THE ELECTRON ACCELERATOR BASED ON THE SECONDARY-EMISSION ELECTRON SOURCE FOR MATERIAL-SURFACE TREATMENT

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Abstract

Results are reported from the studies on the electron beam parameters of the accelerator based on a secondary emission source. The accelerator forms the electron beam with an electron energy of up to 100 keV, a current up to 110 A, a pulse duration between 10 and 20 μs with a repetition rate of 3 to 5 Hz, the power density on the target surface being ~ 2 MW/cm^2. Targets from various materials were exposed to radiation.

INTRODUCTION

Powerful electron beams present one of the efficient methods for modifying surface properties of materials. This is currently central for increasing the strength, wear resistance and corrosion resistance of structural reactor materials, for lengthening the service life of reactor components, aircraft and car engines, for removing spent coatings, etc. It has been demonstrated in [1] that the following electron beam parameters are optimum for material surface modification: electron energy 50 … 150 keV, energy density 15 … 80 J/cm2, power density on the material surface under treatment 1…5 MW/cm2, pulse length 5…50 μs.

The reliability and service life of accelerating devices are to a wide extent determined by the lifetime of the electron source. In the accelerator under study, a magnetron gun with cold secondary-emission cathodes in crossed fields is used as an electron source. These guns are simple in design, hold down emission after a multiple letting-to-air, their service life may attain 100 000 hours. In the present work the parameters of the electron beam on the target are investigated as functions of magnetic-field amplitude and distribution.

THE EXPERIMENTAL FACILITY AND RESEARCH TECHNIQUES

The electron accelerator (Fig. 1) comprises the following main units: a HV pulse generator 1; an electron source with a secondary-emission cathode 6 and anode 7 placed in a vacuum chamber 3; a solenoid 4, which generates a longitudinal magnetic field, with a power supply 5; a target device with a Faraday cup 8; a computer-aided measuring system 9 to measure the beam parameters.

To energize the electron source of the accelerator, it is necessary to have a pulse generator providing voltage pulses of great duration [2]. The voltage bump amplitude ranges between 30….160 kV, the bump decay duration is about 0.3 μs, the amplitude of the pulse flat-top part makes about 20…100 kV, the pulse duration is between 30 and 15 μs, and the pulse-recurrence rate is 3 … 5 Hz (Fig. 2)..

The electron source is a coaxial system with a secondary-emission cathode 6 in crossed fields. The anode 7 is connected to the earth through the resistor R5. The system has the following dimensions: the cathode diameter is 40 mm, the inner diameter of the anode is 78 mm, the lengths of the cathode and anode are 85 mm and 140 mm, respectively. The cathode and the anode are made from copper and stainless steel, correspondingly. The electron source was placed in a vacuum volume 3, where the pressure was measured to be ~ 10^{-6} Torr.

The magnetic field for electron beam generation and transport was created by the solenoid 4 consisting of 4 sections, which were energized by dc sources 5. The amplitude and longitudinal distribution of the magnetic field could be regulated by varying the current value in the solenoid sections.

The target device was arranged on the end part of the stainless steel Faraday cup, which was cooled with water and was at a distance of 100 mm from the gun. The cup surface carried the fixed targets exposed to radiation.
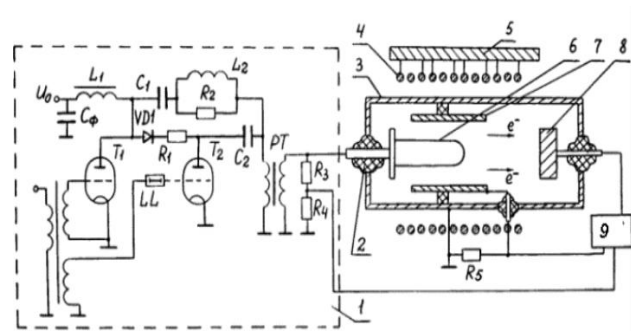

Figure 1: Accelerator circuit. 1 – pulse generator, 2 – insulator, 3 – vacuum chamber, 4 – solenoid, 5 power supply of the solenoid, 6 – cathode, 7 – anode, 8 – Faraday cup, 9 – computer-aided measuring system.

The measurement data on the voltage pulse, the beam current at the Faraday cup, the anode current and the stability of their values were processed by a computer-aided measuring system 9 [3]. The measurement error makes 1…2%. The transverse beam size and the radial beam-current distribution were determined with the use of imprints on the targets made from different materials.

EXPERIMENTAL RESULTS AND DISCUSSION

In the present experiments, the electron beam parameters of the accelerator were investigated at a cathode voltage between 20 and 100 kV.

The beam current from the Faraday cup was investigated as a function of the magnetic field distribution along the transport channel. Fig.3 shows the longitudinal magnetic field distributions along the axis of the magnetron gun and the beam transport
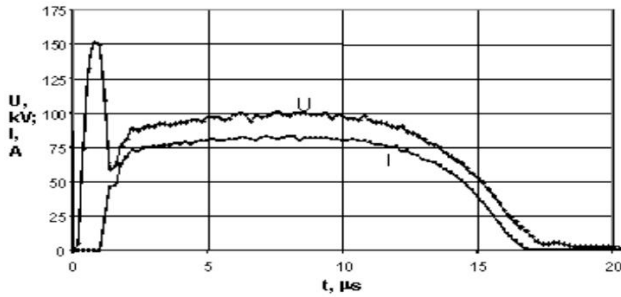

Figure 2: Oscillograms of cathode voltage (U) and beam current (I) pulses.

channel to the Faraday. The same figure schematically shows the layout of magnetron gun components and the Faraday cup.

As demonstrated by the experiments, in the decreasing magnetic fields (Fig. 3, curves 1 and 2) at a cathode voltage of ~ 100 kV, the magnetron gun forms the electron beam with a current of 110 A at a pulse length of 15 μs, and the anode current makes about 0.3% of the beam current. In the case of an increasing magnetic field in the transport region (Fig. 3, curve 3, when the magnetic field amplitude in the cathode region remained practically the same), the beam current decreased by 15 … 20%. Typical oscillograms of cathode voltage pulses and of the beam current are shown in Fig. 2.

It should be noted that the formation of the beam and its parameters in falling magnetic fields with the same diameter of the cathode but with a smaller diameter of the anode (70 mm) were described in ref. [4]. From those
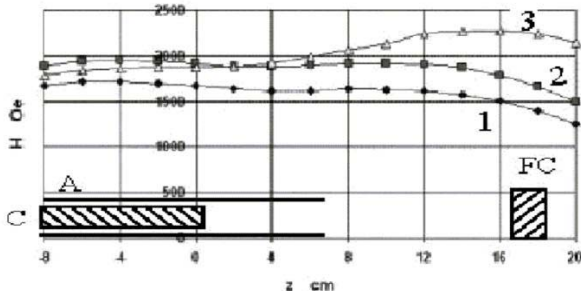

Figure 3: Three cases of longitudinal magnetic field distribution and the layout of components. A – anode, K – cathode, FC – Faraday cup.

results it follows that the optimum magnetic field distribution for beam generation should fall from the cathode to the Faraday cup. In this case, the beam current

is maximum, and the coefficient of azimuthal beam inhomogeneity is minimum and makes K= 1. 1. At a cathode voltage of 50 kV a beam current of 50A was obtained, the power density on the target was ~ 0.6 MW/cm^2. The beam size on the target was measured to be 50 mm in outer diameter and 44 mm in inner diameter.

The beam current to the Faraday cup was investigated as a function of the cathode voltage in the falling magnetic field. The function is found to obey the 3/2 law in the voltage range between 20 and 110 kV. In this case, in the process of measurements for each fixed voltage value there was the optimum magnetic field value, at which the beam current amplitude was maximum.

The width of electron beam generation zone in the magnetic field ΔH (where ΔH = Hmax- Hmin, Hmax and Hmin being, respectively, the maximum and minimum magnetic field values for the beam generation) was measured at different cathode voltages and different forms of magnetic field distribution. The measurement results show that the generation zone width ΔH is dependent on the form of the magnetic field distribution. In the case of homogeneous or increasing-towards-the-Faraday cup magnetic field, the zone width is wider and is found to be within ΔH = 400 … 800 Oe, while in the falling magnetic field we have ΔH = 200 … 300 Oe. Experiments were made to obtain the maximum parameters of the electron beam in the falling magnetic field at a voltage amplitude of ~ 100 kV. It is shown that the beam formation begins at a magnetic field of ~ 1700 Oe at the cathode (Fig. 3, curve 1), and continues until the magnetic field amplitude increases up to ~ 2000 Oe, i.e., the beam generation zone in the magnetic field makes ΔH ~ 300 Oe (Fig. 3, curve 2), and the beam current reaches ~ 110 A. Note that in this case the amplitude and shape of the beam current pulse change but little (~ 2…3 %) at the generation zone boundaries. A considerable beam generation zone width ΔH is very important in the use of the magnetron gun-based accelerator for technological purposes as the accelerator is being tuned.

Measurements of the electron beam size were carried out on targets made from different materials (aluminum, copper, stainless steel). With a magnetic field strength of ~ 1500 Oe at the cathode and its rise towards the Faraday cup up to 1750 Oe (that leads to a reduction in the beam thickness) and at a cathode voltage of 75 kV, the magnetron gun forms an annular electron beam with a current of ~ 60 A (power density on the target ~2 MW/cm^2), the inner diameter being ~ 37 mm and a wall thickness ≈ 2 mm . As is seen from the figure, the beam has a rather high azimuthal homogeneity, this being in agreement with the results of ref. [4]. Beam imprint on the target from different materials show on fig.4.

Fig 5 shows the radial electron density distribution of the beam in relative units (the plot was obtained from computer-aided processing of the imprint in one of the modes). It can be seen from the figure that the homogeneity of the electron density makes ± 17 %.

Targets made from different materials were exposed to radiation. Among the materials, there were titanium (Table 1) and tool steel (U12M, KhVG, Kh12N) having the surface hardening property.
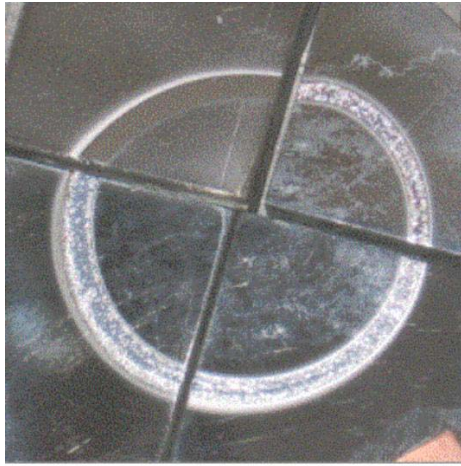

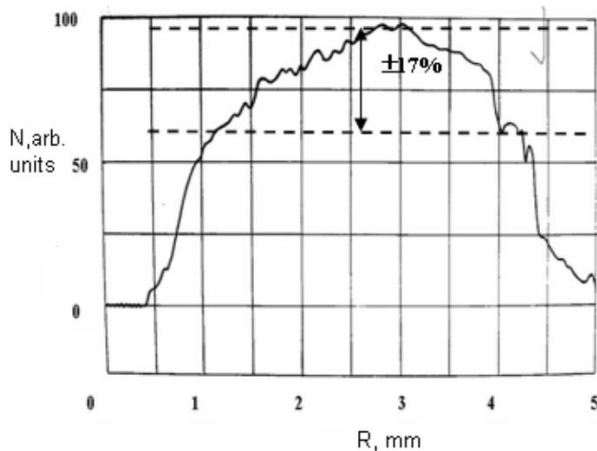Figure 4: Beam imprint on the target from the different materials.

Figure 5: Radial electron density distribution of. beam.

The irradiation of targets was performed under the same conditions, in one experiment, with all 4 specimens fixed on the target device. It is obvious from the table that approximately a two-fold increase in the microhardness of steel takes place.

Table 1.

Material under treatment	Electron energy, keV	Power density on the target, MW/cm^2	Micro-hardness before treatment, kg/mm^2	Micro-hardness after treatment, kg/mm^2
Steel KhVG	~ 75	~1.6	232	473
Steel U12M	~ 75	~1.6	232	550
Steel Kh12N	~ 75	~1.6	192	412
Titanium	~ 75	~1.6	148	210

CONCLUSIONS

Thus, the investigations of the beam formed by the electron accelerator with the magnetron gun as the basis have resulted in attaining the maximum parameters, at which the beam current on the target makes ~ 110 A, the electron energy is ~ 100 keV at a pulse duration of ~ 15 μs. At these parameters, the specific beam power reaches ~ 2 MW/cm2, this permitting the use of the electron beam of the accelerator in technological processes for modifying the material surfaces and for conducting research investigations.

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