the main arc discharge the current in the magnetic coils drops insignificantly since the coil time constant is by an order of magnitude higher than maximum length of the main discharge.

The developed electric power supplies forming the energy complex have the following characteristics:

Initiating discharge power supply:

- voltage amplitude – 12 kV;
- current amplitude – 15 A;
- pulse length – 25 μs;
- pulse frequency – 1÷10 Hz;
- step of pulse repetition rate variation – 1 Hz;

Main discharge power supply:

- maximum output voltage – 800 V;
- discharge current – 20÷250 A;
- step of discharge current variation – 5 A;
- pulse length – 50÷200 μs;
- step of pulse length variation – 5 μs;
- main discharge pulse frequency – 1÷10 Hz;
- step of pulse repetition rate variation -1 Hz.

Magnetic coil power supply:

- voltage pulse length – 10–50 μs;
- step of pulse length variation – 1 μs;
- maximum output voltage – 300 V;
- magnetic coil current – 1÷10 A;
- step of magnetic coil variation – 1A;
- pulse repetition rate – 1÷10 Hz;
- step of pulse repetition rate variation – 1 Hz.

Besides, we used a ready-made *high-voltage accelerating power supply* having the following characteristics:

- output voltage – 5÷25 kV;
- nominal load capacity – 5 kW;
- step of output voltage variation – 1 kV.

A magnetic coil power supply is constructed according to the scheme depicted in Fig. 3. The input circuit voltage is transformed into the constant one by means of a network transformer and rectifier with a capacitive filter and further it is applied to the induc-tive load (coil) by means of a switch. The load current amplitude stabilization is realized owing to application of pulse-width modulation. Application of the pulsed mode of magnetic coils allowed decreasing the heat generation and refusing from water cooling that considerably simplified their design.

A schematic diagram of the power supply of the initiating and main discharges is presented in Fig. 4. The input circuit voltage is transformed into the constant one by means of the network transformer and rectifier with a capacitive filter. Forming of the initiating high-voltage pulse with uncontrolled voltage is realized by means of the capacitor switching to the primary winding of a high-voltage transformer through a ballast resistor. Such circuit design allows obtaining at the output a relatively sharp voltage edge that essentially simplifies the glowing auxiliary

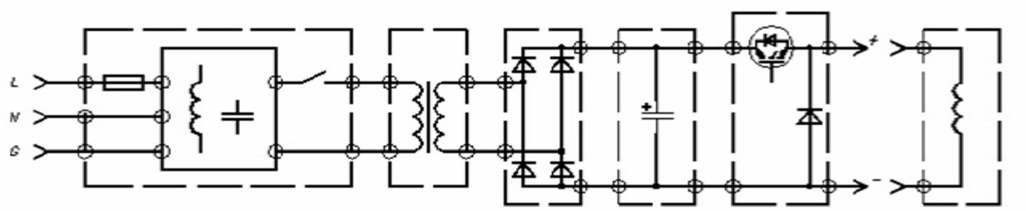

Fig. 3. Schematic diagram of the coil pulsed power supply

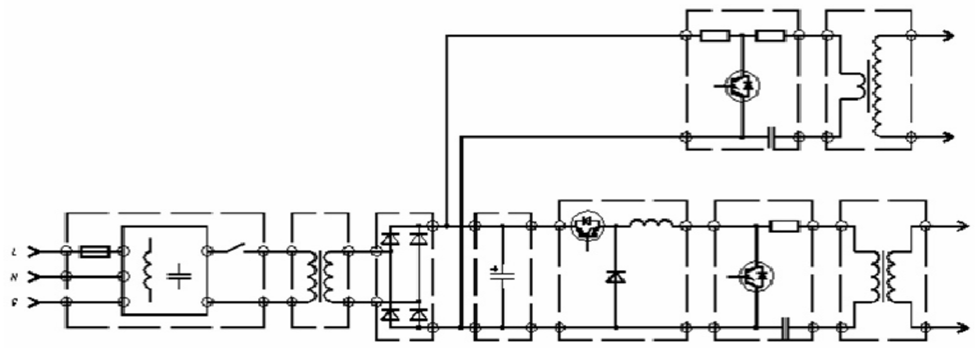

Fig. 4. Feed circuit of initiating and main discharges

discharge initiation in a wide pressure range and increases initiation stability of the main discharge.

Forming of the main discharge current pulse occurs in a similar way. To control the main discharge current, a constant-voltage step-down converter stabilizing the required voltage at a capacitor is installed at the input. The value of discharge capacitors is chosen from the capacity discharge condition to be no more than 5 % during a pulse.

It is necessary to note that voltage of the insulation between the primary and secondary windings of the transformers presents the sum of the secondary winding voltage and accelerating voltage and is no less than 35–40 kV, therefore all transformers are disposed in an oil-filled tank.

To decrease the setup operation influence on the supply circuit and to increase electric safety, a block including a safety device, an electromagnetic interference filter, and an AC switch is installed at the input of each power supply.

Synchronization of all electric power supplies is realized from a microprocessor control panel that gives reference voltages and control pulses.

The described power supplies are not the separate functionally independent assemblies but a common synchronized system of the electron gun electric power supply. Fig.5 presents the structural diagram of the automation.

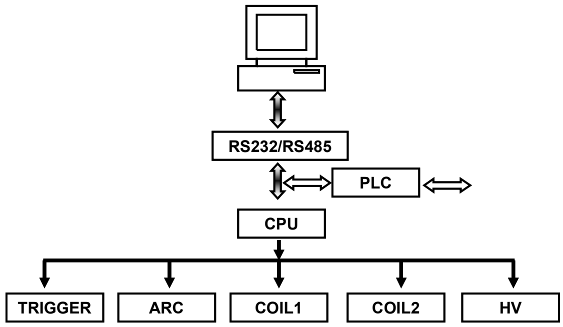

Fig. 5. Structural diagram of setup automation

One of the main requirements to the analogous energy complexes is automation of a technological process. In the given case, the process automation allows organizing two successive stages of thermal treatment of material surfaces (1 – heating mode , 2 – treatment mode). In the first mode, as a rule, heating is realized by low-amplitude current, large number of pulses, with high pulse repetition rate. Correspond-ingly, the second stage of material surface treatment has the opposite parameters, and namely: high current amplitude, small number of pulses and low pulse repetition rate.

Availability of a serial data port in the control panel allows integrating the electric power supply system into a unified energy complex. Organization of remote control by a standard industrial interface RS485 binds the necessary vacuum equipment and manipulator by three coordinates. A remote control device is a personal computer equipped by visualization system.

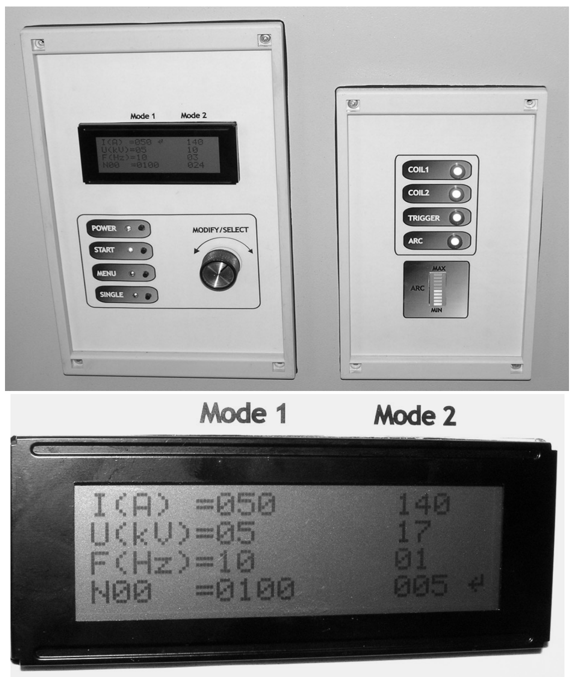

Fig. 6. External view of control panel and LCD display

A necessary attribute of modern equipment is as well a convenient and informative operator interface allowing not only programming a technological process but also its controlling. In the developed complex there is a LED indication scheme allowing the operator controlling the propagation of the following current pulses: the initiating and the main discharges, currents of two magnetic coils, and beam current. Fig. 6 presents the external view of the setup control panel and LCD display. The whole complex of the electric energy supply and control is assembled in a standard 19-inch cabinet.

The developed electric power supply system includes the circuit of the beam current control. The min function of the latter is control of energy deposition into the treated surface of materials. The circuit provides comparison of the present beam current pulse length with the given length and if the difference is more than 10 %, then the pulse is not recorded by the control system. Decrease of the beam length in comparison with the reference value can be related to appearance of a high-voltage gap breakdown. After realizing the whole initially prescribed number of pulses an automatic addition of the omitted number of pulses occurs.

Conclusion

Resulting from the work that was carried out a system of electric power supply and control intended to treat materials by a pulsed electron beam has been created. The chosen technical solutions allowed providing an independent control of length and amplitude of the electron beam current, realizing efficient initiation of the main discharge in the whole range of operation frequencies, decreasing energy consumption of magnetic coils, automating the thermal treatment technological process, realizing control of the energy deposition value into the treated surface, providing interference protection of the control system.

References

[1] B. Radchenko, O.I. Khomutov, http://aomai.ab.ru/Books/Files/1999-03/HTML/17/pap_17.html

[2] N.N. Koval, P.M. Schanin, V.S. Tolkachev, L.G. Vintizenko, PTE, 2005, No 1, pp. 135–140.

[3] Koval N.N., Schanin P.M., *in Proc. IV All-Union Conf. on Modification of Properties of Constructional Materials by Charged Beams*. Tomsk, 1996, p. 47.