# CHARACTERISTICS OF SEALED-OFF ELECTRON GUN WITH WIDE BEAM

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*Abstract*

Compact sealed-off electron gun is a new promising type of devices. The gun generates wide beam of electrons with energy up to 200 keV and high peak power in 2-μs pulses. The beam is extracted to the atmosphere or a gas through the foil being uniformly distributed over the area of exposure. The gun contains the long cathode of oxide type, the electrodes intended to form required distribution of the beam, the output window with 20 μm titanium foil, the high-voltage ceramic insulator, and the vacuum casing of rectangular shape. The gun is applied in the radiation technology system intended for the treatment of continuously moving tapes with 300 mm width. The gun design provides ±10% uniformity of the radiation dose on the tape width.

## INTRODUCTION

Compact sealed-off electron guns present a new promising class of devices forming a wide electron beam with energy up to 200 keV and pulse power of several megawatt. The electron gun is pumped out and sealed-off in the course of manufacturing. The electron beam is extracted into atmosphere or other gas medium through a thin titanium foil and irradiate a product across a rather large area without using a special beam scanner. Unlike other electron guns, the sealed-off electron gun is a compact and long-life device which does not require an application of complicated vacuum pumping system, needs a short time to be prepared for service, provides interchangeability and good reproducibility of the parameters.

The “Istok” was the first firm in the world which developed devices of this unique design. The development of sealed-off electron guns has been stimulated by the prospects of application of relatively low-energy electron beams in the industry, medicine, laser technology and other fields [1]. Based on the sealed-off electron guns, compact systems for the radiation treatment of products and materials by accelerated electron beams have been developed [2, 3]. These systems are intended for radiation processing of thin polymer materials in order to improve their physical and chemical properties or to produce new materials. In the field of medicine, such systems can be used for surface radiation sterilization of medical products (synthetic crystalline lenses, implantable electrodes, etc).

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## DESIGN OF ELECTRON GUN

The sealed-off electron gun with wide beam is intended for radiation processing of a continuously moving wide tape. To produce the wide electron beam, the gun applies a long ribbon cathode [4].

Design of the gun is shown in Fig. 1. The gun contains the following components:

*1* - Ribbon cathode with heater and forming electrodes;
*2* - Vacuum casing of rectangular shape;
*3* - High-voltage ceramic insulator;
*4* - Miniature vacuum pump;
*5* - Output window with thin foil.

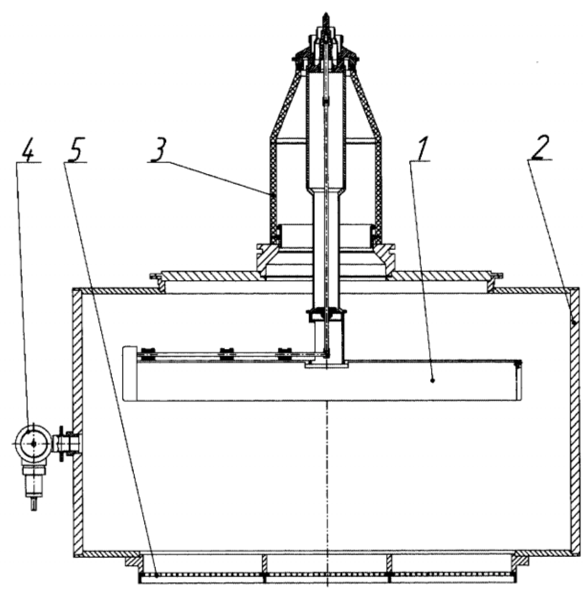


Fig. 1. Design of sealed-off electron gun

The main requirements to the ribbon cathode design are the uniformity of temperature along the cathode length, the stability of shape while heating the cathode, and the reliable operation of the cathode heater. Besides, the cathode filament current should not exceed 5 A to simplify a design of the high-voltage pulse transformer.

All the problems have been solved as a result of performing R&D work. The extended ribbon cathode comprises four interconnected elementary ribbon oxide cathodes with 80mm length each. The forming electrodes are applied to form a diverging electron beam and obtain good beam distribution on the output window.

The rectangular shape of the vacuum casing makes it possible to place the guns close to each other when it is necessary to use several guns simultaneously in a single radiation technology system.

The high-voltage ceramic insulator is made of a cylinder and cone joined together. Such design provides for a reliable compact connection of the insulator with the high-voltage pulse transformer. Usually the insulator as well as the pulse transformer are placed into an oil.

The built-in miniature electric-discharge vacuum pump has pumping rate of 1l/min. It ensures high vacuum inside the gun during the operation.

The important aspect is the development of a reliable and technological output window. The output window should use thin foil made from a material with low density. The 20 μm titanium foil meets all requirements, including ecological, mechanical, vacuum and thermal requirements.

The elongated output window includes three copper lattices designed to support the foil and remove the heat from it. Each lattice has rectangular shape and contains round or rectangular holes to pass the electron beam through (Fig. 2).

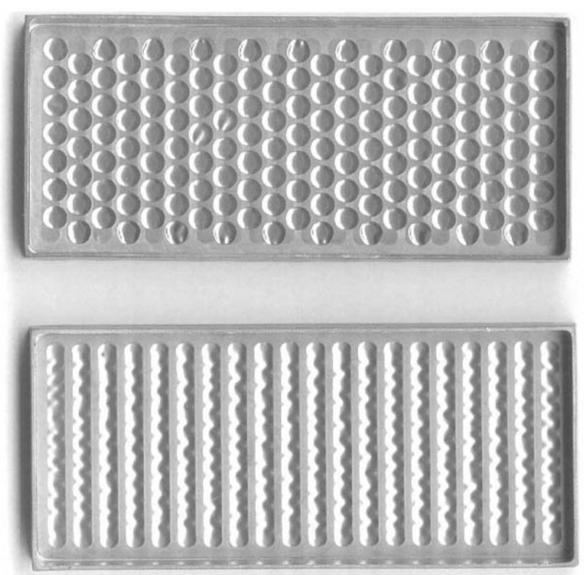

Fig. 2. Lattices with round and rectangular holes.

The lattices are brazed together and brazed to the vacuum casing. To provide a reliable long-term operation of the gun, an effective removal of heat from the foil is needed. The priority issue is the thermal stability of the output window: there has been developed a special designing method and performed a great amount of experimental studies on the optimization of the thermal mode [1]. The window is cooled by water running through channels located along the periphery of the window.

The technology of manufacturing vacuum-tight windows is based on the diffusion welding of the foil to the lattice. The welding is executed in a vacuum furnace at 700-800°C using special devices whose operation principle is based on the difference in the linear expansion coefficients of the materials. The output window with round holes is more reliable in operation although its geometric transparency is lower than that of the window with rectangular holes (Table 1).

Table 1. Main dimensions of the electron gun.

| | |
|---|---|
| Outer dimensions of gun | 480×430×120 $mm^3$ |
| Dimensions of ribbon cathode | 320×6 $mm^2$ |
| Irradiation area | 300×40 $mm^2$ |
| Foil in output window | Ti 20 μ |
| Dimensions of lattice | 108×48 $mm^2$ |
| Transparency of lattice:<br>round holes<br>rectangular holes | <br>62 %<br>67 % |

## PARAMETERS OF ELECTRON GUN

Important characteristic of the electron gun intended for a radiation processing is a uniformity of the distribution of the radiation dose that is determined by the distribution of extracted electron beam along the output window. To obtain good dose distribution, the electron optical system with special shape of forming electrodes has been developed. It was optimized using the computations and experimental investigations.

The electron beam dynamics have been computed by three-dimensional code. It gave a possibility to obtain rather good distribution of the electron beam incident on the output window. But the study has showed that the distribution of the electron beam outside the window differs from that of the incident beam due to the deviation of electrons by the foil and the edges of the window. That is why the final selection of the focusing electrodes has been made with regard to the experimental data for the distribution of the radiation dose behind the window.

Fig. 3 shows a version of distribution of the electron beam incident on the output window. Two-dimensional distribution of the beam current density on a half of the window is shown. The beam distribution along the window is rather uniform. However, the measured dose distribution behind the output window had waning edges (see Fig. 5).

To improve the dose uniformity, the correction of the distribution of the incident beam density has been performed. Increasing the current density on edges has been obtained by means of a special selection of shape and dimensions of the forming electrodes. Fig. 4 shows a version of the distribution of incident electron beam with corrected distribution of the current density. The density is increased at the window edges approximately by a factor of 1.5.

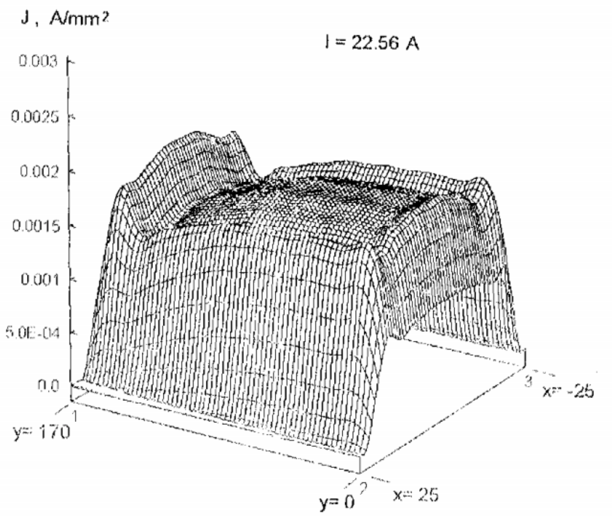


Fig. 3. Calculated distribution of incident electron beam without correction.

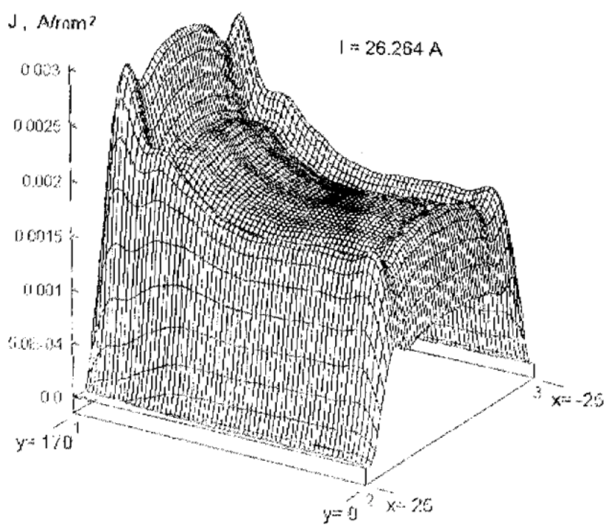


Fig. 4. Calculated distribution of incident electron beam with correction.

Fig. 5 shows measured distributions of the radiation dose along a half of the irradiation area. The distributions of dose without and with the correction are given. The doses were measured at 20 mm distance from the output window. In the case with the correction, the dose non-uniformity along 150 mm distance is within ±10%.

Output parameters of the sealed-off electron gun are given in Table 2. The gun has 6 MW pulse power of the incident electron beam and provides very high pulse power of the radiation dose.

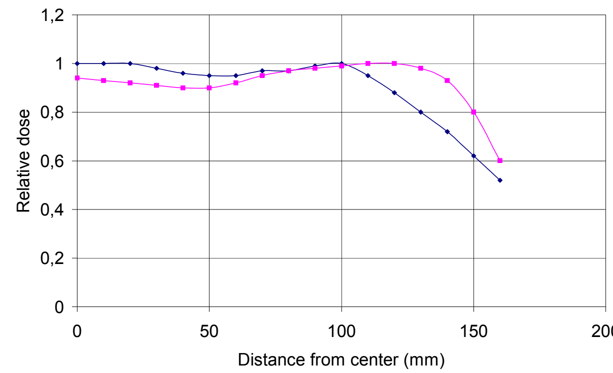


Fig. 5. Measured dose distribution along a half of irradiation area without and with correction of edge slope.

Table 2. Output parameters of the electron gun.

| | |
|---|---|
| Pulse voltage (regulated) | 100 - 200 kV |
| Maximum pulse current from cathode | 30 A |
| Maximum dose rate | 60 kGy/s |
| Maximum pulse power of dose | $2\times10^5$ kGy/s |
| Uniformity of dose distribution along 300 mm irradiation area | ± 10 % |

## CONCLUSION

The development and study of sealed-off electron guns with ribbon cathodes demonstrated that high pulse power, large radiation dose rate, and good uniformity of the dose can be obtained. The guns have compact design and ensure reliable operation.

Application of the sealed-off electron guns makes it possible to develop radiation technology systems for processing continuously moved tapes, in particular, made from polymer materials in order to modify their properties.

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