HIGH-POWER SMALL RF ACCELERATOR OF ELECTRONS ILU-8 WITH LOCAL RADIATION PROTECTION

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Wide experience in the maintenance of industrial RF pulse linear accelerators of electrons of the ILU-6 type has revealed a number of their advantages in design over direct-action ones of rectifying type [1]. Among them there are a high gradient of the accelerating voltage (up to 170 kV/cm at a beam current of up to 1 A), small sizes of the elements placed inside the local protection, a comparative simplicity of the beam extraction into the atmosphere using a device with several extraction windows; in addition, their powering and control are relatively simple owing to a hot-cathode system. Undoubtedly, the pulse RF accelerators are advantageous in service, such an accelerator is capable of attaining the rated operating conditions without any losses in time, no difficulties arise because of the use electrically-reinforcing means and in high-voltage feeder, and the construction is free from the vessels and the gas lines with high pressure. A comparative simplicity of the design of a RF accelerator simplifies its service under industrial conditions.

Owing to these data, the development has been initiated of a high-power small RF pulse accelerator of electrons ILU-8 with local radiation protection using the components of the accelerator ILU-6. The aim to make the overall dimensions and the weight of the radiation protection minimal has resulting in the necessity to design an autonomous RF generator to be placed outside the protection system; moreover, the possibility has arisen to reduce the sizes of the resonator due to an increase of its characteristic frequency from 110 to 176 MHz.

The accelerator ILU-8 comprises two important components: a RF resonator with a cathode-grid unit and a RF generator with coupling lines (Fig. 1).

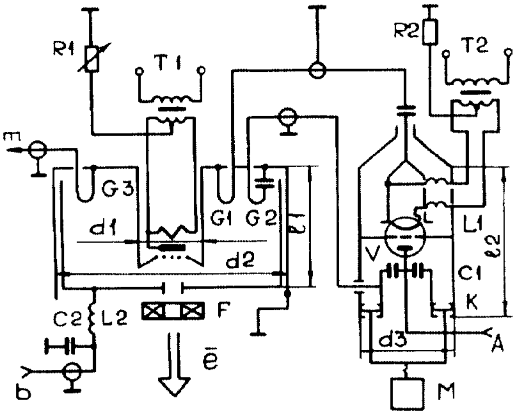

Fig. 1. Layout of the accelerator ILU-8.

The RF resonator of the accelerator is assembled on a horizontal disc-like stainless steel base. A cooper cup is installed on the base by means of ceramic insulators so that the distance between the bottom of the cup and the base's surface is equal to 40 mm. This cup is covered by the other copper cup with its edge on the disc-like base. The sizes of the cups are such that the gap between their cylindrical surfaces equals 6 mm, while the edge of the cylindrical part of the lower cup and the bottom of the upper one are about 20 mm apart. Thus, the lower cup is isolated both from the upper one and from the base. In the centre of the bottom of the upper cup there is an inner cylindrical protrusion with holes in the end section intended to install the cathode unit with a control electrode. Such a hole is made also in the central part of the bottom of the lower cup for the electrons to leave the accelerating gap. In the disc-like base there is a hole to connect the components of the section through which the accelerated electrons pass from the resonator, to the extraction unit. The accelerating high-voltage gap is formed by the end of the protrusion on the upper cup and the central part of the bottom of the lower cup. Both copper cups are covered by a stainless steel cup, upside down on the disc-like base of the resonator. This outer cup jointly with the disc-like base forms a sealed tank of the resonator pumped by magnetodischarge pumps of 200 l/s total capacity. The basic sizes of the resonator *d1*, *d2* and *l1* are equal, correspondingly, to 130, 746 and 364 mm. The accelerating gap is 45 mm long. The wave resistance of the resonator is 150 ohm at a *Q*-factor of about 30 000.

The filament current of LaB_6 hot cathode of 17 mm diam is supplied through a filament transformer *T1*, and the emission current of the chatode takes the path to the grounded circuit through a resistor *R1*. Varying the quantity *R1* one can vary the bias voltage and, hence, the current of the accelerator beam. The lower cup of the resonator is applied, through a terminal *b*, by a constant negative voltage of about 10 kV to suppress a high-frequency vacuum discharge and to remove the ions from the accelerating gap. The filter *L2G2* is used to safeguard the power supply circuits against high-frequency voltage. The high-frequency voltage in the resonator is measured by means of a loop *G3* and a terminal *m* .

A RF generator with a GI-50A tube, having a positive feedback through a resonator is a construction comprising copper cylinders with maximum diameter *d3* and height *l2*, equal to 370 and 1500 mm respectively. The cathode current of the generator tube takes the path to the grounded circuit through the inductance *L1*, the winding of the filament transformer *T2* and through a resistor *R2*. The voltage drop on it is a negative shifting of the tube grid. A 20 kV anode voltage of the generator tube is applied through the terminal *A*, and the RF component of the anode current flows through the capasitors *C1*. To refine the tuning of the anode tuned circuit of the generator there is a plunger *K* with an electric driver *M*. Use is made also of a quarter-wave coaxial transformer to make the high-ohmic input of the generator tube coincident with the low-ohmic feedback feeder in the generator. The capacitor *C3* is used to separate the feedback circuits with respect to the direct current component.

The RF power of the generator is applied to the resonator by means of an air coaxial feeder and the loop *G2*. The feedback voltage is applied to the generator from the loop *G1* by a feeder with solid insulation. The RF power of the generator is roughly equal to 1 MW at a 600 μs duration of the anode pulse. At a 50 Hz repetition frequency of the anode pulses the average power is about 30 kW.

The anode and cathode electrodes of the accelerating gap in the resonator are spheric surfaces having a common centre. Their radii are 35 and 80 mm respectively. For a 1 MV voltage at the gap, the electric field intensity on the surface of the cathode electrode is 125 kV/cm, and 286 kV/cm on the surface of the anode electrode. The control electrode of the cathode system is a diaphragm of 18 mm diam with a set of radial pins, which is 3 mm distant from the cathode. The diameter of the anode hole is 18 mm

The electrons, accelerated and formed as a beam $\bar{e}$ (Fig. 1), are directed to the extraction unit through a magnetic focusing lens *F* intended to match the beam sizes with dimensions of the extraction window. The pulse current of the beam achieves 1 A at 0.7 MV accelerating voltage and 300 V positive cathode voltage with respect to the control electrode (bias voltage). The mean current of the beam is 30 mA at 50 Hz repetition frequency. About 60% of the total beam current lies within the 0.7 – 0.6 MeV interval of energies and about 25% in the 0.6 – 0.45 MeV range. The beam current reduces with increasing the bias voltage and, at the same time, it is observed a growth of the share of highly-energetic electrons in the energy spectrum

The local radiation protection of the accelerator is designed as a box assembled from steel plates. Its design dimensions are 1.8×1.8 m at a height of about 3 m. The inside of the box is divided into two parts. The upper part includes a resonator, ion vacuum pumps, and a device to preliminary pump down the resonator tank and the extraction device. In the lower part there are an extraction device, air lines of the ventilation systems, and technological equipment. In the hollow back wall of the box there are the channels-labyrinths for cable, air and water lines. The exterior wall of the box serves as the door of the protection. The thickness of the radiation protection is 250 mm at the bottom and 160 mm at the top. Its total weight is about 25 t. At the electron energy 0.7 MeV the attenuation factor for X-ray radiation is no less than $5\cdot10^7$.

As experience in the employment of accelerators as the integral part of technological facilities has shown, a particular technological process requires for an individual unit to extract the electron beam into the atmosphere. The sketches of the extraction units which are suitable for the devices on the basis of the accelerator ILU-8 are given in Fig. 2. The conventional extraction unit having one extraction window for a one-sides irradiation of the materials like films, varnishes, fabrics, and the products like cable, filaments, tubes, discrete products on a conveyer, etc. (Fig. 2a). This window is 980×75 mm is size. A system of beam deflection allows a complex profile of the beam density to be shaped along the extraction window. For a continuous double-sided irradiation of the products like cable, pipes, films, fabrics, use is made of the unit with two extraction windows placed one above the other (Fig. 2b). Each of them is 320×75 mm in size and they are 500 mm distant. The system of beam deflection offers the possibility of controlling the current distribution over the windows and of redistributing arbitrarily the beam power between the windows. The extraction unit, shown in Fig. 2c, is designed to irradiate liquids and granular substanses. The dimension of each of this windows is 600×90 mm. The distance between the axes of the windows is equal to 200 mm. The system of beam deflection enables one to form a complex profile of the current density over the extraction windows and, simultaneously, to distribute the current among the windows and across the central window in the arbitrary way. A set of current probes is used to control the beam deflection along and across each of the windows. The cooling technique for window foils minimizes the emission of ozone and nitric oxides in the air, and prevents the leakage of gaseous substances from the radiation protection of the accelerator.

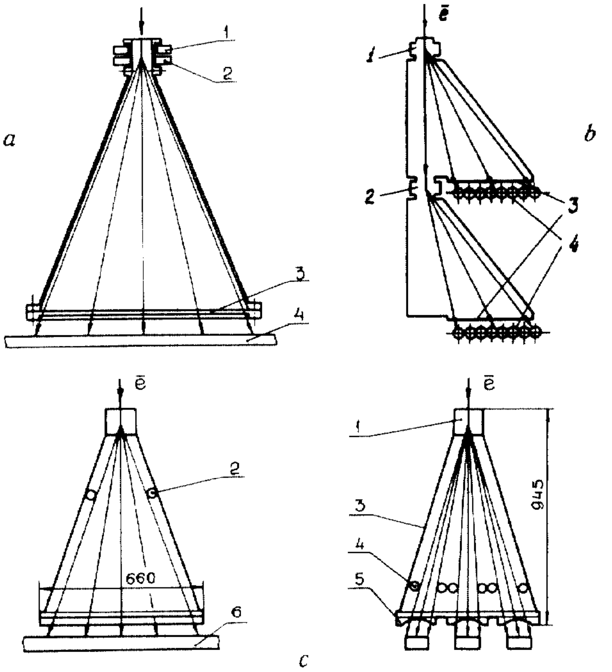

Fig. 2. Extraction devices for the accelerator ILU-8:
a — extraction device with one window: *1*, *2* — coils for beam scanning along and across the window, *3* — foil of the extraction window; *4* — product being irradiated; *b* — extraction device with two windows: *1*, *2* — coils for beam scanning in the upper and lower windows, *3* — window, *4* — wire to be irradiated; *c* — extraction device with three windows: *1* — magnetic system for beam scanning, *2* — probes of beam declination along the windows, *3* — body of the device, *4* — probes of beam declination across the windows, *5* — windows, *6* — object to be irradiated.

A 50 μm thickness titanium foil is used to divide the atmosphera from the vacuum in the extraction windows of all devices. The ultimate density of the current for extraction is 200 μ/A cm^2.

The control and power supply system of the accelerator ILU-8 is similar to that of the accelerator ILU-6 [2]. It is mounted in four cabinets, $900\times900\times2000$ mm in size. One of them, which is used as the control desk is placed in the room in which there are all the control devices of the whole accelerating facility. The remaining three cabinets, used as a modulator of anode voltage, are placed autonomously or near the electron accelerator. The accelerator can be manually- or computer-controlled.

The automatic control of the accelerator comprises a computer, a crate in the CAMAK standard to connect the computer to the accelerator, and autonomous control board with a colour display. Such a structure of the automatic equipment is convenient for the accelerator systems to make integral with the technological equipment. In this case, the colour display and an autonomous control board are the autonomous control terminal for the technological system on the basis of the accelerator ILU-8.

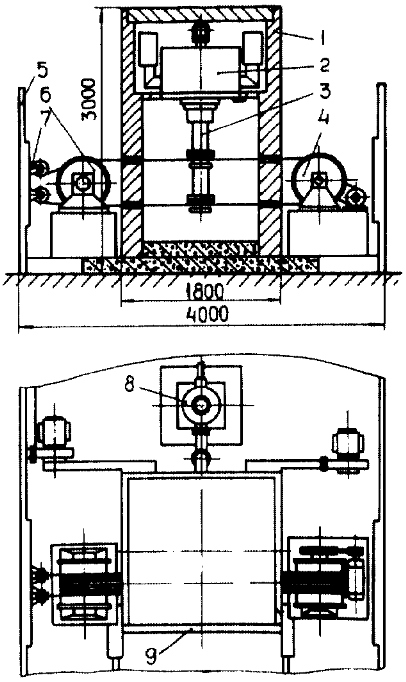

Fig. 3. Basic components of the installation ILU-8RU:
1 — local radiation protection of the accelerator, *2* — RF generator, *3* — extraction device with two windows, *4* — driving drum, *5* — wall protection, *6* — passive drum, *7* — guide rollers, *8* — RF generator, *9* — rolling-aside protection wall.

Fig. 3 shows the basic components of the installation on the basis of ILU-8. It is designed to irradiate the plastic insulation of wires and can be used to irradiate filaments and thin pipes. On this figure, one can see two elements of the accelerator: a resonator *2* and a RF generator *8*. A schematically shown device for beam extraction with two windows is used for double-sided irradiation of wires. In the local radiation protection *1* having a rolling-aside wall *9* there are the slits of 300×8 mm in cross section which are necessary for wire rewinding. Having left the slits, the X-ray radiation attenuates down to permissible values by the wall protection *5*. The technological equipment comprises the winding drums *4*, *6* and guide rollers *7*. Prepared in the form of a dense tape, the wire is passed below the extraction windows many times, as required. Since the radiation intensity below the upper and lower windows of the extraction device is equal, the wires are irradiated uniformly from two sides. The insulation of the wire being irradiate from two sides turns out to be about 3 times thicker than in the case of one-sided irradiation, at the same electron energy. Due to a band-shaped preparation of the wire, the efficiency of accelerated electrons, with respect to the area, is close to unity.

The basic parameters of the installation ILU-8RU are:

Electron energy, MeV	0.4 — 0.7
Average current of the beam, mA	0 — 30
Diameter of irradiated wire, mm	0.3 — 3
Maximum velocity rate of irradiation, m/min	600
Consumed power, kW	60

The installation ILU-8RU is used at a cable factory in the USSR.

References

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