Automated Power-Complex for Pulse Surface Treatment of Materials by Electron Beam

N.N. Koval, N.S. Sochugov, V.N. Devyatkov, S.V. Grigoriev,
I.R. Arslanov, A.V. Mikov, V.G. Podkovyrov and Kensuke Uemura*

Institute of High Current Electronics SD RAS, 634055, Akademichesky ave. 2/3, Tomsk, Russia,
E-mail: koval@opee.hcei.tsc.ru
** ITAC Ltd. 8-2 Kamisuwa, Tsubame City Niigata 959-0181 Japan*

Abstract – In this paper is given a description and the main characteristics of power-complex created for surface treatment of metal samples. It includes an electron source generating high-current low-energy electron beam and automated power supply and control units. Electron beam with current up to 300 A, regulated pulse duration (50–200) μs and pulse repetition rate up to 10 Hz is formed in gas-filled diode with plasma cathode. At accelerating voltage up to 25 kV electron beam transported in axial pulse magnetic field on the distance up to 30 cm in space of its interaction with a solid body.

Power supplies of electron source based on high-voltage transistor keys provide operative control of electron source parameters and allow treating the samples in several modes with an independent setting up for every process stage. The element base used in power supplies defines a possibility of parameters remote set and allows automating of a process of samples treatment at using of external control system on personal computer base. At current densities over 100 A/cm^2 beam provides power density of ≥10^6 W/cm^2 enough for melting and evaporation of metal and composite material surface during one or several pulses of (50–200) μs duration.

1. Introduction

Electron beam with the high power density is used in different technological processes, such as welding of responsible production, remelt of chemically active refractory metals, also surface modification due to fast heating and cooling of surface layer [1–5]. At creation of equipment for pulse electron-beam treatment of the material surfaces by high-current low-energy beam it is necessary to solve a number of physical problems related to the formation and transportation of the electron beam, and a number of technical problems at realization of power supplies and electron source control. The described electron-beam power-complex was created basing on the laboratory installation for metal surface treatment by the electron beam [6], where a part of these problems was substantially solved. As a result of the modernization of electron source and its power supply schemes there were improved not only parameters of formed electron beam, but also the range of its possible application was also expanded. New decisions used in the schemes of power supply and control system of the electron source allow carrying out more complicated technological processes of treatment of metal and composite materials surfaces, and carrying out the treatment in automated regimes.

2. The configuration of power-complex and operation principle

The power-complex, block scheme of which is given on Fig. 1, consists of an electron source 1 setting up on the chamber 2, the system of vacuum pumping and power supply rack of the electron source 3. The rack with power supplies includes discharges system power supplies of electron source 5, 6, power supplies of magnetic field coils 7, 8, accelerating voltage source 9 with high-voltage storage capacitors 10 and high-voltage isolating transformers 11. The controlled gas inlet valve 12 is used for inflow to the source of working gas (Ar). Power supplies can work as well off-line controlled by microprocessor unit 13, as controlled by external system based on personal computer (PC) 4. The work mode control of power-complex at work without PC is carried out with usage of microprocessor unit control panel, and check of electron source currents with usage of oscillograph 14.

2.1 Construction and principle of operation of electron source

The construction of modernized electron source based on plasma emitter with the grid stabilization of plasma boundary is given on Fig. 2. The source in comparison with this source [6] has the other sizes of construction elements and changed magnetic system. There also were made some changes in the system of initiating discharge.

The initiating discharge, functioning within short (up to 25 μs) pulse duration is ignited between electrodes 1 and 3. Electrode 1 is located into magnetic field with induction of 0,1 T of permanent magnets 2. At first initiating discharge is ignited in glow regime and than the cathode spot appears on electrode 3.

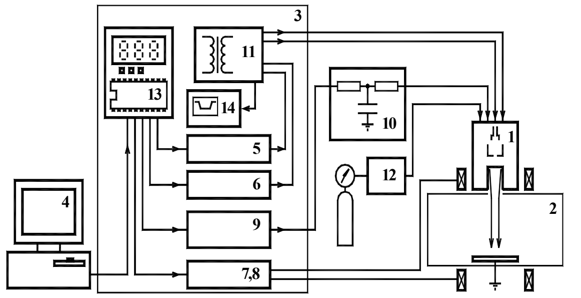

Fig. 1. The power-complex blocks scheme. 1 – electron source; 2 – vacuum chamber; 3 – power supplies rack, 4 – controlling PC; 5 – power supply of initiating discharge; 6 – power supply of the main arc discharge; 7,8 – power supplies of magnetic field coils; 9 – accelerating voltage source; 10 – high-voltage storage capacitors unit; 11 – isolating transformers unit; 12 – gas inlet valve; 13 – microprocessor unit; 14 – oscillograph

The usage of electrode 3 as a cathode for initiating and main discharge made it possible to decrease requirements to main discharge power supply. The main arc discharge with a regulated pulse duration (50–200) μs is ignited between electrode 3 and a hollow anode 6 through the constricted channel 5 in electrode 3 with following discharge switching to the grid emission electrode 7. As there is a cathode spot in the moment of main discharge ignition on magnesium electrode 4 for ignition and stable discharge operating it is possible to use a power supply with relatively low open-circuit voltage (≥100–150 V). Differential pressure between two discharge systems makes a constricted channel 5, and it makes initiating discharge ignition easer. Grid electrode 7 with an emission hole with a diameter of (40–50) mm is covered by the grid with cell sizes of ~0.3×0.3 mm and transparence of 50–60 %. The resistance of R=10–100 Ohm was located between electrodes 6 and 7.

High direct accelerating voltage 5÷25 kV is applied between electrode 7 and accelerating electrode 8 from power supply providing work mode with a partial discharge of storage capacitor. Electrons extracted out of cathode plasma and accelerated by high voltage make plasma in the drift tube due to work gas ionization. In gas-filled diode we realize a system consisting of cathode plasma emission surface, stabilized by grid, and plasma anode with moving plasma boundary. The whole system is placed into axial magnetic field created by two magnetic coils 10 for stabilization of electron beam in accelerating gap and drift space. These coils are located in the top and bottom faces of vacuum chamber outside of pumping volume, and make axial magnetic field with a magnitude up to B=0,05 T in space of electron beam formation and transportation. Electron beam is transported in metal tube 9 with a diameter of 82 mm and length of 200 mm up to the moment of input to the work chamber. Diagnostics of electron source pulse currents is carried out by using of Rogowski coils.

2.2. Systems of power supplies and control

The characteristic peculiarity of electron source power supplies is in usage of IGBT-transistors as commutation elements there and in usage for control overall units with the help of microcontroller. The usage of fully controlled transistor switch allows changing discharge current amplitude operatively

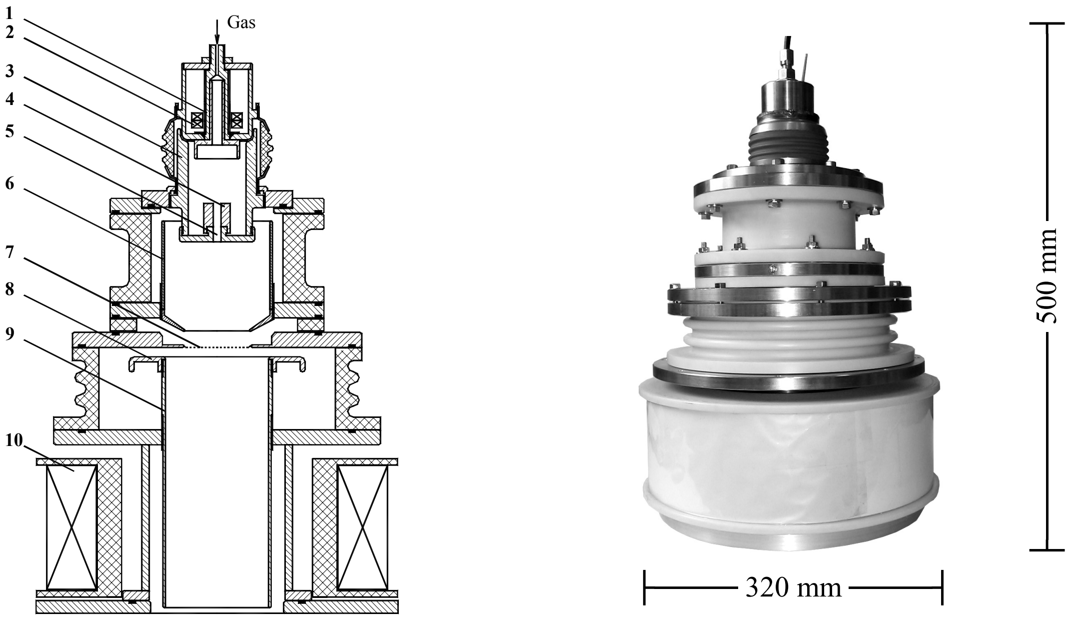

Fig. 2. Construction and appearance of electron source with the plasma emitter

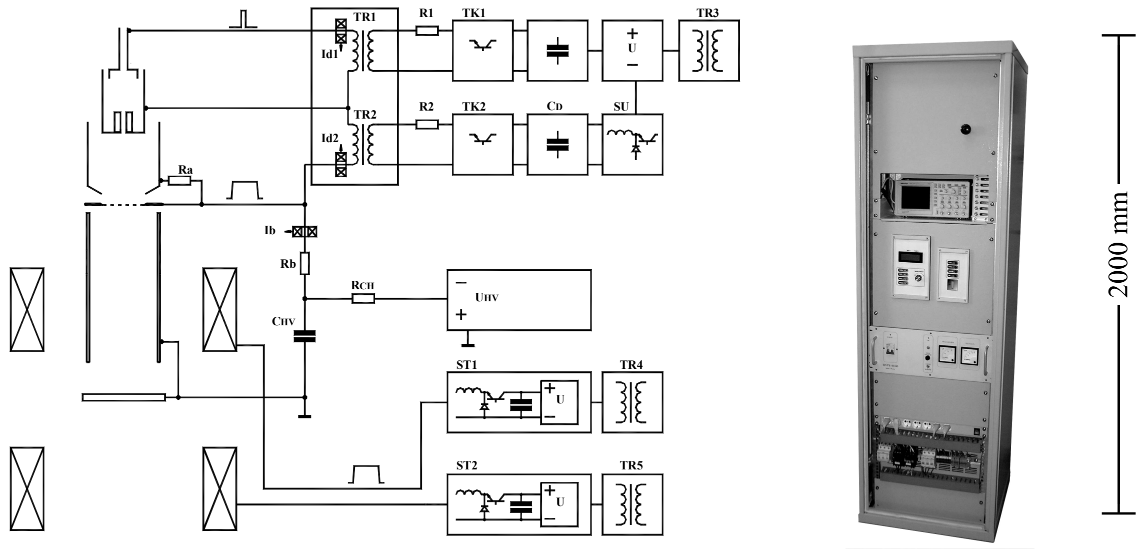

Fig. 3. Power supply structural schematic of power-complex and appearance of rack with power supplies and control units

and in wide range, and consequently to change electron beam current, electrons energy, to control transporting magnetic field. Besides, it is possible to change opera-tively the duration of beam current pulses without switching of power supply scheme elements.

There are the structural diagram of electron source discharge power supplies and magnetic coils and the appearance of rack, where power supplies and electron source control are built in, on Fig. 3. Power supplies include: the source of arc discharge initiation, arc discharge power supply and two power supplies of magnetic coils. At power supplies turning on, the line voltage is commutated by symistor units and come through the TR3-TR5 mains transformers to the rectifiers schemes. Arc discharge initiation unit includes reservoir capacitors, IGBT-module (TK1) and TR1 pulse high voltage isolating transformer. The operating principle of this scheme is the commutation of big capacity storage capacitors by IGBT-transistor to the transformer primary winding. The pulse duration is defined by time of commuting transistor "on" condition (about 25 μs).

Power supply of the main arc discharge includes SU pulse voltage regulator, C_D storage capacitors, IGBT-module TK2 and TR2 pulse transformer. The operation principle of this scheme is voltage regulation and stabilization on the storage battery and its commutation by IGBT-transistor to the pulse transformer primary winding. Arc discharge current amplitude is determined by voltage on CD, resistance of R2 ballast resistor and resistance of arc discharge.

One of the problems appearing at creation of transporting magnetic field system is a problem of possible overheating of magnetic coils. The usage in power-complex of pulse power supplies of magnetic field coils (ST1, ST2) created on the base of current stabilization schemes allowed full disposing of coils overheating at synchronous increasing of magnetic field maximal value. As a source of UHV accelerating voltage we used HVPS25/60 source (2 kW) or HVPS25/200 (5 kW) [7].

Control over all power supply elements is carried out by controlling unit based on microcontroller. There are control elements and LCD-display where is displaying of fixed parameters and the course of set-point program of samples treatment on the unit front face. Controller unit includes RS485 interface, and it allows making a connection between power supplies microcontroller and remote desk or personal computer. There is a possibility of treatment program carrying out in the controller program, consisting of two stages with an independent setting up of all parameters for every stage. The usage of external controlling PC allows full automation of power-complex work. Besides, in this case for the treatment process practically any arbitrary sequence of parameters can be used.

3. Power-complex parameters

The described power-complex can be installed on different vacuum chambers. At pressure in vacuum chamber of p=($1\cdot10^{-2}$–$1\cdot10^{-1}$) Pa electron beam is transported in axial magnetic field to the treated samples. Changing currents in magnetic coils and the distance to the collector it is possible to regulate beam diameter and energy density on the sample.

Though, the more optimal, from point of view of formation magnetic field for transporting e-beam, is using of vacuum chamber with a height up to 15 cm, the electron source can be installed on the chamber with a height up to 30 cm. Parameters of e-beam are as follows: diameter of (1–3) cm, electrons energy (5–25) kV, regulated pulse duration (50–200) μs and energy density up to (50–100) J/cm^2.

The oscillograms of discharge current 2, emission current 3 and collector current 4 at pulse duration of 200 μs are presented on Fig. 4.

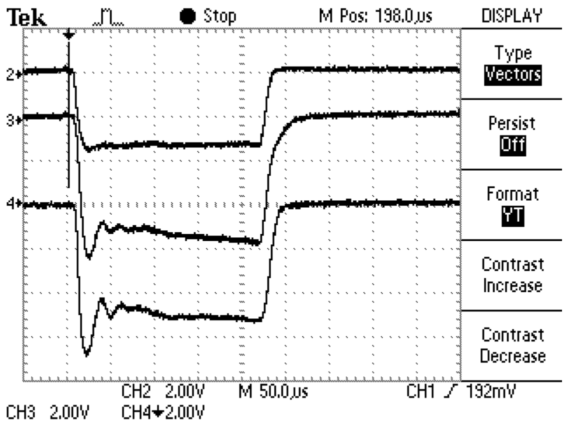

Fig. 4. Typical waveforms of the electron source current pulses. Accelerating voltage U=15 kV, magnetic field B=0.04 T, pressure $p=2.6\cdot10^{-2}$ Pa. Scale: 40 A/div, 50 μs/div

Power-complex using possibilities can be demonstrated by example of two stages treatment of samples made out of hard alloy based on tungsten carbide. The sample, preliminary heated up to ~1000 °C is treated during the second stage to the obtaining of mirror surface without microcracks and microcraters. It allows excluding the process of mechanical production polishing. An electron beam with large duration current pulses (hundreds μs) at using of plasma cathode allows in number of cases to avoid formation of microcraters at pulse thermal treatment of metal surface. Also it allows obtaining of modified layers of relatively large depth (≥10 μm).

4. Conclusion

Successful solution of some technical problems at creating of power-complex allowed making of electron-beam equipment with wide technological possibilities comparing with analogical installation. Expanded range of pulse durations of electron beam current, operative regulation of beam parameters, introduction of several treatment stages with different parameters of e-beam and possibility of electron source mounted on relatively high vacuum chambers expand field of application of power-complex and nomenclature of treated materials and production. Automation elements of power-complex provide a capability of its using not as a laboratory, but as industrial equipment.

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[7] Institute of Electrophysics UD RAS, Russia, e-mail: pulsar@iep.uran.ru