ELECTRON ACCELERATOR FOR ENERGY UP TO 5.0 MEV AND BEAM POWER UP TO 50 KW

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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 operation regime is a pulsed regime, the maximum pulse repetition rate is 50 (60) Hz, a pulse duration is 0.4-0.5 ms.

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]. The base model of the family is ILU-6 This machine has rather high parameters at modest dimensions and can be used for wide spectrum of technological processes. The protected hall with inner dimensions 3*4*5 m is big enough for its placement. The necessary volume of concrete for construction of such hall is about 180 m^3 (the required wall thickness is of about 1.5 m).

The model ILU-6 is widely used as in our country and abroad. A principle of high-voltage acceleration is used in majority of modern accelerators, i.e., the energy of electrons corresponds to the voltage generated by the rectifier. The industrial accelerators type ILU are the exception of this rule. A principle of acceleration of electrons in the gap of HF resonator is used in the ILU machines. Such accelerator does not contain details, potentials of which in respect to the ground is comparable to accelerating voltage. So the complex high-voltage units (accelerating tubes, sections of rectifiers and etc.) which are damaged by the occasional discharges are not used in ILU machines. And so there is also no necessity to use insulating gas and high-pressure vessels.

Use of a principle of high-frequency acceleration has allowed to create rather simple design of the machine having modest dimensions and weight. As a result the machine can be placed inside the hall of the smaller dimensions comparing with the halls for high-voltage accelerators having the same parameters.

The pulse nature of electron beam generated by ILU machines enables one to direct the beam into various channels of the beam extraction device without beam losses. Hence, there is the opportunity to create the extraction devices forming an irradiation zone according to the form of a treated product, that permits to increase efficiency of beam usage.

The model ILU-8 is the result of its further development. It is designed mainly for processing of cables and tubes. This accelerator does not require construction of a special protected premise (hall) and can be placed in usual industrial shop. It can work inside the local biological shielding. The local shielding of the accelerator is a kind of a box made from steel plates. Inside the box is divided into two parts. The top part is used to place accelerating system with HF resonator, spallation vacuum pumps and forevacuum system. The beam extraction device, air pipes of ventilation system and technological equipment are placed in the bottom part of the shielding. The back wall of the shielding has the channels (labyrinths) for input of cables, air and water pipes. The removable front wall serves as a door of a protective box. The thickness of radiation shielding in side walls part is 330 mm and in top is 240 mm. Gross weight of shielding is 76 tons. The reduction factor for brake radiation (Bremsstrahlung) at electron energy 1.0 MeV is not less than $5*10^7$.

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.

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.

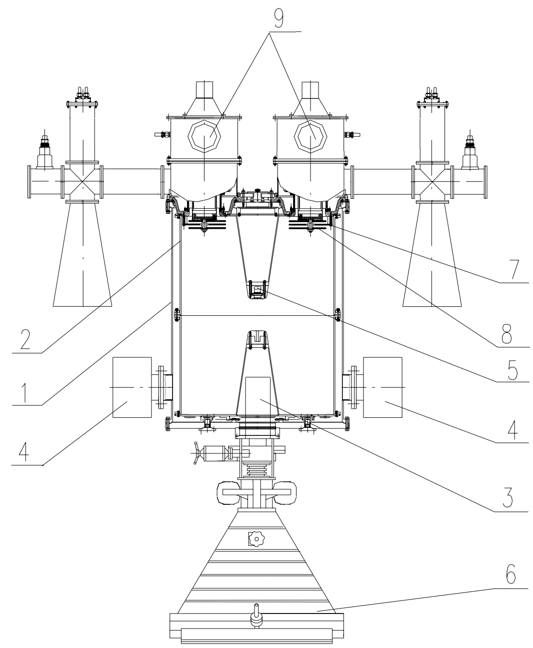

Figure 1: ILU-10 accelerator. 1 – vacuum tank, 2 – copper toroidal cavity, 3 – magnetic lens, 4 – ion pumps, 5 – grid-cathode unit, 6 – beam extraction device with linear scanning, 7–-coupling loop support, 8 – vacuum capacitor, 9 – RF generators

BEAM INJECTION

As mentioned above, use of the internal injection, when the cathode with the control grid is placed directly at the accelerating gap entrance, is the ILU-type accelerator's feature. The opposite electrode of the cavity acceleration gap is used as an anode.

The grid-cathode unit is located on the upper electrode directly at the accelerating gap entrance (see Fig. 2). The triode gun consists of the cathode, control grid, and lower accelerating gap electrode in the role of the anode. The grid and upper electrode are the united peace made of copper. The cathode unit is installed on the insulator ahead of the grid. The 16 mm diameter cathode tablet is made of lanthanum hexaboride (LaB_6). 20 amperes current flows at a voltage of 12–15 V through the cathode heater which is a cone helix made of tungsten wire of 0.6 mm diameter. The anode hole has 30 mm diameter. A magnetic lens is installed inside the lower electrode allowing the beam transverse size at the output device entrance to be controlled. At this injection method, the current is formed by RF field penetrating into the grid-cathode gap from the accelerating gap and is determined by the grid penetration factor.

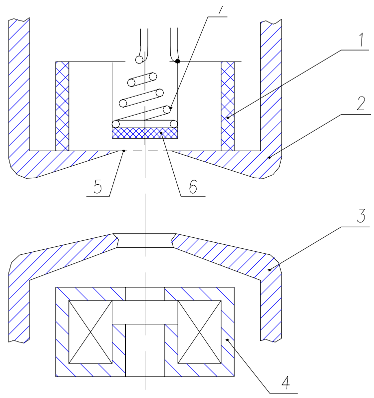

Figure 2: Accelerating structure with grid-cathode unit. 1 - cylindrical ceramic insulator, 2 - upper protrusion (electrode) of resonator, 3 - lower protrusion (electrode) of resonator, 4 - focusing lens, 5 – grid, 6 – cathode (electron emitter), 7 - cathode filament

The maximal current micropulse value is obtained practically at maximum of the accelerating voltage in the cavity gap. The injected current micropulse phase duration together with accelerated beam energy spread may be somewhat changed by varying the constant stopping potential on the grid. Here, there are no backing 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 the energy spectrum of electrons ought to be made more narrow and the part of electrons with maximum energy ought to be increased because the electrons of the low energy part of spectrum 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.

ELECTRON BEAM EXTRACTION

The pulse nature of electron beam generated by ILU machines permits to design the beam extraction devices for radiation technologies forming the irradiation zones for multilateral irradiation of objects having the various forms. It enables one to increase beam usage efficiency and in some cases to reduce the electron energy required for irradiation, or to expand the nomenclature of treated products.

Beam extraction device for extraction of electrons into air, is attached to the vacuum tank's lower flange through a separating valve. The electron beam extracted into the air through foil. Usually three types beam extraction device can be used: linear scanning device for treatment of flat product, 3-window extraction device for 4-side tube or cable irradiation and beam extraction device with X-ray converter.

In the linear scanning device each pulse of the beam is scanned along the length of extraction window (Fig.1). In the 3-window extraction device beam pulses are scanned sequentially along its upper windows and along the left and right parts of lower window.

Scanning magnets, installed on scanning chambers, are used for scanning of the beam. The magnets are fed by current stabilizer, providing initial beam position at the start of beam pulse, and by a pulse transformer, providing scanning of beam along the window.

The irradiation of wires, cables and tubes ought to be made at least from two sides. Bilateral irradiation is acceptable for miniature or flat multi-strand wires, bands, etc. But in case of bilateral irradiation of thick cables and pipes the inhomogeneity of a dose all over the perimeter of a product occurs to be too high. Moreover, the usage of usual irradiators with linear scanning of a beam and underbeam transportation device ensuring bilateral irradiation of cable on one level does not give good results due to twist of a product around its longitudinal axis during rewinding. The irradiation scheme is convenient for radiation processing of cables and tubes if it is free from changing of the direction of bending of the treated product during rewinding, i.e., in such scheme the product is irradiated on two levels and at least from two sides. Such organization of irradiation process is realized by means of the 3-window extraction device for 4-side tube or cable irradiation (Fig.3).

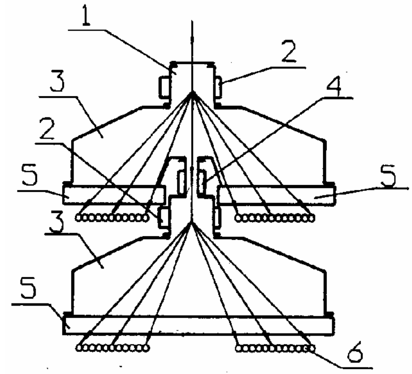

Figure 3: Beam extraction device for 4-sided irradiation. 1-beam deflection unit, 2-core of the deflecting magnet, 3-body of the device, 4-focusing lens, 5-extraction windows, 6-treated objects

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.4 [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 distance of 15 cm from the converter.

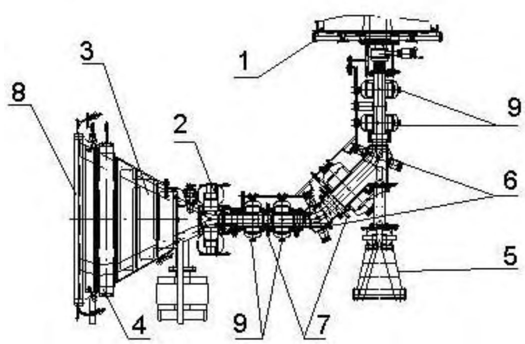

Figure 4: Beam extraction device with X-ray converter. 1-vacuum tank, 2-scanning magnet, 3-extraction device, 4-correcting magnet, 5- direct extraction device, 6-bending magnets, 7-pick-up stations, 8-converter, 9-quadruple lenses

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.

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 17 kGy with the conveyor equivalent speed of 1 mm/s. Dose distribution along the beam window is presented in Fig.5.

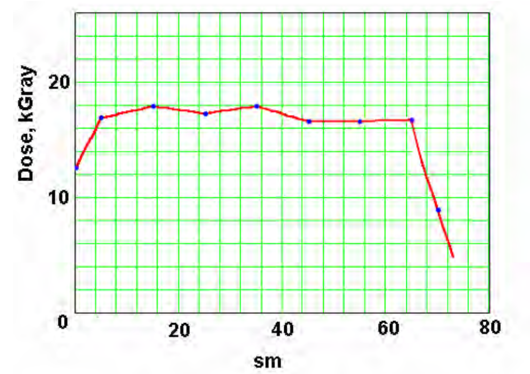

Figure 5: Dose distribution along the beam window

TECHNOLOGIES

The important direction in works of Institute of Nuclear Physics are medical, biological and pharmacological applications of our accelerators. The sterilization technology for medical single use products with the use of the beam of accelerated electrons is well studied and widely used both in our country and abroad [1]. This technology appeared as an alternative to the gamma irradiation by the installations with isotopes Co and Cs. Table 2 shows the X-ray applications and dose values collected by IAEA.

The ILU-10 machine that can reach maximum energy of 5.5 MeV ideally suites for the irradiation centers purposed for treatment of wide spectrum of goods. The electron energy of 5 MeV permits to treat the products that can have the surface density up to 3 g/cm^2 if the two-sided irradiation is organized. It means that the products can be treated in the packed form – in the cartoon boxes containing the several sets of products.

The maximum beam power of ILU-10 machine is 50 kW, so the productive rate of the irradiation facility can be up to 300-700 kg per hour assuming the sterilization dose of 25 kGy.

The project of the irradiation facility purposed for radiation synthesis of the new medical preparations and sterilization of the medical, pharmacological and other product is now on the final stage of development. The irradiation installation will start to work in nearest time – the planned date is year of 2006.

Now one ILU-10 machine in BINP is regularly used for sterilization of single use medical dressing sets and sets of instruments. The treated products are packed in the cartoon boxes having dimensions of 420mm*500 mm and height up to 150 mm (up to 10 sets in box), the weight of the box usually does not exceed 3 kg. The market for sterilization services is now actively growing and the demand for the irradiation of different products is constantly increasing. The phytogenous raw materials (herbs, ground roots, etc.) are efficiently sterilized by electron beam treatment without loosing of their medicinal action.

Table 2: X-ray Applications and dose values collected by IAEA

Benefit	Dose (kGy)	Products
Inhibition of sprouting	0.05-0.15	Potatoes, onions, garlic, root ginger, yam etc
Insect disinfestation and parasite disinfection	0.15-0.5	Cereals and pulses, fresh and dried fruits, dried fish and meat, fresh pork, etc.
Delay of physiological processes (e.g. ripening)	0.25-1.0	Fresh fruits and vegetables.
Extension of shelf-life	1.0-3.0	Fresh fish, strawberries, mushrooms etc.
Elimination of spoilage and pathogenic of food	2.0-7.0	Fresh and frozen seafood, raw or frozen poultry and meat, etc.
Improving technological properties of food	2.0-7.0	Grapes (increasing juice yield), dehydrated vegetables (reduced cooking time), etc.
Industrial sterilization (in combination with mild heat)	30-50	Meat, poultry, seafood, prepared foods, sterilized hospital diets.
Decontaminatio n of certain food additives and ingredients	10-50	Spices, enzyme preparations, natural gum, etc.

The electron beam power generated by ILU-10 machine can be up to 40-50 kW at energy of 5 MeV so this accelerator can be used as powerful X-ray source.

The usage of X-ray mode permits to widen the range of the treated products, but the economical efficiency of this treatment is sufficiently lower (in 50 times) comparing with the electron beam treatment.

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