https://doi.org/10.46813/2022-140-154

SMALL-SIZE "DI-2" ACCELERATOR WITH THE PLASMA CURRENT SWITCH AND INDUCTIVE ENERGY ACCUMULATOR AS A MATERIAL IRRADIATION TEST RIG

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This scientific paper delves into the basic characteristics of the updated "DI-2" accelerator, i.e., currents, voltages and pulse duration as a function of a delay time between the pulses generated by the major pulse current generator (PCG) and the PCG for plasma guns (PG). Consideration was given to the possibility of the use of heavy-current accelerators "VGIK-1" and "DI-2" as test rigs to study the effect of the heavy-current electron beam onto the surface of different materials to modify their physical and chemical properties.

PACS: 29.27.−a, 79.20.Rf

INTRODUCTION

One of the most promising methods used for the modification of the near-surface layer of the items made of different materials to improve their surface-volumetric strength and corrosion–operative properties is considered to be at the moment the electron-beam pulsed treatment. In comparison to the widely spread laser technology the electron-beam technology has great opportunities for the control and monitoring of the amount of energy supplied to the large areas of the treated surface and it differs by the energy distribution volumicity in the pre-surface layer of the treated material and by a high efficiency coefficient [1].

Heavy-current accelerators of a direct action generate the electron beam with the power up to 10^9 W/cm^2 in μs-, ήs- range of action. In particular, these include also the accelerators with the inductive energy accumulator (IEA) and plasma current switch (PCS) [2]. Appropriate impact energies result in super-high heating rates ($10^8…10^{10}$ K/s) attaining melting temperatures followed by the subsequent cooling of the thin near-surface layer of the material ($10^{-7}…10^{-6}$ m). Rather short time ($10^{-6}…10^{-3}$ s) of action of high temperatures, formation of maximum temperature gradients (up to $10^7…10^8$ K/m) that provide cooling of the near-surface layer due to the heat removal to the basic volume of the material at the rate of $10^4…10^9$ K/s create favorable conditions for the formation of amorphous-, nano-, and submicrocrystalline structure in the near-surface layer.

The main problem of the use of the accelerators of this type for applied technology purposes is relating to the difficulties of the recording of the output beam parameters. It results in the difficulties of the standardization of the treatment process and in origination of the spread in the characteristics of the treated parts. The solution of this problem requires the introduction of efficient numerical methods of the control of the primary circuit parameters and computer-aided synchronization systems and at the present time NSC KIPT is involved in the solution of this problem.

PROBLEM STATEMENT

Consideration was given to the use of the heavy-current accelerators of a direct action of μs- and ήs-ranges "DI-2" and "VGIK-1" that were developed by NSC KIPT to arrange the test rig for the treatment of the materials by heavy-current electron beams:

- Small-size electron accelerator of a direct action "DI-2" with the inductive energy accumulator and plasma current switch [3, 4] was arranged in a basement and flooded with water. After that it was rebased and upgraded. Maximum parameters of the upgraded accelerator "DI-2" allow for the generation of the high-energy electron beams up to 400 keV, with the current up to 200 kA and duration of 10 ns to 300 ns. The accelerator "DI-2" includes the pulsed current generator (PCG) based on the low-induction capacitor IKM-50/3 (3 μF, 50 kV) and coaxial vacuum duct, i.e. the IEA that is pumped with energy during the discharge of the major PCG, the PCS and the vacuum diode that form the electron beam source.
- The small-size electron accelerator "VGIK-1" was built based on pulsed voltage generator (PVG) according to the Arkadev-Marx diagram with the following parameters: electron beam energy up to 300 keV, current 15 kA, and the pulse duration of 1 μs. In the past, the accelerator "VGIK-1" was used for the experiments carried out to modify the surface-volumetric properties of different materials [5].

The experimental data obtained for the effect of the electron beam of a μ-second range were described in detail in [6]. Expectedly, the use of shorter pulses with controlled parameters will result in the generation of the physical and chemical properties of the treated materials required for the industry.

EXPERIMENTAL DATA OBTAINED USING THE "DI-1" TEST RIG

The upgraded "DI-2" accelerator showed that the high-power pulsed source can be created using the small-size heavy current electron accelerator of a direct action in combination with the IEA and PCS and it can be used for the solution of a wide range of applied problems of the material science and appropriate experiments.

The "DI-2" accelerator was modified to create a new power supply and accelerator control system that enabled the reduction of energy losses and improvement of the control of the repeatability of the experiments. An increased stability of the output parameters of the accelerator can be attained through an increase in the plasma density in the discharge gap and through more uniform distribution of the plasma density in the anode-cathode gap.

Some experimental data obtained using the "DI-2" accelerator are given below for different delay times T between the pulses of the PCG, PG, and the major PCG.

The load (diode) voltage was measured using the calibrated capacitive voltage divider with the division factor of K = 2000 [7]. The currents were measured using 2 Rogovsky belts (of a μs- and ήs-range) that were arranged on the capacitor bank of the major PCG in the region of the vacuum diode. The Rogovsky belt (of a μs-range) was also used for the current control of PG. The measurements were taken using the numerical oscilloscope SIGLENT SDS2204X with the bandwidth of 200 MHz. The charge of capacitive banks was controlled using ohmic voltage dividers and digital voltmeters [7]. The obtained measurement data are given in Fig. 1.

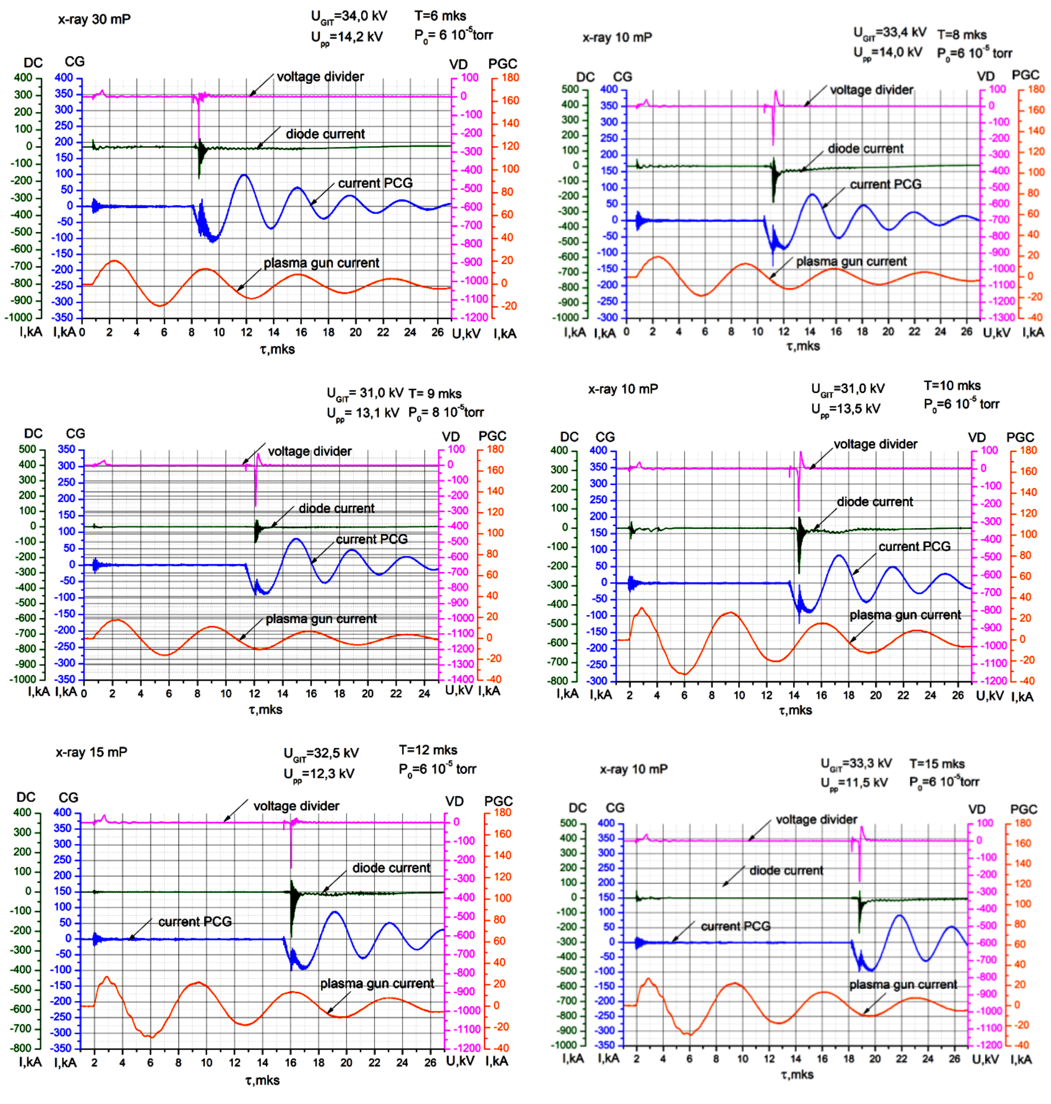

Fig. 1. Standard oscillograms with different time delays

The oscillograms show the following channels: voltage divider (C) that is the capacitive voltage divider on the load (diode), the diode current (total accelerator current), the current of the PCG, i.e. the current of the major PCG, the PG current (total current of 12 PGs). The oscillograms give the initial conditions in the upper right corner, in particular the charge voltage of the major PCG, the charge voltage of the PCG for PG, the delay time between the triggering of the PCG of PG and the major PCG – T, the residual pressure in the chamber – P_0 (Torr). Some oscillograms show the values of γ-measurements (X-ray) that were recorded by the accumulating dosimeter ID-0.2 designed for the measurement of the absorbed dose of radiation. The current pulse duration varied on average in the range of 20 to 300 ήs.

Fig. 2 gives the overvoltage pulse oscillogram for the capacitive voltage divider at a fixed delay time of T = 7.52 μs. The given delay value enables the generation of the overvoltage pulse above 300 kV at a time of tens ns. The experiment also shows a high data repeatability at a fixed delay time value.

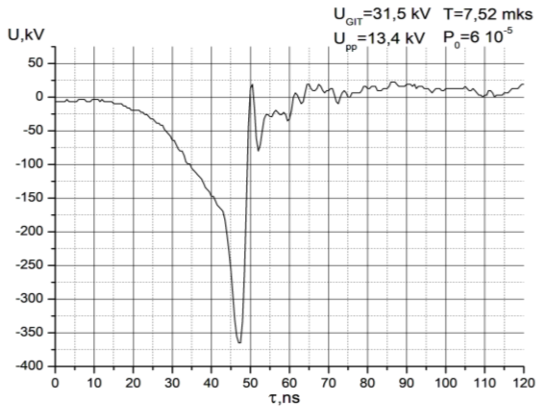

Fig. 2. Voltage pulse oscillogram for the capacitive voltage divider

DISCUSSING THE EXPERIMENTS

The main task when upgrading the accelerator was to get good data repeatability and the possibility to control the output parameters of the accelerator pulse (the diode overvoltage and current and the impact phase duration). To attain this goal we were to preset the parameters of the primary circuit, in particular PCG, PG and the major PCG voltage, to control the residual pressure of the neutral gas and preset the delay time between the triggering of the controlled dischargers of PCG – PG and the major PCG (T). The charge voltage of the capacitive bank of the PCG was limited by the opportunities of the used electrotechnical circuit elements that should be correlated with the geometrical configuration of the accelerator. The pressure was also limited by the opportunities of the vacuum evacuation system that enabled the operation at the acceptable level of $(5…8)\cdot 10^{-5}$ Torr. Hence, it is reasonable to use particularly the delay time T for the regulation and search of the optimal mode. Pulse oscillograms in Figs. 1 and 2 show that the control of only this single parameter enables the smooth control of the electron beam energy, the impact phase duration and respectively the temperature affecting the treated materials.

CONCLUSIONS

Based on the previous data obtained for the accelerator “VGIK-1” and experimental data obtained for the accelerator “DI-2” as described in the paper we can draw the following conclusions:

- The heavy – current accelerators used in combination with the IEA and PCS to treat the material surface have great prospects due to their high parameters and short impact time of the electron beam and also due to the opportunity to exercise control of its repeatability.
- Varying just one parameter (delay T) at constant charge voltages of capacitive accumulators we can select the required parameters (I, U) of the impact of the electron beam on the materials.
- At sufficiently high beam power density a low electron energy provides a low radiation level that simplifies the radiation protection that plays an important role in the accelerators used for technological purposes.
- The use of the accelerators in combination with IEA and PCS nullifies the need for the use of bulky high – voltage generators that noticeably reduces the overweight characteristics of the electric power supply circuits of the accelerator and it also reduces the high voltage protection expenditures and decreases the overall overweight parameters of the accelerator.

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Article received 08.08.2022

МАЛОГАБАРИТНИЙ ПРИСКОРЮВАЧ «ДІ-2» З ПЛАЗМОВИМ КОМУТАТОРОМ СТРУМУ ТА ІНДУКТИВНИМ НАКОПИЧУВАЧЕМ ЕНЕРГІЇ ЯК СТЕНД ДЛЯ ОПРОМІНЕННЯ МАТЕРІАЛІВ

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Наведено основні характеристики модернізованої установки “ДІ-2”, струм, напруга та тривалість імпульсу в залежності від часу затримки між імпульсами основного генератора імпульсного струму (ГІС) та ГІС плазмових гармат (ПГ). Розглянута можливість використання прискорювачів “ВГІК-1” та “ДІ-2” у якості дослідницького стенду по впливу сильнострумового електронного пучка на поверхню різних матеріалів для модифікації фізико-хімічних властивостей.