THE HIGH-FREQUENCY ELECTRON ACCELERATOR FOR THE USE IN INDUSTRIAL TECHNOLOGICAL LINES

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The electron accelerator ILU-6 is a basic model in the family of ILU type accelerators. It is designed at the Novosibirsk Institute of Nuclear Physics both for the development of new technologies and for the use in industrial technological processes. Main accelerator parameters are the following: electron energy $1 \div 2.5$ MeV, beam power is no less than 20 kW within the whole energy range. The ILU-6 accelerator is simple in its design, has a high reliability and maintainability; it is easily serviced and simply controlled. Computer control is also envisaged.

The Operation Principle and the Accelerator Peculiarities

The ILU-6 accelerator is a single-resonator linear accelerator operating in the pulsed 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 mounted inside the stainless steel vacuum tank *1*. On the cylinder-shaped parts of resonator (protruding into the resonator cavity) the electrodes are installed for shaping the accelerating gap (about 10 cm). The electron injector *5* consists of a grid, made in the upper electrode, and a cathode node 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 with respect to the grid.

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

The RF current of the resonator is shorted out by a coaxial line, which is formed by the side surfaces of the resonator halves and 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 and, consequently, to minimize the RF power losses at this volume.

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

This type accelerator operational experience has shown, that the accelerating gap of the resonator reliably operates at RF voltage of up to 3 MV (maximum tensions on the surfaces up to 600 kV/cm). In this case, sparking in the gap does not decrease the voltage level.

The high-frequency generator is placed directly on the vacuum tank of the resonator and it is connected to the resonator by means of the inductive loop. This self-excited generator using a grounded grid circuit operates at a coupling frequency close to the eigen-frequency of the resonator ($115 \div 120$ MHz). The feedback regime is adjusted by means of a moving plate of the capacitor *11*, which connects the anode and the cathode, and of the cathode stub *12* having a moving shorting-out contact. The anode circuit of the generator is preliminarily adjusted by varying the capacitance of the capacitor *10* and by varying the position of the base *9* of the coupling loop.

To stabilize the high-frequency pulse leading edge while powering the tube anode, the generator is pre-excited by supplying the anode with the $0.9 \div 1.5$ kV constant voltage.

In comparison with the widely used high-voltage accelerators the accelerator ILU-6 has a number of peculiarities in its construction and operation.

The major peculiarity is that none of the accelerator units have a potential relative to the housing, which is comparable with the accelerating voltage, i. e. these units do not require high-voltage insulation. The highest voltage is the pulse voltage of up to 30 kV which supplies the tube anode.

Owing to this, there is no necessity to apply complex units, which fail at breakdowns (accelerating tube, rectifying sections and so on). The insulating gas in the vessels under pressure is not required either. Consequently, it is very difficult to destroy the basic assemblies. Even if considerable vacuum deterioration occurs (by personnel's error) the accelerator will be ready to operate after a proper cleaning and training. The units of limited lifetime are, as a rule, commercial products or those having simple design and cheap in manufacturing. This enables one to repair the accelerator units under the conditions of any industrial plant.

Using the principle of RF acceleration, we have the relatively simple design of the accelerator, small overall dimensions and weight. Therefore, the irradiation hall may be smaller in dimensions as compared to the hall necessary for a high-voltage accelerator.

The posibilities and the production rate of an industrial irradiation technological line are determined by the electron energy, beam rower and the efficiency of beam utilization.

The average power of the beam generated by a linear accelerator is determined by the power produced by a RF generator. The average RF power supplied by the ILU-6 generator tube at matched load is 50 kW (with the pulse power of 2 MW). The shunt

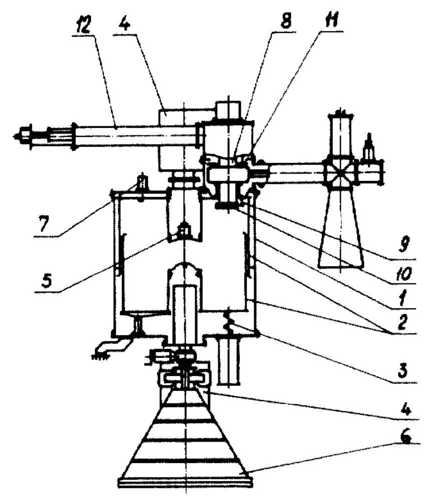

Fig. 1. The general view of the accelerator:
1 — vacuum tank; *2* — resonator; *3* — inductive coil of the bias at the lower half of the resonator; *4* — magnetodischarge pumps; *5* — electron injector; *6* — extraction device; *7* — measuring loop; *8* — generator tube; *9* — base of the coupling loop;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

resistance of the ILU-6 resonator is about 4 MΩ. At 2 MV on the resonator gap and duty factor 40 the losses in the ILU-6 resonator are 12 kW. Hence, the beam power can reach 38 kW at an electron energy of 2 MeV. If the accelerator operates in a wide range of energies and beam currents, the tube load varies considerabely. Consequently, the RF power released by the tube to the load is lower than a maximum one within the operating range and achieves its maximum value only in a comparatively narrow, middle part of the range. Therefore, in the $1 \div 2.5$ MeV range, at the end points the beam power is 20 kW, while in the middle part ($1.7 \div 1.9$ MeV) it can reach 40 kW.

For technological processes calling for a narrow range of energies the beam power can achieve $35 \div 40$ kW, depending on the average energy of this range, through a proper adjustment of the accelerator.

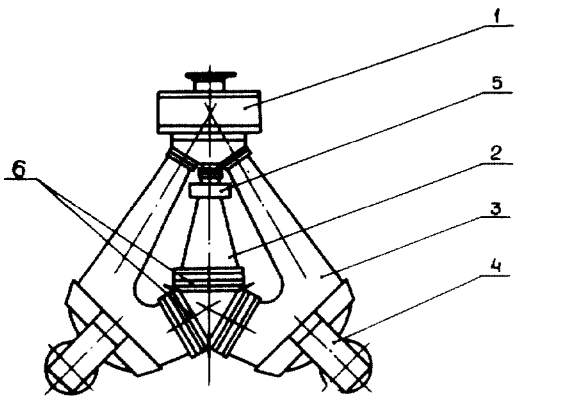

Fig. 2. «Quasiring scanning» type extraction device:
1 — distributing magnet; *2* — middle channel; *3* — side channels;
4 — bending magnets; *5* — scanning magnet; *6* — extraction windows.

The required electron energy is determined by the thickness and shape of the product to be irradiated. Irradiation of the products of complex or round shape can be successful at lower energy if the shape of the irradiation zone corresponds to the shape of the product to be irradiated. In case of three-sided irradiation of round products the required energy is more than twice lower than that required for singlesided irradiation of the same product. For the case of plane multilayer products, similar results can be obtained using double-sided irradiation.

The pulse nature of the ILU-6 beam enables one to direct it into different channels of the extraction device whithout losses in the average beam power. Therefore, the extraction devices are capable of forming the irradiation zone in accordance with the shape of the products being irradiated. The efficiency of beam utilization increases also due to a shortening of the electron path in the air.

These peculiarities of ILU-6 allow in some cases the same production rates to be achieved when performing the technological processes calling for as high electron energy as 5÷6 MeV at a beam power from 50 to 60 kW in case of the conventional single-sided irradiation.

The following types of beam extraction devices are designed for the most widely used industrial irradiation processes.

1. A device with linear scanning of the beam along the extraction window for single-sided irradiation of flat or band-like products («linear scanning» shown in Fig. 1). The beam is scanned along the entire useful length of the extraction window during each pulse. An additional coil of the pulse transformer supplying the generator tube anode is used to feed the scanning system. This enables one to avoid the deterioration of extraction window foil in case of falure of scanning system power supply. The preliminary beam bending is performed by means of separate DC source.

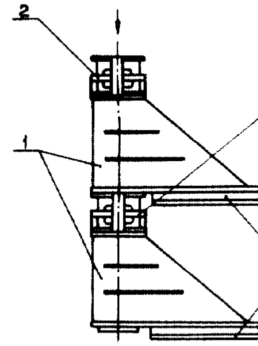

Fig. 3. «Fir»-like extraction device for double-sided irradiation:
1 — vacuum chamber; *2* — upper scanning magnet; *3* — lower scanning magnet; *4* — extraction windows.

2. A device for three-sided irradiation of round products at an angle of 120° («quasiring scanning», Fig. 2). The current pulses are turned in sequence to three extraction channels by means of the distributing magnet. The magnets on the side channels bend the beam to the side extraction windows. The scanning magnet of the central channel distributes the beam current along the central extraction window. The beam distribution along the side windows is performed by changing current in the distributing magnet during the pulse.

3. A device for double-sided irradiation of long products at two levels («fir-like scanning», Fig. 3).

Some other types of extraction devices can be designed by special request of a customer.

The features of the accelerator mentioned above together with its relatively small size, its simplicity in control and relatively low maintenance expenditure is quite a substantial compensation for its comparatively low efficiency (electron beam power is about 30% of the total power consumed from the mains).

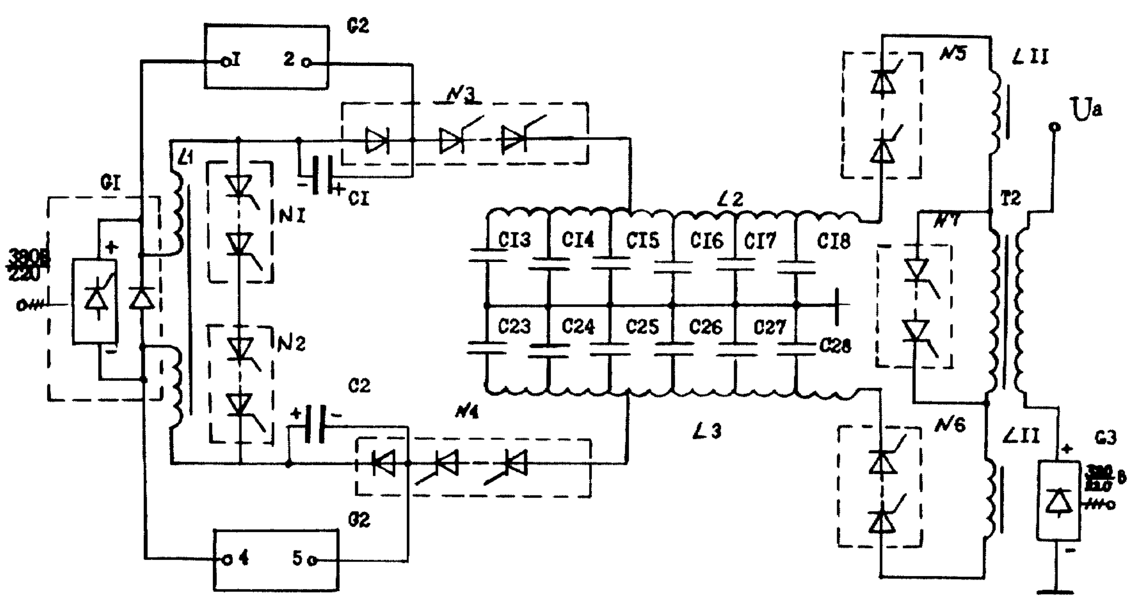

Fig. 4. Simplified block-diagram of the pulse voltage source:
G1 — rectifier; *L1* — inductive storage; *G2* — recharge circuit; *C1* and *C2* — recharge capacitors; *N1* — *N7* — thyristor switches; *C13* — *C28*, *L2*, *L3* — forming line; *T2* — pulse transformer; *G3* — preexcitation voltage source.

The Pulse Voltage Source

The pulse voltage source supplying the tube anode of the RF generator operates directly on the 380/220 V three-phase mains (Fig. 4).

The thyristor rectifier *G1* is connected to the inductive storage *L1*. During the time of shorting of tne inductive storage by The switches *N1* and *N2* the storage current increases. After the switches *N3* and *N4* are on the switches *N1* and *N2* become off, the current ceases to accumulate and the full energy stored in the inductive storage *L1* is transferred to the capacitors of the forming line (*C13*–*C28*, *L2* and *L3*) charging them up to a voltage, determined by the stored energy. After the charge stops the switches *N5* and *N6* open and tney connect the pulse transformer *T2* to the forming line. On the load of the transformer secondary winding (on the tube anode of the RF generator) the pulse is formed whose parameters are: voltage – up to 30 kV, duration – 0.4–0.7 ms at a load current of up to 150 A.

The trailing edge of the pulse is formed by means of the switch *N7* which shorts the primary winding of the pulse transformer.

The pulse repetition frequency can be changed step-by-step from 2 to 50 Hz (to 100 Hz when the pulse amplitudes are low).

The constant voltage, necessary for the RF generator pre-excitation, is applied to the tube anode from the source *G3* through the secondary winding of the pulse transformer. It is also used to demagnetize the transformer core after a high-voltage pulse.

The use of the inductive storage enabled us to avoid the use of a high voltage rectifier and, also, to decrease the size of the pulse source.

Up to date about 20 accelerators of ILU-6 type are mounted at the different organizationes both inside of country and abroad (in Poland, Hungary, India, China). Many of them are being used in industrial technological lines and are successfully operated from 20 to 24 hours a day on a 6 to 7 days a week basis, numbers of years.

The long term experience of using accelerators of this type evidenced of their high maintenance efficiency and reliability.

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