ELECTRON ACCELERATOR FOR ENERGY UP TO 5.0 MEV AND BEAM POWER UP TO 50 KW WITH X-RAY CONVERTER

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Abstract

The report describes the industrial electron accelerator ILU-10 for electron energy up to 5 MeV and beam power up to 50 kW specially designed for use in industrial applications. The ILU-10 accelerator generates the vertical electron beam. The beam line turns the beam through an angle of 90° and transports the beam to the vertically posed X-ray converter to generate the horizontal beam of X-rays.

INTRODUCTION

Since 1970, BINP SB RAS has been developing and manufacturing the ILU-type electron accelerators for the work in the research and industrial radiation-technological installations. The design and schematic solutions of the installations envisage a continuous round-the-clock operation under conditions of industrial production.

The ILU-type accelerators overlap the energy range from 0.7 to 5 MeV at an accelerated beam power of up to 50 kW. The intrinsic features of these accelerators are the simple design, ease in maintenance and the long term reliable operation under conditions of industrial production. Table 1 shows the basic parameters of the ILU-type accelerators produced by BINP [1,2,3].

Table 1: Basic parameters of the ILU-type accelerators

Parameters	ILU-6	ILU- 8	ILU-10	ILU-12 Project
Energy of electrons, MeV	1.2-2.5	0.6-1.0	2.5-5.0	4.0-5.0
Average beam power (max), kW	20	25	50	300
Average beam current (max), mA	20	30	15	60
Power consumption, kW	100	80	150	700
Accelerator weight, tons	2.2	0.6	2.9	5
Weight of local protection, t	-	76	-	-

The basic model of the ILU accelerators is the ILU-6 accelerator [1]. On the base of the ILU-6 accelerator, the ILU-10 accelerator was developed to satisfy the needs of technological processes requiring the energies up to 5 MeV. This report describes the ILU-10 machine.

GENERAL DESCRIPTION OF ILU-10 ACCELERATOR

The basic component of the accelerator is a toroidal copper cavity with an operating frequency of 116 MHz with axial protrusions forming the accelerating gap having length of 270 mm. The protrusion shape was chosen from the conditions of the formation and focusing of an electron beam in the processes of its injection, acceleration and further passage through the extraction system with minimum losses.

The cavity 2 is placed into the vacuum tank 1 (Fig.1). The electron injector 5 is formed by the cathode unit and the grid mounted in the upper protrusion. The lower electrode and injector form a triode accelerating system. The beam current of accelerated electrons is controlled by varying the value of the positive bias at the cathode with respect to the grid.

Under the lower electrode of the cavity there is a magnetic lens shaping an electron beam in the accelerator channel and the extraction device 6.

Two RF autogenerators 9 based on powerful triodes type GI –50A are installed directly on the vacuum tank. Generators 9 assembled according to the common grid circuit are working at frequency about 116 MHz that is near the specific frequency of the cavity. Anode circuits are coupled to cavity through the inductance loops. The coupling rate is determined by the square of loop and the tuning of the anode circuits. The generator feedback is provided by the additional capacitance made in the form of a disk inserted between the tube's anode and cathode. The value of capacitance is about 20 pF. The fine tuning of the feedback value and its phase is made by the cathode short-circuited tail with a movable shortcut contact moved by a servodrive. The coupling rate of generator with cavity is tuned during the accelerator's preliminary adjustment by varying the capacity of the vacuum capacitor 8 and the square of the coupling loop by varying the position of its support 7.

The measuring loop is installed on the upper flange of the tank. Its signal proportional to the cavity gap voltage is used for measuring the energy of accelerated electrons.

For stabilization of the leading front of the high frequency voltage pulse when applying the pulse voltage to the tubes anode, an additional excitation of the generator by the direct voltage of 0.9 - 1.5 kV is used.

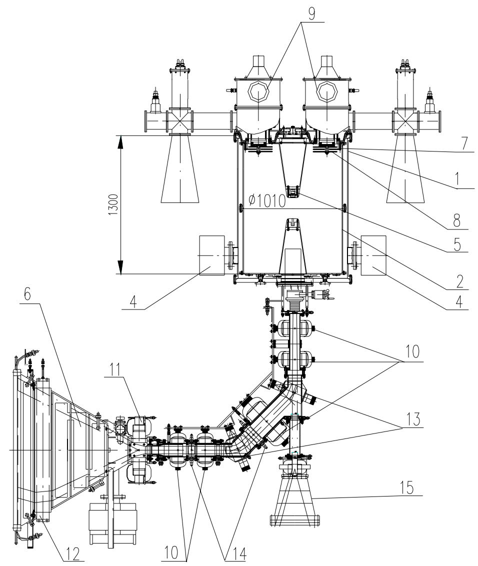

Figure 1: ILU-10 Accelerator. 1-vacuum tank, 2-copper toroidal cavity, 3-magnetic lens, 4-spallation pumps, 5-cathode unit, 6-extraction device, 7-support of coupling loop, 8-vacuum capacitor, 9-RF-generators, 10-quadruple lenses, 11-scanning magnet, 12-correcting magnet, 13-bending magnets, 14-pick-up stations, 15-direct extraction device.

The cavity is placed into the vacuum vessel made of stainless steel. The high vacuum pumping is done by four spallation pumps placed at the cylindrical surface of the tank. The forevacuum pumping is provided by the forevacuum aggregate through the nitrogen trap. All the sealings in the vacuum vessel are made of metal (copper and indium). The operating vacuum is of 10^{-7} Tor. In the normal operation of the accelerator intervals of about two days do not require the forevacuum pumping for switching on the spallation pumps. The vacuum tank pressure is measured by the current value in the spallation pumps.

The ILU-10 accelerator is a novel development and it is mainly designed for the processes requiring high energies of electrons and beam power. The accelerator overall dimensions are somewhat larger than those of the ILU-6 accelerator.

ELECTRON BEAM EXTRACTION

In recent years, in the majority of countries the beam technologies are being developed aiming at their use for irradiation products in the food industry. However, in the use of the electron-beam technology one should take into account that the electron beam permeability is rather small thus putting limitation to the amount of the irradiated material. A reasonable alternative seems to be the use of powerful fluxes of X-rays. To generate this radiation the electron beam can be directed to the X-ray converter. The technological process of the product treatment requires the certain type of the extraction device. For example, the beam bent at an angle of 90 grades enables a substantial simplification in the design of the conveyor system for subjecting the treated product to two-sided irradiation.

General view of the bending system design is given in Fig.1 [4]. The beam from the accelerator reaches the bending channel and is turned there throgh an angle of 90 grades and hits vertical long optimized X-ray converter, which is an aluminum plate coated by the layer of tantalum.

The channel is an electron optical system having two 45 grades bending magnets with the parallel ends, quadruple lens with a large radial aperture, two adjustable lens doublets, scanning magnet and correcting magnet. The scanning magnet in a period of 500 mks scans the beam from above to down along the converter of 1 m in length. The scanning angle is ranging from -25 to +25 grades.

For the formation of the technologically optimum dose field, an electron beam should be incident at the converter edges at an angle close to 90 grades. This is provided by the use of the correcting magnet located at dis6tance of 15 cm from the converter. All the components of the beam channel have the water cooling systems enabling to remove totally of up 5 kW heat in a continuous regime. The system of vertical extraction of a beam through titanium foil is kept for expanding the technological capabilities of the accelerator.

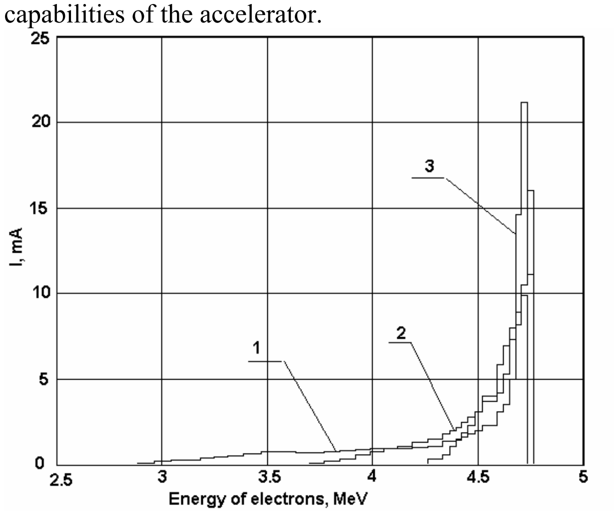

Figure 2: Experimental spectrum of beam electrons.

The ILU-10 accelerator is the RF machine and so the initial energy spectrum of electrons in beam is not monochromatic but has the certain energy spread. To increase the X-ray power output the energy spectrum of electrons ought to be more narrow because the low energy electrons do not make the input into the X-ray power, and their energy is transformed into the heating of target. It is possible to improve the energy spectrum of electron beam (to decrease the part of low energy electrons) by applying the high frequency bias voltage on the grid-cathode gap of the accelerator's electron gun. Experimental data obtained from beam spectral characteristics measurements at ILU-10 output at the constant grid-cathode bias (1) and with the use of the first (2) and third (3) harmonics are presented in Fig.2.

A magnetic spectrometer with not uniform magnetic field and electron beam rotation angle of 150° at 200 mm radius was used during measurements. 3 mm wide collimating slots were installed at the spectrometer input and output.

CONCLUSION

During the tests the following parameters are obtained: the maximum electron energy of 5.5 MeV at a low beam power, electron energy of 5 MeV at a beam power of 50 kW and 4.5 MeV at a beam power of 60 kW.

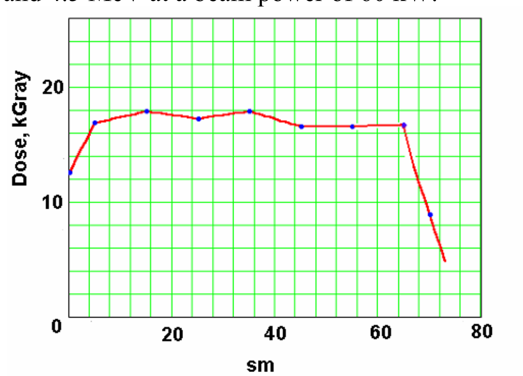

Figure 3: Dose distribution along the beam window.

The ILU-10 accelerator is a pulse machine, the maximum pulse repetition rate is 50 Hz, the pulse duration is 400-500 mks. In the work with the tantalum converter, a rather homogeneous dose distribution on the irradiated material surface was obtained. At the scanning width of 60 cm, the average dose value was 18 kGy with the conveyor equivalent speed of 1 mm/s. Dose distribution along the beam extraction window is presented in Fig.3.

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