ACCELERATING UNITS FOR COMMERCIAL RESONATOR LINACS MODEL UELR-10-10S DESIGNED FOR RADIATION STERILIZATION DEVELOPMENT AND RESULTS OF TESTING

V.A. Alexeev, A.E. Baranovsky, A.V. Belousov, V.N. Davydov, M.I. Demsky, K.A. Denisov, A.M. Fialkovsky, L.P. Fomin, Yu.N. Gavrish, S.N. Kochin, V.A. Larionovsky, K.N. Maslov, V.M. Nikolaev, D.A. Obodinsky, A.V. Orlov, A.V. Ryabtsov, V.V. Ryabov, Yu.P. Shchepin, V.V. Terentjev

FSUE "D.V. Efremov Scientific Research Institute of Electrophysical Apparatus" St. Petersburg, Russia

E-mail: npkluts@niiefa.spb.su, fax/phone: 812-4646220

Some specific design features of the accelerating units for LINACs model UELR-10-10S designed for radiation sterilization and the electron beam characteristics obtained experimentally are considered.

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The linear electron accelerator model UELR-10-10S is intended for the commercial radiation sterilization and pasteurization of foodstuffs. The radiation parameters of this machine are shown in Table 1.

Table 1. *The radiation parameters of the electron accelerator model UELR-10-10S*

Energy of accelerated electrons in the nominal mode, MeV	10
Average electron beam power in the nominal mode, kW	10
Range of energy variation, MeV	8…10
Average electron beam power in the 8 MeV mode, kW	9.5
Pulse repetition rate, l/s	300, 150, 100, 50
Scanning line size 100 mm from the foil of extraction window, mm	up to 800×20
Radiation field flatness over scanning length, %.	± 5%
Scanning frequency of electron beam, Hz	1…5

The KUY-147A klystrons produced by FSUE "Toriy" are used as a source of RF energy. At the consumer's request, it is possible to use other types of klystrons produced by foreign firms and generating a pulse power of 6 MW at a frequency of 2856 MHz with an average beam power up to 30 kW.

The standing wave accelerating structure contains a five-stage buncher, which ensures narrow energy spectrum and RF focusing of the beam of accelerated electrons. The main operating mode is the mode without an external solenoidal focusing magnetic field, which ensures the production of the beam of accelerated electrons with an energy of 10 MeV and small energy spread.

In the first machine of this model, a double-electrode gun IED-50-0.4 with BaNi cathode of 5 mm diameter was used. In the second such a machine, we applied a gun with a cathode of 14 mm diameter.

The main experiments were carried out to measure the kinetic energy of accelerated electrons, the range of energy variation, energy spectrum and current of accelerated electrons. The energy of accelerated electrons was mainly varied by varying the beam current, which ensured high electron efficiency.

A so-called injector device, a beam current regulator, was the main means used to vary current magnitude. It is positioned between the electron source and accelerating structure and consists of a focusing lens, a drift tube and a collimator. By changing the lens current, we changed the losses of the beam passing through collimator, the current injected and the beam losses in accelerating structure.

In some cases when measuring load characteristics, the beam current was changed by varying the filament of electron gun. In standard version of the accelerator, two Al plates located in the atmosphere beyond the vacuum window of the scanning magnet chamber were used to control the kinetic energy of beam current. The energy of accelerated electrons was estimated from the absorption of the beam current in the first Al plate. To measure energy spectrum in our studies, we used a magnetic energy analyzer. The effective energy of the beam extracted to the atmosphere was measured in compliance with the ASTME 1649-94 standard by using a set of Al plates of 2 mm thickness. Film dosimeters of the SPDF-5/50 model were placed between Al plates.

In the beginning of the experiments with the first accelerating unit, some difficulties emerged in the use of current regulator. The reason was parasitic magnetic fields in the area of electron gun produced by an annular magnet, a component of an ionization lamp used to control vacuum. These fields distorted the trajectories of the electrons injected to accelerating structure. To correct the position of the beam at the inlet to accelerating structure, we were forced to use the magnetic fields produced by the solenoid coils encircling this accelerating structure. To produce these fields, a current of 16 A was applied to the coils of solenoid. By varying the current in current regulator from 230 up to 300 mA, we managed to control the current at accelerator outlet and to obtain the load characteristics shown in Fig.1. These characteristics were measured in different ranges of lens current variation. At lower magnetization current, one load characteristic was less steep, which evidently can be explained by higher beam losses on the walls of accelerating structure. At low current in the lens, the accelerating structure was loaded with a current higher than the current recorded by the beam absorber located at the outlet of accelerator.

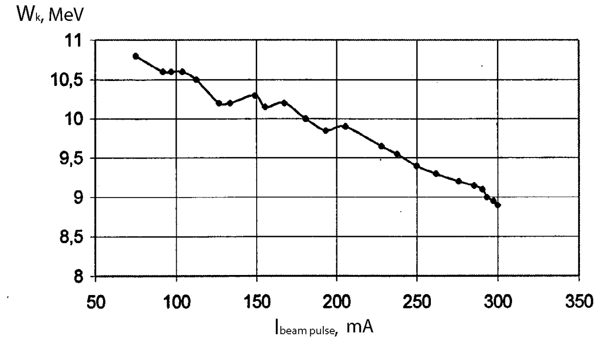

Fig.1. The load characteristic of the first accelerating structure with current varying in current regulator. I_{beam} *= 230-280 mA*

The 10 MeV kinetic energy of electrons was attained at a beam pulse current of 0.21 A. When a standard pulse klystron modulator with a duty cycle of $Q_{RF} = 240$ was used, the duty cycle of the current of accelerated electrons was $Q_I = 270$, taking into account the time necessary for the onset of oscillations in the accelerating structure.

The 210 mA pulse current corresponded to an average beam current of 0.78 mA, which in turn would correspond to an average beam power of 7.8 κW and did not ensure specified average beam power.

In the course of studies of the first accelerator carried out without current regulator, it was experimentally confirmed that an average power of 7.8 (8.2) kW was obtained at a kinetic power of 10 MeV (see Fig.2). In this case, to change beam current, we varied the filament current of electron gun. We succeeded in obtaining high current of accelerated electrons by increasing the current in the coils of solenoid up to 50 A (Fig.2).

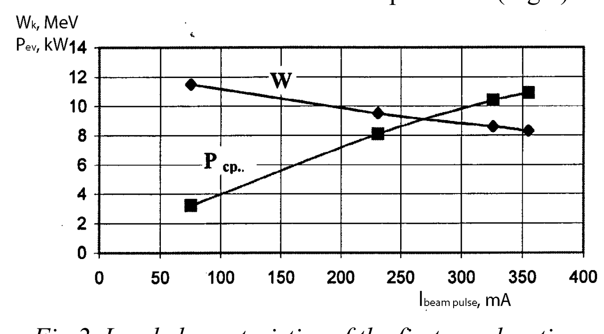

Fig.2. Load characteristics of the first accelerating structure without current varying in current regulator

The average kinetic energy of accelerated electrons in both the cases considered above was estimated from the absorption of current in Al plate of 10 mm thickness. It should be noted that the total current values shown in Figs.1 and 2 were determined as a sum of currents in these two plates. Due to leakage, these values were less by 6% than the current measured by beam absorber. In this connection, the average beam power attained at a kinetic energy of electrons of 10 MeV could be considered equal to 8.2 kW instead of 7.8 kW, and the pulse power generated by the klystron was estimated to be 4.5…5 MW.

With the magnetic energy analyzer used, the spectral energy characteristics in the first accelerating structure were measured at a current of 58 A in the first focusing coil and 35.5 A in the second and third coils. The dependencies of the kinetic energy of accelerated electrons at the maximum spectrum and maximum FWHM on the frequency of RF oscillations were measured at the same current (see Fig.3). The minimum width of energy spectrum obtained FWHM of spectral curve was 2.8% and the kinetic energy at the maximum energy spectrum was 9.7 MeV at a beam pulse current of 253 mA.

Spectral characteristics were also measured without focusing field. In this case, pulse current was reduced by 13…17%, and the kinetic energy at the spectrum maximum and optimal frequency of RF oscillations increased up to 10 MeV, which evidently can be attributed to a decrease in the current of accelerated electrons ("unloading" of accelerating structure). Fig.4 shows the beam energy and energy spread as a function of the frequency of RF oscillations. It is important that without solenoid coils, the energy spectrum width FWHM of spectral curve was reduced to 2%.

It should be also noted that with RF focusing only, we managed to attain a beam of accelerated electrons with smaller diameter.

When testing the second accelerating unit, we used the KUY-147A klystron with a pulse power of 6 MW, approximately, (duty cycle was $Q_{RF} = 240$).

We used the methods of the ASTM 1649-94 standard to measure the effective energy of the beam; it was 10.9 MeV at a pulse current of accelerated electrons of 270 mA. With a standard duty cycle of the beam of $Q_{RF} = 270$, this pulse current corresponds to an average beam current of 1 mA, i.e. an average beam power of 10.9 kW is attained. At reduced kinetic energy, higher beam power can be obtained, for example, by increasing the beam current by feeding currents to the coils of focusing system without changing the filament of electron source.

As was mentioned above, when testing the second accelerating unit, we used the double-electrode gun with the cathode of 14 mm diameter. In this case we obtained lower density of the current removed from the cathode, however, wider energy spectrum was observed (up to 10% HWFM spectral line), and higher beam losses occurred when passing through accelerating structure. Probably, the use of this electron gun with new optical elements contributed to larger diameter of the beam on extraction foil, which was placed 1300 mm from the outlet of accelerating structure. Besides, to increase the cross-section size of the beam, we used the current of the lens of current regulator and the currents of focusing coils (Table 2).

The beam diameter was measured with a film dosimeter of the SPDF-5/50 model, and the method of photometry was used.

The radiation field flatness over the scanning length not worse than ±5% was obtained due to programmed shape of the current in the coils of scanning magnets.

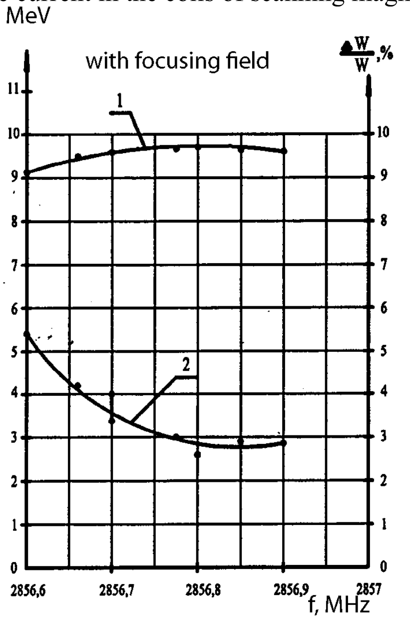

Fig.3. Kinetic energy of accelerated electrons at the maximum spectrum (curve1) and maximum FWHM (curve2) as a function of operating frequency

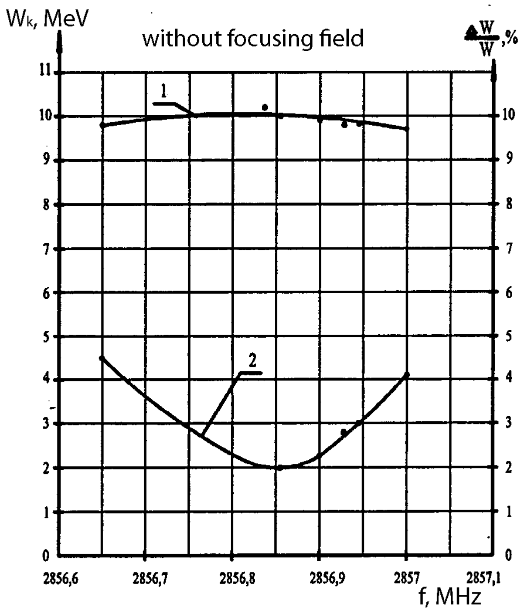

Fig.4. Kinetic energy of accelerated electrons at the maximum spectrum (curve1) and maximum FWHM (curve2) as a function of operating frequency

Table 2.*The current of the lens of current regulator and the currents of focusing coils*

Lens current, mA	Current of the 1st focusing coil, mA	Current of the 2nd and 3rd focusing coils, mA	Beam diameter, half-height, mA
275	0	0	2,1
260	26	6	4,4
255	26	12	4,4
245	26	18	4,1

A 30-minute test of accelerating unit was performed under rated operating conditions. In so doing, the steady-state thermal mode of the equipment of accelerating unit was attained. The instability of the energy and current of the beam of accelerated electrons was less than 2%, even without stabilization systems with feedback circuits. This test was performed for a short period of time to limit the radiation impact on the ionizing radiation-sensitive units, which were located in the area of radiation danger because of the layout possibilities on test stand.

When experimentally studying the accelerating units of UELR-10-10S LINACs, we obtained convincing evidences that the klystrons with a pulse power of 6 MW and an average power of 25…30 kW allowed the obtaining of the beam performances necessary for effective application of these linear electron accelerators to commercial systems for radiation processing.

РАЗРАБОТКА И РЕЗУЛЬТАТЫ ИСПЫТАНИЙ УСКОРЯЮЩИХ УСТРОЙСТВ КОММЕРЧЕСКИХ РЕЗОНАТОРНЫХ ЛУЭ МОДЕЛИ УЭЛР-10-10С ДЛЯ РАДИАЦИОННОЙ СТЕРИЛИЗАЦИИ

В.А. Алексеев, А.Е. Барановский, А.В. Белоусов, В.Н. Давыдов, М.И. Демский, К.А. Денисов, А.М. Фиалковский, Л.П. Фомин, Ю.Н. Гавриш, С.Н. Кочин, В.А. Ларионовский, К.Н. Маслов, В.М. Николаев, Д.А. Ободинский, А.В. Орлов, А.В. Рябцов, В.В. Рябов, Ю.П. Щепин, В.В. Терентьев

Описываются некоторые особенности конструкции ускорителей модели УЭЛР-10-10С, приводятся и обсуждаются характеристики электронного пучка, полученные экспериментально.

РОЗРОБКА І РЕЗУЛЬТАТИ ВИПРОБУВАНЬ ПРИСКОРЮВАЛЬНИХ ПРИСТРОЇВ КОМЕРЦІЙНИХ РЕЗОНАТОРНИХ ЛПЕ МОДЕЛІ УЕЛР-10-10С ДЛЯ РАДІАЦІЙНОЇ СТЕРИЛІЗАЦІЇ

В.А.Олексієв, А.Е. Барановський, А.В. Белоусов, В.Н. Давидов, М.І. Демський, К.А. Денисов, А.М. Фіалковський, Л.П. Фомін, Ю.М. Гавриш, С.Н. Кочин, В.А. Ларіоновський, К.Н. Маслов, В.М. Ніколаєв, Д.А. Ободинський, А.В. Орлов, А.В. Рябцов, В.В. Рябов, Ю.П. Щепін, В.В. Терентьєв

Описуються деякі особливості конструкції прискорювачів моделі УЕЛР-10-10С, приводяться і обговорюються характеристики електронного пучка, отримані експериментально.