The Automated Installation for Surface Modification of Metal and Ceramic-Metal Materials and Products by Intensive Pulse Sub-Millisecond Electron Beam[1]

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Abstract – The paper describes the design of a fully automated facility with a low-pressure vacuum-arc-discharge electron source for surface modification of metal and cermet materials and products and considers the main parameters and the technical characteristics of its basic units.

1. Introduction

Now, pulsed electron beam surface treatment of metal and cermet products is finding ever-increasing use. This treatment allows superfast surface melting and decreased surface roughness $R_a = 0.05 \sim 0.1$ µm (polishing) due to surface tension. Moreover, the process makes possible structural surface modification to a depth of ~ 50 µm, resulting normally in a considerable decrease in grain size up to submicron and nanosizes, and this improves the service properties of the treated objects.

The paper describes the design of an automated submillisecond high-density low-energy electron beam facility for surface modification of metal and cermet products. The facility design is the next step in developing of pulsed electron beam equipment for surface modification at the Plasma Emission Electronics Laboratory of the Institute of High Current Electronics, SB RAS [1–3]. The facility features improved e-beam parameters, a two-coordinate scanning manipulator for increasing the e-beam-treated area, and PC control of all units and devices with programmable preset and control of the e-beam parameter and of the treatment process.

2. Design of the facility

The facility comprises a plasma-cathode pulsed electron beam source with grid plasma boundary stabilization, a rectangular vacuum chamber with a peephole and a two-coordinate desk-manipulator, power supplies of the electron source, a PC-based control system with microcontroller units, a gas-supply and a diagnostic system for controlling the source and e-beam parameters.

The main characteristics of the facility are the following:

– dimensions of the facility are 1350×2150×2000 mm;
– dimensions of the vacuum chamber are 600×500×400 mm;
– amplitude of the e-beam current is 20–250 A;
– electron energy is 5–25 keV;
– duration of the e-beam current pulse is 50–200 µs;
– pulse repetition rate is 0.3–20 Hz;
– maximum power consumption, depending on the accelerating voltage source used, is 2.5–10 kW;
– operating pressure is 0.01–0.05 Pa;
– working gas is argon;
– imprint diameter (surface melting zone without resort to the scanning mode) is 2–5 cm;
– the dimensions of the manipulator scanning region are 200×200 mm;
– water flow rate for cooling is no greater than 0.4 m^3/h.

A photo of the facility is shown in Fig. 1.

Fig. 1. Photo of the pulsed electron beam facility for surface modification

The facility consists of three modules.

1. A control rack comprising a PC, controllers of the vacuum system, a gas supply system and manipulator controllers. The control PC program can be operated with a keyboard and a mouse, as well as with a touch screen by pressing the corresponding facility units displayed on the monitor screen. Fig. 2 shows

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the window of the control program working with vacuum system. Figs. 3 and 4 show windows of the program working with electron source and manipulator.

2. A unit comprising a vacuum chamber with a vacuum pumping system and a manipulator, an electron source placed upright on the upper wall of the chamber, and storage capacitors of the accelerating high-voltage source.

3. A rack with power supplies (PS) of the pulsed electron source. The PS can be operated both in the off-line mode (from the PS controller panel) and with PC control.

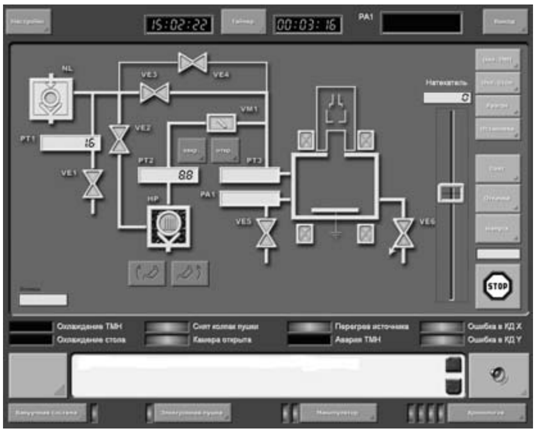

Fig. 2. Window of the control program during the operation with the vacuum system

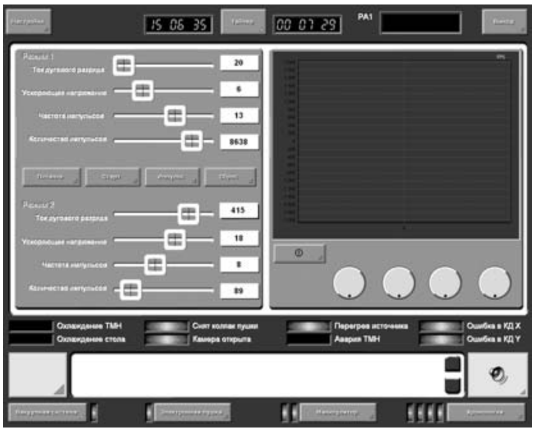

Fig. 3. Window of the control program during the operation with the electron source

The vacuum chamber is pumped down by a guided-vane rotary pump with a rate of 5 liter/s and by a turbomolecular pump with a rate of 500 liter/s. The turbomolecular pump makes it possible to stabilize the pumping rate of the system and to considerably decrease the ingress of oil vapors to the working chamber, which is required for stable operation of the electron source. Vacuum is controlled by digital vacuum gauges based on thermocouple vacuum gauges PMT-2 (vacuum gauge ATV-2.1) and ionization gauges PMI-51 (AIV-51.1) incorporated in the control system. The working gas (Ar) supply and the gas pressure are controlled by an RRG-10-type gas leak-in.

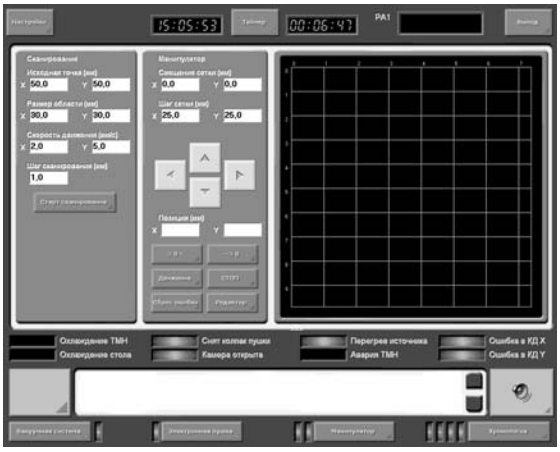

Fig. 4. Window of the control program during the operation with the manipulator

Figure 5 shows a photo of the manipulator arranged in the chamber. The manipulator ensures conveyance of treated objects of total weight up to 25 kg along two coordinates. The manipulator desk with holes for fixing the treated objects is displaced by two step motors located outside the vacuum chamber.

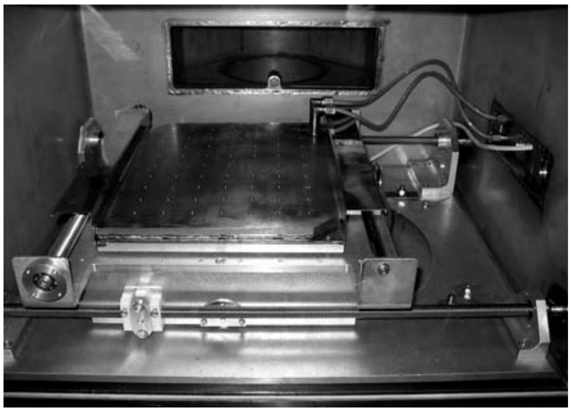

Fig. 5. Photo of the vacuum chamber and water-cooled manipulator

When operated at 10–20 Hz, the electron source, having an average power up to 5–8 kW in this mode, is capable, in addition to pulsed surface treatment, for preliminary bulk heating of objects, and this allows an increase in the quality of surface treatment for a range of treated products. In this case, the treatment is realized in two stages. At the first stage, a product is heated by current pulses of small amplitude and high repetition rate. At the second stage, a high beam current sufficient for surface modification within one or several pulses is used. Overheating of the manipulator desk is precluded by its water cooling.

Figure 6 shows a block diagram of the facility.

A pulsed electron beam is produced in a plasma-filled diode with a transporting magnetic field [4] using a low-pressure vacuum arc ignited between electrodes 2 and 3 by the auxiliary discharge initiated between electrodes 1 and 2. The discharges are powered by the secondary windings of high-voltage isolation

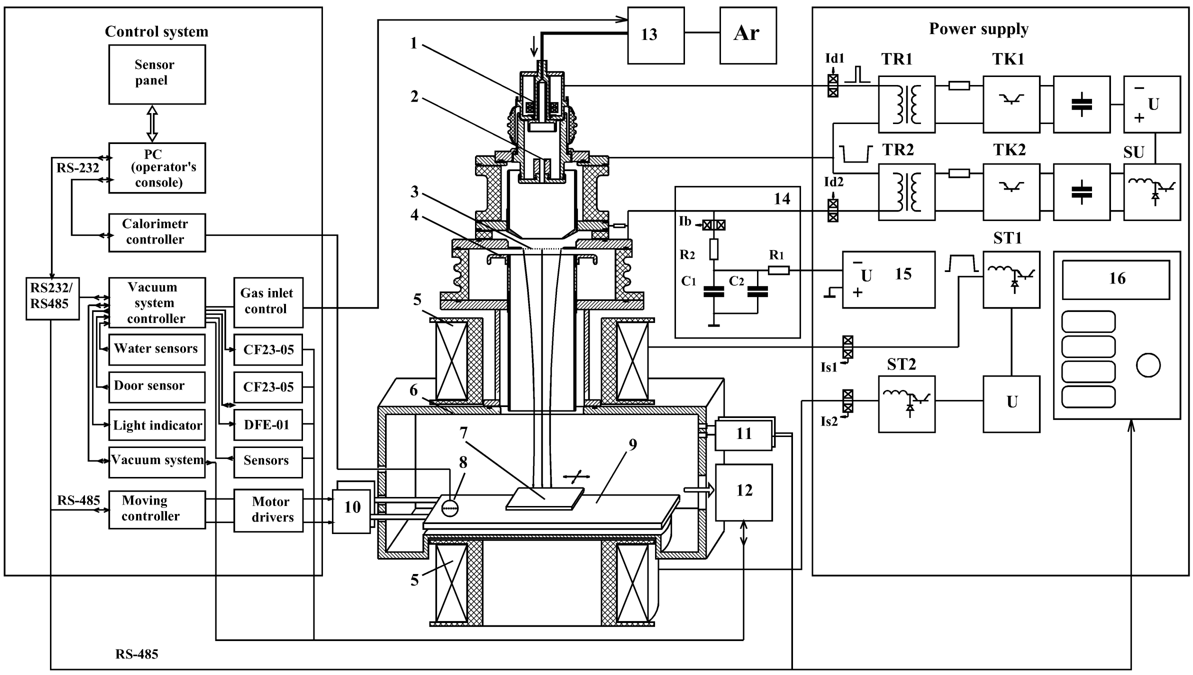

Fig. 6. Block diagram of the facility

transformers TR1 and TR2. The duration of the main discharge and thus that of the electron beam pulse is controlled by transistor switches TK1 and TK2. The power supplies ST1 and ST2 (produced as controlled current stabilizers) are used to produce a pulsed magnetic field. The electrons extracted through the grid meshes of the electrode 3 are transported in drift tube 4 in a magnetic field of 0.03–0.05 T produced by solenoids 5, and are delivered to vacuum chamber 6 and to treated products 7. The products are fixed on manipulator desk 9 and are movable by two stepping motors 10. The acceleration gap of the electron source is powered using high-voltage storage capacitors (capacitor unit 14) charged by DC voltage source 15. The operation of all power supplies of the electron gun is controlled by controller 16. The controller allows operation of the electron source both in the off-line mode (with a key board and an LCD display of the controller) and with the PC-based control system. The working chamber is pumped down by vacuum system 12. The pressure in the vacuum chamber elements is controlled by digital vacuum gauges 11. In the operating mode, the supply of the working gas (Ar) and control of the pressure in the vacuum chamber are provided by gas leak-in 13.

The facility also includes hard- and software for controlling the operation of the electron source and electron beam diagnostic devices. The pulsed currents in the electron source circuits are measured using Rogowski coils Id1 and Id2. The signals from the coils can be measured using both an additional external oscilloscope and built-in measuring devices (oscillographic USB attachment to the PC) with display of the oscillograms on the monitor screen of the control system. In this case, the oscillograms of the current in the circuits of the electron source are displayed in a special window of the program of a virtual oscilloscope. Detectors based on Hall Effect Is1 and Is2 allow, if required, to control the currents in the solenoid coils. The parameters of the electron beam in the region of its interaction with the treated objects can be measured by a calorimeter. For this purpose, the facility is equipped with a multi-channel calorimeter for measuring the electron beam energy density and the total beam energy per pulse and estimating the energy distribution over the beam cross section.

Calorimeter detector 8 (Fig. 6) is a set of Faraday cups with thermistors fixed on them and is connected to the calorimeter controller operating by a special program in the control computer. The beam energy is measured through comparing the temperature of the Faraday cups by the thermistors before and after the current pulse of the electron beam.

The PC control system provides automatic pumping of the vacuum system and precludes emergency conditions, including blocking of false actions of the operator. The current state of the facility is displayed on a three-color light indicator located above the facility. In the case of continuous (no-break) power supplies, safe shutdown of the facility is ensured, including automatic closure of the mechanically driven vacuum valve with the drive motor powered by a frequency converter DFE-01. Safe shutdown of the turbomolecular pump powered by a frequency converter CF23-05 is also ensured. In the operating mode, the PC software provides setting of the required operating pressure and the modes of the electron source operation, and control of the manipulator desk motion by the preset program. An important feature of the manipulator control program is that in addition to manual control, the manipulator desk motion is controllable in the programmed regime. In this case, a set of instructions preset in a special editor window is executed. The control program may contain not only control instructions for the manipulator, but also those for the electron beam source. Thus, the program of treatment of a definite product can be stored in a separate PC file and reused for treating similar products in the automatic mode.

3. Conclusion

1. The automated facility for surface modification of metal and cermet materials and products by a submillisecond intense pulsed electron beam with programmable preset and gradual control of the e-beam parameters (electron energy, beam current, repetition rate, and pulse width) has been designed.

2. The control system of the facility provides an up-to-date service and increased safety during the operation of the equipment. The automated treatment process makes it possible to increase the reproducibility of pulsed e-beam surface treatment of materials and products.

3. The diagnostic devices and on-line control of the electron beam parameters allow selection and optimization of the modes of electron beam treatment for a wide range of materials and products.

4. The facility is applicable for electron beam surface polishing of metal and cermet products, pulsed surface quenching from the molten state, surface conditioning by removal of fusible components, and other processes requiring controllable energy fluxes in the form of a pulsed electron beam.

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