High-Frequency Powerful Electron Accelerators Type ILU for Industrial Applications

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Abstract

The powerful high-frequency electron accelerators type ILU are designed in the Novosibirsk Institute of Nuclear Physics for various applications in the industrial technological lines. The energy range covered by the different models of those accelerators is 0.4–5.0 MeV, and the electron beam power range is 20–50 kW.

The design of the accelerators itself and different beam extraction devices for various applications is described.

The ILU application examples in different technological lines for the polymer tubes, cables and wires treatment, single-use medical goods sterilization, production of the thick-layer hybrid integrated circuits etc. are also described.

The ILU accelerators and their technological lines are fully automated.

1. INTRODUCTION

During last few years many industrial technological processes using electron beam irradiation have been developed. Different types of electron accelerators designed especially for industrial purposes are widely used in these processes. Most of them are based on the principle of high voltage electron acceleration, i.e., the electron energy is equal to the voltage generated by a rectifier.

The ILU-type industrial accelerators are an exception from this rule. They use the principle of electron acceleration in a high-frequency resonator gap. Owing to this, there is no necessity to use complex units, which fail at breakdowns (accelerating tube, rectifying sections and so on). Also there is no need in the insulating gas in the vessels under pressure.

The increase in the electron energy of a high voltage accelerator requires an enormous increase in the insulating gap of the high voltage terminal and accelerating tube length. This leads to the considerable increase in the accelerator's dimensions.

We realized a relatively simple accelerator's design with small dimensions and weight using the principle of the high frequency (HF) acceleration. This permits to reduce the dimensions of the irradiation hall, as compared with the hall necessary for a high voltage accelerator.

The pulse nature of the ILU-type beam producted by the ILU-type accelerators enables one to direct it into the different channels of the extraction device without losses in the average beam power. Therefore, the extraction devices are capable of forming the irradiation zone according the shape of the irradiated products. This increases the beam usage efficiency and gives some compensation to accordingly low accelerator efficiency (about 25–30%).

The ILU type accelerators are the most suitable for such technologies because of their small dimensions, simplicity of construction and maintenance, high reliability and flexibility. Computer control is envisaged for all the models of the ILU accelerators.

2. ILU-6 ACCELERATOR

The electron accelerator ILU-6 is a basic model in the family of ILU type accelerators. It is designed both for the development of new technologies and for the use in industrial technological processes. Main accelerator parameters are the following: electron energy 1–2.5 MeV, beam power is no less than 20 kW within the whole energy range (and up to 40 kW in the middle of range).

The ILU-6 accelerator is a single-resonator linear accelerator operating in the pulse regime. The copper toroidal cavity 2 (see Fig. 1), which is made of two separate halves (the upper half partly entering the lower one) is

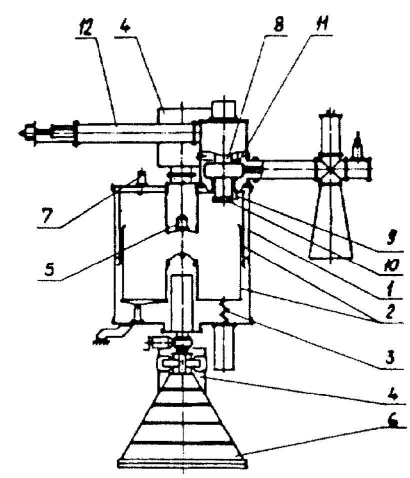

Fig. 1. The general view of the ILU-6 accelerator:
1: vacuum tank, 2: resonator, 3: inductive coil of the bias at the lower half of the resonator, 4: magnetodischarge pumps, 5: electron injector, 6: extraction device, 7: measuring loop, 8: generator tube, 9: base of the coupling loop, 10: vacuum capacitor of the coupling loop, 11: movable plate of the feedback capacitor, 12: cathode stub.

mounted inside the stainless steel vacuum tank 1. The accelerating gap (with the width about 10 cm) is formed by the electrodes installed on the cylinder-shaped parts of resonator protruding into the resonator cavity. The electron injector 5 consists of a grid, made in the upper electrode, and a cathode unit installed at an insulator on this electrode. The lower electrode in combination with the injector forms a triode accelerating system. The accelerated beam current is controlled by changing the value of the positive bias voltage on the cathode concerning the grid. Thus the beam current may be controlled easily from pulse to pulse and during the pulse.

The lower half of the resonator is installed on the insulators and supplied with a bias voltage of −6 — −8 kV through the coil 3 to suppress the high frequency discharge.

The HF current of the resonator is shortened out by a coaxial line formed by the side surfaces of the resonator halves. This line is loaded on the volume between the lower half of the resonator and the bottom of the vacuum tank. Varying the shape of this volume one is able to minimize the input resistance of this coaxial line minimizing so the HF power losses in this volume.

Under the lower electrode there is a focusing lens forming the accelerated beam in the accelerator channel and in the extraction device 6.

The high-frequency generator is placed directly on the vacuum tank of the resonator and connected with the resonator through the coupling loop. This self-excited generator using a grounded grid circuit operates at a coupling frequency close to the eigen-frequency of the resonator (115–120 MHz). The feedback regime is adjusted by the moving plate of the capacitor 11 and the cathode stub 12 having a moving shorts contact. The anode circuit of the generator is preliminary adjusted by varying the capacitance of the capacitor 10 and by varying the position of the base 9 of the coupling loop.

The HF generator is preexcited by supplying its anode with a permanent DC voltage 0.9–1.5 kV to stabilize the leading edge of the high frequency pulse. So, between the anode feeding pulses generator operates at a low regime.

3. ILU-8 ACCELERATOR

The obtained results stimulated the development of a powerful, compact accelerator ILU-8 with a local radiation shielding. The HF generator was designed as the autonomous unit placed outside the local shielding to ensure the minimal total dimensions and weight of the radiation protection. The reduction of the cavity dimensions increased its eigen frequency from 115 to 176 MHz. The main parameters of this accelerator are: electron energy range: 0.5–1.0 MeV at beam current of up to 30 mA. A standard local shielding was designed for the energy range up to 1.0 MeV.

The main components of the ILU-8 accelerator are the HF cavity with an electron injector unit and the HF generator with communication circuits (Fig. 2).

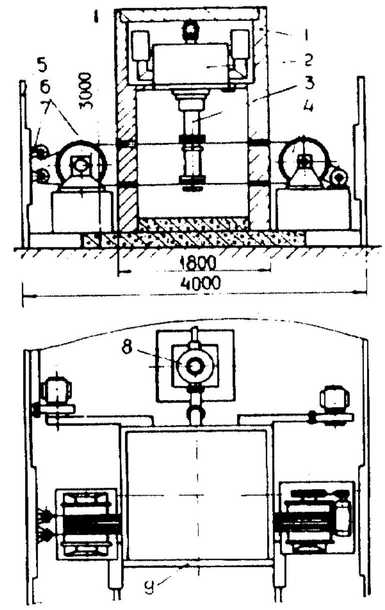

Fig. 2. ILU-8 installation with local protection:
1: local protection box, 2: resonator, 3: beam extraction device, 4: driving drum, 5: protection shields, 6: passive drum, 7: guide rollers, 8: HF generator, 9: movable front wall.

The HF cavity of the accelerator is assembled on the horizontal round stainless steel base. The lower half of the cavity is mounted on the base with the use of ceramic insulators. It is covered by the other half installed upside-down on the round base. The lower cup is insulated both from the upper one and from the base. In the centre of the bottom of the upper cup there is an inner cylinder protrusion with a triode electron injector placed on its end. The lower cup has a hole for the electrons to let them leave the accelerating gap. The round base has a flange for the extraction device components' connection. The accelerating high voltage gap is formed by the end of the protrusion of the upper cup and the central part of the bottom of the lower cup. The accelerating gap has the width 30 mm.

The accelerator's local radiation shielding is designed as a box assembled from steel plates. Its dimensions are 2.0×2.7 m and the height is about 3 m. Inside the box is divided into two parts. The upper part contains a resonator, ion vacuum pumps and a device for preliminary pumping down the resonator tank. In the lower part there are an extraction device, air lines of the ventilation system and technological equipment. The rear wall of the box has the channels (labyrinths) for the cable, air and water lines. The front wall of the box serves as an entrance door to the protected area. The thickness of the radiation protection is 350 mm at the bottom and 260 mm at the top. Its total weight is about 75 tons.

4. ILU-10 ACCELERATOR

The experience of the development of ILU accelerators shows, that the resonator accelerating gap width 10 cm is sufficient for a reliable electron acceleration to the energy up to 2.5 MeV. So, the dimensions of this type accelerator, designed for electron energies of 3–5 MeV should be not large. The main problem of such an accelerator is the power of the HF generator. This power can be increased by using two HF generator units for the single resonator.

The experiments were provided to achieve this aim. The results of these experiments have shown, that two ILU-6 generators installed on an ILU-6 resonator enable one to achieve a beam power of 55 kW at an electron energy of 2.2 MeV and a power of 24 kW at an energy of 3 MeV.

The new resonator with the accelerating gap width 20–25 cm and the shunt resistance of 9 MOhm was designed based on these results. This model enables one to achieve a beam power of 25–35 kW at electron energies of 2.0–3.5 MeV using one HF generator and one ILU-6 pulse power supply. Losses of the resonator at a voltage of 5 MV should be about 1.4 MW during the pulse (average losses up to 30 kW), so, with two HF generators we hope to achieve an average beam power of up to 50 kW in the electron energy range of 2–5 MeV.

The accelerator with such resonator is now under testing. The testing should be finished by the end of 1992. In case of success this model enables us to expand the area of the ILU accelerator application. It should be the most suitable for medical sterilization and electron—X-ray conversion (one of such accelerators is equal to an X-ray source of 300 kCurie).

5. BEAM EXTRACTION DEVICES

The use of pulse accelerators as radiation sources enables one to implement the complex systems of electron beam extraction into the air producing a zone of multi-side irradiation of various products. Such systems provide a maximum accelerated beam power usage efficiency and the reduction of electron energy required.

The irradiation of wires, cables and tubes should be done at least from two sides. The two-sided irradiation is convenient for the miniature and flat multicore wires, bands etc. Nevertheless the two-sided irradiation leads to a very high doze inhomogeneity in case of thick cables or pipes. In the conventional irradiation system with the use of an ordinary linear scanning even the two-sided irradiation is provided poorly because of the wire or pipe twist occurred during its rewinding.

The most convenient system for cable or pipe irradiation is such a system where the direction of the product bending does not vary during the process of rewinding and the product is irradiated on two levels at least from two sides. Such an irradiation scheme can be realized with the help of a special beam extraction system (Fig. 3). The beam is deflected successively by 45° on two levels which provides a four-sided irradiation of the product rewinded under the beam. Such a system is sufficiently universal and enables one to realize two- or four-sided irradiation or linear beam scanning only by varying the operation regime of deflecting magnets.

Any of the ILU-type accelerators can be equipped by a linear scanning system or by any of the mentioned above beam extraction devices.

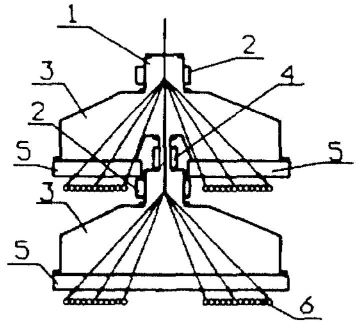

Fig. 3. The multi-sided irradiation beam extraction device: 1: :scanning unit, 2: scanning magnet core, 3: vacuum chamber, 4: focusing lens, 5: extraction windows, 6: irradiated product.

The high efficiency of the electron beam use, the reduction of energy required for the radiation treatment of a product enable one to produce highly efficient technological lines for irradiation of cables and pipes using the ILU-type accelerators.

6. ILU ACCELERATORS UNDER USE

The main area of the ILU accelerators' usage is the treatment of thermoshrinkable tubes and cables. For this purpose tube or cable underbeam transporting systems are developed for wide range of the tube or cable diameters. For thick cables or tubes the four-sided irradiation system is used.

Various kinds of underbeam transporting systems are developed for treatment of cables, tubes and bands inside the ILU-8 local protection.

Underbeam transporting systems for various products' treatment in R & D installations are developed also.

Up to now the ILU-type accelerators are widely used in our country and abroad for various purposes. The main of them are:

- large scale treatment of thermoresistant and thermoshrinkable PE tubes and films—9 accelerators are operating, 3 of them are in Hungary and Poland and 3 accelerators are under delivery to Yugoslavia, Roumania and China.
- R & D—10 accelerators are operating, 1 of them is in India, 2 accelerators are under delivery to Cuba and Italy.
- industrial cable treatment—4 accelerators are operating, 3 of them are in China and in Czechoslovakia.
- production of thick-layer hybrid circuits—1 accelerator is operating and 1 accelerator is under delivery.

The results of the experimental work have shown the efficiency of the ILU-6 model application for sterilization of syringes and some other medical tools in trade packings at electron energies of 2–2.5 MeV. The installations for large scale of such production treatment are now under construction.