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DIRECT-ACTION ACCELERATOR BASED ON THE MAGNETRON GUN WITH A SECONDARY-EMISSION CATHODE AND ITS APLICATION IN RADIO-TECHNOLOGIES

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Studies have been made into the parameters of the electron beam produced by the accelerator with the secondary-emission cathode magnetron gun as the basis. The experiments were performed in the energy range between 80 and 150 keV with a specific beam power on the target from 5 to 20 J/cm^2, this permitting the use of the beam for irradiating material surfaces. Plane metal samples were subjected to irradiation, and the radiated structure of material surface was examined by metallography methods. Experiments were made to measure the accelerator beam size in both decreasing and increasing magnetic fields; the possibility of irradiating inner and outer of cylindrical surfaces was demonstrated.
KEY WORDS: accelerator, magnetron gun, secondary-emission cathode, electron beam, irradiation, cylindrical surface.

УСКОРИТЕЛЬ ПРЯМОГО ДЕЙСТВИЯ НА ОСНОВЕ МАГНЕТРОННОЙ ПУШКИ С ВТОРИЧНОЭМИССИОННЫМ КАТОДОМ И ЕГО ПРИМЕНЕНИЕ В РАДИАЦИОННЫХ ТЕХНОЛОГИЯХ

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Изучены параметры электронного пучка ускорителя на основе магнетронной пушки с вторичноэмиссионным катодом в области энергий 80…150 кэВ с удельной мощностью пучка на мишени 5…20 Дж/см^2, что позволило использовать его для облучения поверхности материалов. Проведено облучение поверхности плоских металлических образцов и изучена структура поверхности материала после облучения металлографическими методами. Проведены эксперименты по измерению размеров пучка ускорителя в спадающем и нарастающем магнитных полях и показана возможность облучения внутренней и наружной поверхности цилиндрических областей.
КЛЮЧЕВЫЕ СЛОВА: ускоритель, магнетронная пушка, вторичноэмиссионный катод, электронный пучок, облучение, цилиндрическая поверхность.

ПРИСКОРЮВАЧ ПРЯМОЇ ДІЇ НА ОСНОВІ МАГНЕТРОННОЇ ГАРМАТИ З ВТОРИННОЕМІССІЙНИМ КАТОДОМ ТА ЙОГО ЗАСТОСУВАННЯ В РАДИАЦІЙНИХ ТЕХНОЛОГІЯХ

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Вивчені параметри електронного пучка прискорювача на основі магнетронної гармати з вторинно-емісійним катодом в діапазоні енергій 80…150 кеВ з питомою потужністю пучка на мішені 5…20 Дж/см^2, що дозволило застосувати його для опромінення поверхні металів. Проведено опромінення поверхні пласких металевих зразків і вивчена структура поверхні матеріалу після опромінення металографічними методами. Проведено експерименти з вимірювання розмірів пучка прискорювача в спадаючому та наростаючому магнітних полях і показано можливість опромінення внутрішній та зовнішній поверхонь циліндричних областей.
КЛЮЧОВІ СЛОВА: прискорювач, магнетронна гармата, вторинно-емісійний катод, електронний пучок, опромінення, циліндрична поверхня.

At present in many countries the beam methods (technologies) for material working with energy fluxes are developed and introduced into the industrial production. Using these methods it is possible to increase the wear resistance, corrosion resistance, fatigue strength, surface polishing of materials etc. For solving such problems one uses extensively the accelerators of intense electron beams with electron energy from 100 to 400 keV [1].

Over the last few years, the work is performed at the NSC KIPT Research Complex "Accelerator" to investigate cold-cathode electron sources operating in the secondary emission mode in crossed electric and magnetic fields [2-4]. Physical processes occurring during beam formation were investigated, with particular attention given to the study of beam current stability, azimuthally homogeneity, beam sizes, the influence of magnetic field components on the current amplitude, the electron bunch formation per voltage pulse, etc. [2,5]. Relying on the previous studies, in 2005 the electron accelerator was created. Parameters of a tubular electron beam from the accelerator [4] have been investigated in the electron energy range from 80 to 150 keV and with pulse duration from ~15 μs. Advantages of the secondary-emission source are as follows: no heating, simple design, ability to work under conditions of technical vacuum ($\sim10^{6}…10^{-5}$ Torr), high current density (~50A/cm^2 of the unit of transverse cathode area), cathode emission is not weakened after the air admission. According to evaluations it is generally accepted that the lifetime of cathodes is ~ 100000 hours.

The aims of the present work have been to investigate the electron beam parameters at particle energies between 80 and 150 keV, to modify the surfaces of metals and alloys during their exposure to the electron beam of the accelerator, and also to explore the possibility of the electron beam application for working the internal and external surfaces of cylindrical articles and increasing their corrosion resistance was studied.

ACCELERATOR DESCRIPTION AND RESEARCH TECHNIQUES

The schematic diagram of the accelerator is shown in Fig. 1. The accelerator consists of the following basic units: feeding high-voltage pulsed generator 1, a magnetron gun with secondary-emission cathode C and anode A placed in a vacuum chamber 3, solenoid 4, generating a longitudinal magnetic field, a target device with Faraday cup FC, and computer-aided measurement system 6 for measuring the beam parameters I_b, 2,5 –passed insulators, 7 – control unit. A feed voltage pulse from pulsed oscillator *1* is fed to the cathode of the magnetron gun. In the circuit of the supply pulse generator used is a full battery discharge through the correcting circuit to the step-up transformer, the voltage pulse being formed with the peak surge. Pulsed generator 1 provided the formation of a voltage pulse with an overshoot amplitude of up to 190 kV, an overshoot decay time of ~0.6 µs as for the development of secondary-emission multiplication processes, an amplitude of the flat part of the voltage pulse of up to 150 kV, its length of ~15 µs, and a pulse repetition frequency of (2…10) Hz.

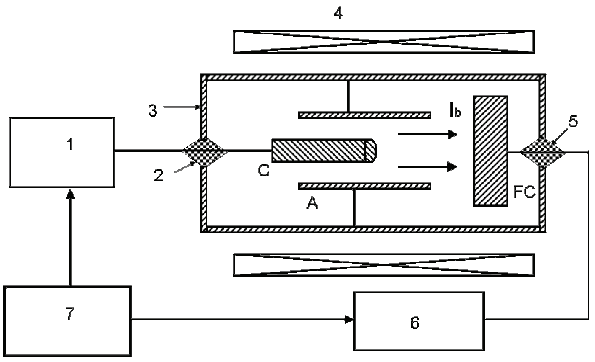

Fig.1. Schematic diagram of the accelerator

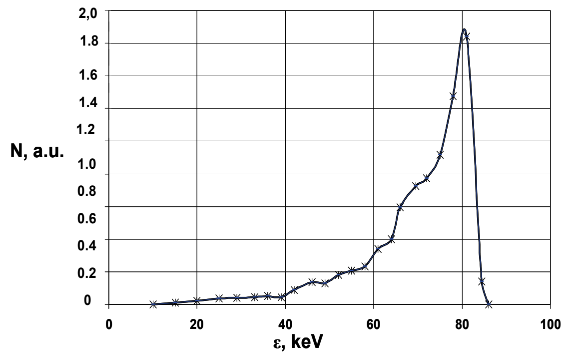

Fig.2. The energy spectrum of the electron beam of the accelerator

The source of electrons is placed in a vacuum chamber 3 with a pressure of $\sim10^{-6}$ Torr. The magnetron gun used to generate an electron beam has the following dimensions: the cathode diameter is 40 mm, the cathode length is 85 mm and the inner diameter of the anode is 78 mm, the anode length is 140 mm; the cathode material is copper and the anode material is stainless steel. The principle of operation of the gun is based on the back bombardment of the secondary-emission cathode with the electrons returned by the magnetic field, the formation of an electron cloud near the cathode, and the shaping of a beam [2].

The magnetic field for the generation and transportation of an electron beam is produced by solenoid 4. The amplitude and longitudinal distribution of the magnetic field can be controlled by varying the current magnitude in the sections of the solenoid. During irradiation, the beam current was considerably varied using this effect, as is shown in the Table, which lists the beam parameters upon the irradiation of the targets

Table

Parameters of accelerator

Energies	I, A	W, J/cm^2
50	55	-
60	68	-
80	85	20
100	110	-
120	125	~25

The electron-beam generation bandwidth over the magnetic field was ΔH ~ 300 Oe, which is of great importance for adjusting the accelerator used for technological purposes. Via processing the current and voltage oscillograms, we derived the energy spectrum of the beam (Fig. 2), which shows that ~80% of the beam electrons are in a range of ±7% with a maximum at 0.93eU (U is the cathode voltage).

The target device is placed on the Faraday cup end part which is made of stainless steel, water-cooled, and at a 100mm distance from the gun. The targets to be irradiated were mounted and fastened at the end face.

IRRADIATION OF METAL TARGET FLAT SURFACES

Irradiation has been performed on targets of various metals: steel, stainless steel, Ti, Zr, Zr+1%Nb alloy. The steels under consideration were chosen for surface hardening and zirconium alloys, applied in reactors, for upgrading their strength properties.

The targets were irradiated under similar conditions in one experiment, when a set of 3 -4 samples was fastened at the target device. The beam energy density was varying in different experiments within the range from 5 to 20 J/cm^2. The results obtained [6] have shown that the electron beam with characteristics, being used for metal surface irradiation, can produce appreciable changes in the near-surface layer structure, decrease the grain size, surface fusing, microhardness changes, etc.

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By irradiating the targets of Zr1%Nb and the energy density of the beam up to W = 20 J/cm^2 leads to the rapid heating of the sample surface to the melting point and, after the completion of the exposure pulse, the heated layer of

a) b) c)

Fig.3. Surface of metal after irradiation.

a) W=20 J/cm^2, mark 300 μm (down on the right)
b) W=20 J/cm^2, mark 30 μm (down on the right)
c) mark 0,5 μm (down)

the material is rapidly cooled. As a consequence of this, the structure and properties of the surface layer change. The modified surface and the interface between the irradiated and unirradiated portions of the sample are shown in Fig. 3a, 3b. The surface differs from the initial surface: cleaner and wider grain boundaries are observed and the grain size hardly changed. By irradiating the targets of stainless steel with a beam current pulse sequence, the nanosized (~100 to 200 nm) formations were obtained at the steel surface (Fig.3c).

The accelerator beam is a circular one, therefore it can be used for annular article irradiation, for example, for modification of collar bushings made from one-piece metal or composed of two layers from different metals [6], and for material surface alloying. Nanosized formations can be used for the research and development of autoemission cathodes and for electron-beam excitation of localized plasmons [7, 8].

IRRADIATION OF THE INNER AND OUTER CYLINDRICAL SURFACES OF THE SAMPLES

Using the accelerator annular electron beam propagating in the magnetic field it is possible to irradiate the internal (in the decreasing field, Fig. 4) or the external (in the increasing field, Fig.6) cylindrical surfaces of tubular samples.

Experiments on the measurement of the sizes of the beam (in the decreasing field, Fig.5c) show, that by during the transportation of the beam in a uniform magnetic field (H~1400 Oe) to a distance of ~100 mm, its diameter is almost unchanged (Fig.5a, curve 2). Further, during the transportation of the beam in a decreasing magnetic field to H ~ 600 Oe, the outer diameter of the beam increases to ~6 cm with a wall thickness of ~4 mm. At a distance of ~240 mm from the edge of the anode of the magnetron gun in a magnetic field of H~300 Oe, the outer diameter of the beam was ~8.5 cm with a wall thickness of 5—6 mm.

Preliminary experiments on the electron beam transport in the copper pipe placed at a distance of ~90 mm from the magnetron gun exit in the decreasing magnetic field were carried out to find optimum conditions for irradiation of the metal pipe internal surface. The copper pipe of 63 mm diameter and 150 mm length (Fig.5b) was composed of 5 rings, each of 30 mm length, the gap between rings from 1,5 to 2 mm. The pipe was placed in the magnetic field produced by a solenoid consisting of 4 sections.

Investigation results show that with ~80 keV electron energy, ~ 70% of beam current are dissipated at the internal pipe surface in the region of the 4th ring (Fig.5a, curve 3) on the ~30 mm length. In the increasing magnetic field

(Fig.5a, curve 1) ~65% of the current is dissipated at 5th ring (Fig.5a, curve 4), the current at the 4th ring decreases by a factor of 5, and, at the same time, the current going onto the central electrode increases by 20%.

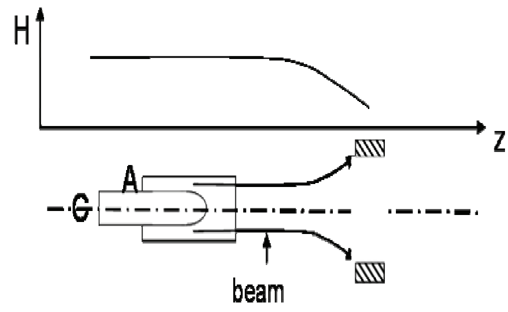

Fig. 4. Scheme of irradiation of the inner cylindrical surface of samples in the decreasing magnetic field

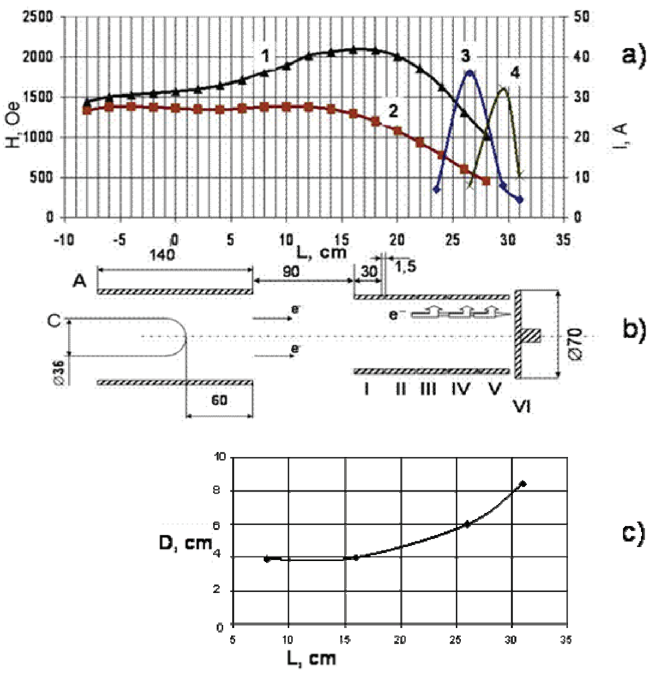

Fig. 5. Experimental results of irradiation of the inner cylindrical surface. a) longitudinal magnetic field distribution in two cases (curves 1,2), current dissipated at rings (curves 3,4) in two cases of longitudinal magnetic field distribution (curves 1,2), b) layout of the metal pipe and gun components, c) diameter of the electron beam D at different distances from the anode of the gun.

To study possibilities for irradiation of the external cylindrical surfaces the experiments have been carried out in which the external and internal beam diameters were measured during the beam transport in the increasing magnetic field.

Scheme of irradiation of the outer cylindrical surface of samples in the increasing magnetic field show on Fig.6. Experiments on measuring the outer of the beam during its transportation in an increasing magnetic field were carried out at a beam energy of ~60 keV and a beam current of ~50 A (Fig. 7). It is evident from the figure that the diameter of the beam decreases and its thickness is also reduced.

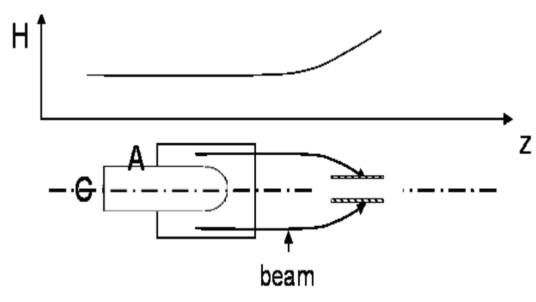

Fig. 6. Scheme of irradiation of the outer cylindrical surface of samples in the increasing magnetic field.

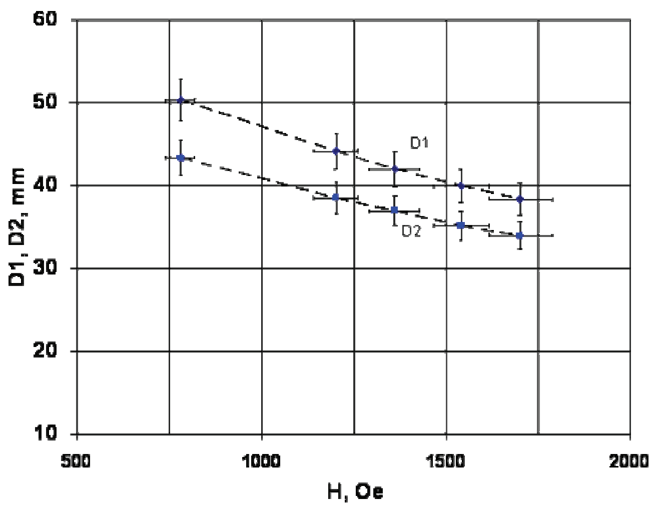

Fig. 7. Dependence of the (D1) outer and (D2) inner diameters of the beam on the amplitude of magnetic field (H) at a distance of 5 cm from the anode.

CONCLUSION

The direct-action accelerator based on the magnetron gun with the secondary-emission cathode can be recommended to use it for the oriented modification of flat and cylindrical surfaces of various metals and alloys, for scientific research and different radiotechnologies.

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