NEW TYPE SEALED-OFF ACCELERATORS OF 200-keV ELECTRON BEAMS

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Abstract

Devised sealed-off accelerators generate wide beams of electrons with energies up to 200 keV and high pulse power. The beam is extracted to an atmosphere through thin titanium foil being uniformly distributed over the area of exposure. Two types of the accelerators have been developed. The first type accelerator contains two round cathodes located at some distance. The second type contains a long ribbon cathode. The output windows have rectangular forms, so specially shaped cathodes and forming electrodes are used to obtain uniform distribution of the extracted beam. The accelerators do not require vacuum pumps, they are reliable and durable. Using the sealed-off electron accelerators, compact systems for radiation processing of materials have been developed.

1. INTRODUCTION

Compact sealed-off accelerators of electrons present a new promising class of devices. They generate wide electron beams and extract them to the atmosphere or a gas. These unique accelerators have been devised in "Istok" State Enterprise (Frjazino, Moscow Region).

The sealed-off accelerator of electrons is a version of a direct-action accelerator that is evacuated and hermetically sealed in the course of manufacturing. The electron beam is extracted through a thin titanium foil. The irradiation is made on a rather large area without using a beam scanner.

The sealed-off accelerator, unlike the other accelerators, is compact and durable unit which does not demand the application of a vacuum evacuation system, requires a short time to be prepared for service, provides interchangeability and good reproducibility of parameters.

The development of the sealed-off electron accelerators has been stimulated by the prospects of application of relatively low-energy (200 keV) electron beams in the industry, medicine and other fields.

Since the penetration of low-energy electrons into a material is not deep (about 0.1 mm), the radiation dose power is high enough even at low electron beam power. So the application of sealed-off accelerators may be efficient for the radiation treatment of thin polymer materials to improve their physical and chemical properties, or to produce new materials.

In medicine these accelerators can be used for the surface radiation sterilization of medical products. 20 kGy radiation dose required for reliable sterilization of medical devices may be received within 0.5 to 1 sec. The surface sterilization is highly efficient in those cases when the irradiation of an object down all the way is just detrimental, for instance, synthetic crystalline lens.

In the laser engineering, such type sealed-off accelerators may be used for the development of lasers powered by electron beams.

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2. ACCELERATORS DESIGN

In the course of development of the accelerators, there have been solved a lot of complicated scientific and technological problems, including development of electron beam optics providing uniform distribution of the beam on the output window, development of vacuum-tight output window with thin titanium foil, development of efficient and reliable cathodes, and development of technology providing for very high vacuum.

Two types of sealed-off accelerators have been designed. The first type unit has two round cathodes, the second type contains cathode implemented as a ribbon. The accelerators design is shown in Fig. 1.

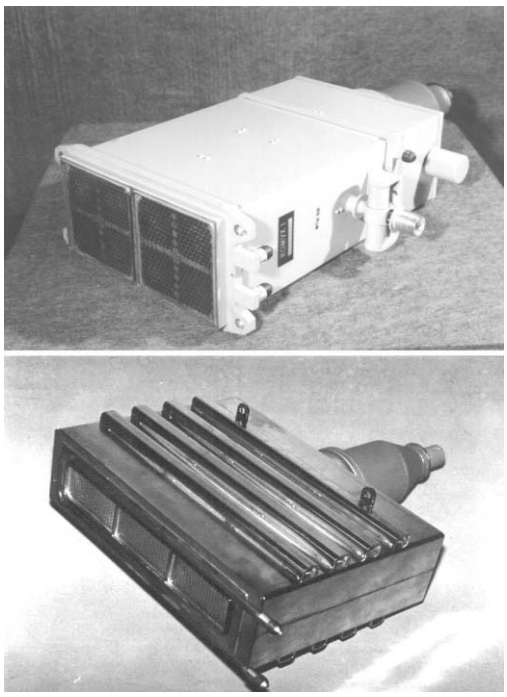

Fig. 1. Sealed-off accelerators with round (top) and ribbon (bottom) cathodes

3. ACCELERATOR WITH ROUND CATHODES

The accelerator design includes the following components:
- electron gun including two cathodes with heaters, forming electrodes, and high-voltage ceramic insulator;
- vacuum casing of rectangular shape;
- output foil window cooled by water flowing down the grooves located along the window outline;
- built-in miniature vacuum pump of electric-discharge type maintaining high vacuum (10^{-6} Pa) inside.

In the process of development of the electron optical system, we have been solved the problems of shaping a diverging electron beam to obtain uniform distribution of the beam beyond the output window and across the cathode area. To meet these requirements, the electron guns have been developed using the cathodes with a planar emitting surface and specially shaped forming electrodes (Fig. 2). Their shape was optimized with the help of 3-dimensional computer program.

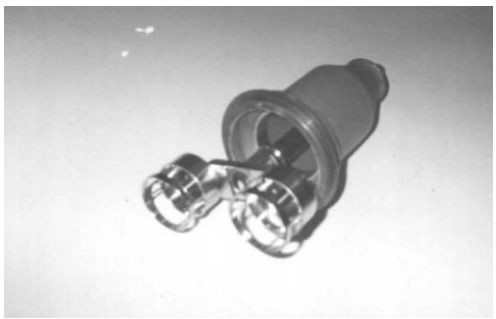

Fig. 2. Electron gun with two round cathodes

The development of output window was one of the major tasks in designing the sealed-off electron accelerators. The window should be reliable and adaptable to streamlined production. It should be equipped with the thinnest possible foil, made from the material with low specific weight. Titanium foil 20 μm thick is best suited to meet all requirements, including ecological, mechanical, vacuum and thermal requirements.

The output window contains two supporting arrays of square shape. The array is manufactured from copper and has a large number of holes providing the penetration of the electron beam. The titanium foil covering the holes is welded to the arrays. Special shape edges are used to strengthen joint between the output window and the casing.

Much attention has been given to the thermal stability of the output window. Since there is produced high power on the foil, to provide long life of the gun it is necessary to make an effective heat sink from the foil. The special method of calculation has been developed as well as a lot of experiments has been completed for optimization of the window [1].

The technology of fabrication of vacuum-tight window with thin foil is based on the diffusion welding foil to array. The welding is performed in the vacuum furnace at high temperature using special type fit-up fixtures. Their operation principle is based on the difference of the material thermal expansion factors.

The distribution of the electron beam beyond the window differs from the distribution before the window due to scattering of electrons by the foil. To obtain good beam distribution, diameters of the holes in the window arrays were selected. For better flattening, a flattener placed outside the accelerator was developed. Radiation dose non-uniformity less than 10% has been achieved using the flattener.

Theoretical and experimental works have resulted in the development of several types sealed-off electron accelerators providing for broad range of beam powers (Table 1).

4. ACCELERATOR WITH RIBBON CATHODE

The sealed-off electron accelerator with ribbon cathode has been designed for the radiation treatment of continuously moving tape. Major problems in designing the accelerator were the following:
- development of a reliable ribbon cathode operating at low filament current (no more than 5A) necessary to simplify a compact high-voltage pulse transformer;
- development of electron optical system providing for uniform distribution of beam on the output window;
- development of elongated output window.

The ribbon cathode (Fig. 3) has the emitting area of 320 x 6 mm. The forming electrodes provide for diverging electron beam with 320 x 40 mm cross-section and uniform distribution on the output window.

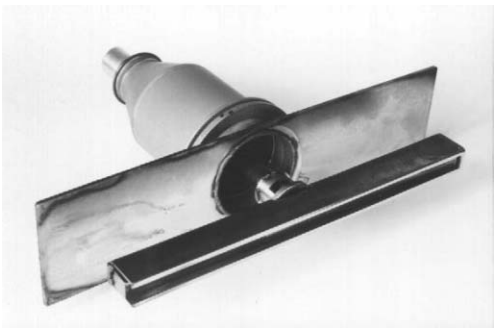

Fig. 3. Electron gun with ribbon cathode

In the course of development of the ribbon cathode, we have been studied two versions: metal-porous and oxide cathodes.

Table 1. Parameters of sealed-off electron accelerators

Type of electron gun	EG -1	EG -2	EG -3	EG-4
Cathode type	Two round			Ribbon
Cathode sizes (mm)	∅ 5.7	∅ 11.4	∅ 20	320×6
Maximum pulse current from cathodes (A)	6	15	80	25
Maximum voltage (kV)	200			200
Irradiation area (mm)	200×100			300×40

The ribbon metal-porous cathode has been made as a set of eight elementary ribbon cathodes 40 mm long each. Full cathode filament power is 200 W.

The ribbon oxide cathode has been made as a set of four elementary cathodes 80 mm long each. The filament power of the cathode is much lower (100 W). So the oxide cathode appears more attractive for the use in the sealed-off accelerator.

The electron output window consists of three parts joined with each other and the accelerator casing by argon-arc welding. Each of the window part is a copper array onto which a titanium foil (20 μm) is diffusion-welded.

By now the accelerator design has been developed, the prototype has been manufactured and tested. Its parameters also are given in Table 1.

5. RADIATION SYSTEMS WITH SEALED-OFF ACCELERATORS

Two types of compact systems for radiation technologies have been developed using the sealed-off electron accelerators.

The PYXIS system is intended for irradiation of objects located under the accelerator in fixed position. The system has two variants differed by the output beam power (Table 2). PYXIS-1 system is located in one unit with 0.7×0.7×2 m dimensions, PYXIS-2 system - in two units.

Table 2. Parameters of radiation systems

System	PYXIS -1	PYXIS -2	TAPIS
Electron accelerator type	EG-2	EG-2	EG-4
Accelerating voltage, regulated (kV)	100-200		
Maximum dose rate (kGy/s)	10	30	50
Maximum pulse dose rate (kGy/s)	7×10^4	7×10^4	2×10^5
Pulse duration (μs)	1	1	1.5
Pulse repetition rate, regulated (pps)	5-150	5-400	5-150

The TAPIS system is intended for irradiation of continuously moving tape with 30 cm width. The system includes the processing unit with 1×1.2×2 m dimensions (Fig. 4) and the power supply unit with 0.7×0.7×2 m dimensions.

In all the systems, the beam parameters may be regulated within broad ranges. The radiation chamber may be filled by nitrogen or other gas. All the systems have reliable radiation shielding and may be exploited in any rooms.

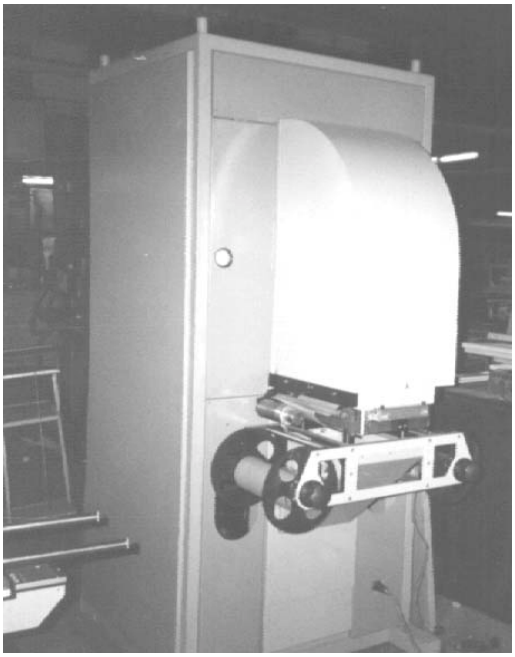

Fig. 4. TAPIS processing unit (radiation chamber open)

6. CONCLUSIONS

Developed sealed-off electron accelerators generate and extract to the atmosphere wide electron beams with 200 keV energy and high pulse power. They have a compact design and provide for reliable operation.

Several radiation technology systems have been developed using the sealed-off accelerators. One of the systems is in operation for more than 4 years now.

The sealed-off accelerator has received the Gold medal of Excellence and the special jury Prize at the World Exhibition of Invention, Research and Industrial Innovation “Brussels-Eureka”.

REFERENCES

[1] K. Simonov. Sealed-off electron guns. "Radio and communications", Moscow, 1985.