LINEAR ELECTRON ACCELERATORS FOR RADIATION PROCESSING. CURRENT STATUS.

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Abstract

NPK LUTS NIIEFA has been developing linear accelerators for industrial applications during about 30 years. More than 150 linear accelerators for different applications have been manufactured by this company and installed in different regions of Russia and abroad. The linear accelerators for radiation sterilization developed in NPK LUTS NIIEFA are reviewed in this report.

For more than 30 years the D.V. Efremov Scientific Research Institute of Electrophysical Apparatus, NIIEFA designs, manufactures and delivers linear accelerators for radiation processing. In machines of the 1st generation manufactured in the '70-80s (ten in number) a long-anode magnetron operating at a frequency of 3 GHz was used as a source of RF power. The accelerators produced electron beams with a kinetic energy of 8 MeV and beam power up to 5-6 kW. Some machines offered a wide range of energy variation and were used both as pilot installations and for production of electron flows under commercial operation. Some of the machines are still in operation nowadays, e.g. at Dunashrink Kft., Anglo-Hungarian Heat Shrink Product Manufacturing and Trading Ltd. in Hungary, Budapest (the accelerator has been operating since 1980); at the Co Rad firm in St. Petersburg; at Radient Nord in France; at a firm in province Shanghai, China and at the the Kurgan joint-stock company of medical preparations and utensils "Sintez" (since 1975).

In 1971 a linear accelerator for electron energy up to 18 Mev and beam power of 10 kW (at 10 MeV) was designed and delivered to the Institute of Nuclear Chemistry and Technology, Warsaw, Poland. A klystron operating at a frequency of 1.818 GHz was employed in the machine. At present it is used for electron beam sterilization and treatment of foodstuffs not only on the territory of Poland but also in other countries of European Union.

In the 1980s the accelerators for radiation processing of the 2ndgeneration were designed on the basis of a multi-beam klystron generating at a frequency of 2.45 GHz a pulse power of 6 MW at an average power of 25 kW. Such a machine has been operated at the Kurgan joint-stock company of medical preparations and utensils "Sintez" since 1992.

The development of powerful electron accelerators of the 3rd generation was started in 2000 and is continued nowadays. The accelerators operate in the "S" band of wavelengths and apply a multiple-beam KPA-147A klystron generating at a frequency of 2.856 GHz.

In the accelerating device of the first accelerator of the 3rd generation – UELV-10-15S a 2100 mm long combined accelerating structure is used. The initial part of the structure is a standing wave buncher, and its main part is a traveling wave disk-loaded waveguide. The accelerating device also includes a three-electrode electron gun and an injection device with a short-focus lens.

The current of accelerated electrons is controlled by an induction current monitor with a feedback applied to the magnetic lens of the injection device. This feedback provides the necessary stabilization of the beam current at the accelerator outlet.

A special ionization chamber is used for monitoring the energy of accelerated electrons, dimensions and characteristics of the scanned electron beam The chamber is equipped with two rows of collecting electrodes and one raw of measuring probes installed along the scanning length between the collecting electrodes [1]. Energy is periodically checked from the current measured in an Al barrier. For this purpose, as well as for periodic check of the induction current monitor, a two-plate beam absorber, installed directly behind the above ionization chamber, is used.

The energy of accelerated electrons is controlled by varying the current of accelerated electrons, RF power at the inlet to the accelerating structure and frequency of RF oscillations.

Table 1: UELV-10-15S Beam Parameters

Nominal energy of accelerated electrons, MeV	10
Range of energy variation, MeV	5-12
Average beam power in the nominal mode, kW	14
Pulse current of accelerated electrons in the nominal mode, A	0.33
Beam current pulse length, μs	14
Pulse repetition rate, l/s	300
Injection energy, kV	50
Pulse injection current in the nominal mode, A	up to 0.5
Irradiation field sizes 10 cm from the extraction window foil:	
Scanning line length, mm	500
Scanning line width (at 10 MeV and 80 μm Ti-foils) mm	about 25

The above parameters can be attained at the following characteristics of the RF power supply system:

- RF frequency, GHz 2.856
- Pulse RF power at the accelerating structure inlet, MW up to 5.7
- RF pulse repetition rate, l/s 300

Tests of the accelerating device carried out in NIIEFA with an available modulator have demonstrated that beams with the following power and energy can be produced: 10 MeV – 13 kW, 12 MeV – 6.7 kW and 4.9 MeV – 7.6 kW

FWHM in the nominal mode is 10-12%.

The accelerating device was delivered to the Center for Advanced Technology, Indore, M.P., India. In June, 2004 a 10 MeV beam of accelerated electrons was produced.

The LUER-10-10S is a basic machine of the 3rd generation accelerators intended for radiation processing and primarily for radiation sterilization.

Table 2: LUER-10-10S Beam Parameters

Energy of accelerated electrons in nominal mode, MeV	10
Average beam power in nominal mode, kW	10
Maximum average beam power, kW	12
Energy variation range, MeV	8 – 10
Average power of electron beam in the 8 MeV mode, kW	9,5
Current pulse duration, μs	15
Pulse repetition rate, l/s	300, 150, 100, 50
Scanning length 100 mm from extraction foil, mm	800x20
Dose rate flatness over radiation field along scanning length, %	± 5
Scanning frequency, Hz	1-5

A biperiodical standing wave accelerating structure with axial coupling cavities is applied in the accelerating device.

Under tests of the accelerator carried out in NIIEFA the required beam power in the 10 MeV mode has been attained. The beam power in the 8 MeV mode amounted to 12 kW (energy reduction was obtained due to current loading of the accelerator). Narrow energy spectra of accelerated electron beams were obtained (3% FWHM).

It should be noted that the required beam parameters could be also attained with switched off focusing coils.

Low beam losses in the accelerating structure are provided due to RF focusing in the buncher.

The accelerator is rather a compact facility for radiation processing. Some units of the machine are shown in Fig. 1.

a)

b)

Figure 1: The units of LUER-10-10S accelerator – a) irradiator, b) cabinet of automated control system

At present the accelerator has been delivered to Slovakia.

An accelerator for an energy of 3 MeV and 2.5 kW beam power with local radiation shielding [2] reducing radiation level on the outer surface of the facility to 1μSv/h has been designed in NIIEFA. Such an accelerator can be installed practically in any industrial premises.

The facility is intended for irradiation of foodstuff, medical products, mails and parcels, etc.

The facility for radiation sterilization comprises a linear electron accelerator UEL-3-2.5S, a chamber for irradiation of objects with a system for these objects' transport. The main feature of the facility is its local radiation shielding providing safety of the attending personnel in the vicinity to the operating facility.

The facility is made as a single block housing the accelerator equipment with the scanning system and the irradiation chamber with the system for irradiated objects' transport.

Table 3: Main Performances of the Facility

Parameters of Accelerated Electron Beam	
Nominal average energy, MeV	3
Nominal average current, mA	up to 1
Nominal average power of the beam extracted to the atmosphere, kW	2.5
Nominal pulse current, A	0.4
Current pulse duration,μs	8 or 6.5
Pulse repetition rate, pulse 1/s	300 or 360
Beam diameter at the scanning system output window (90% of electrons), mm	20
Maximum scanning length (scanning in the vertical plane), mm	400
Dose variation along the scanning length, %	± 5
Radiation leakage-X-ray dose rate on the facility surface, μSv/h	1
Parameters of the Irradiation, Scanning and Transport Systems	
Sizes of irradiated objects: Depth, mm Height, mm Length, mm	 200 350 500
Scanning frequency, Hz	1-10
Speed of an irradiated object transport in the process of scanning ,m/min	about 1
Under two-sided irradiation, the cassette with an irradiated object is turned through 180° by the transport system	
Dimensions and Weight of the Facility	
Length, mm	4500
Width, mm	2400
Height, mm	1800
Weight, t	up to 35

The equipment of the UEL-3-2.5S is given in Fig. 2.

Figure 2: UEL-3-2.5S accelerator-based facility

The KPA-168 klystron operating at reduced pulse power is a source of RF power.

A combined-type accelerating structure and a double-electrode gun with a short-focus lens are applied in the accelerator.

The facility based on the UEL-3-2.5S accelerator is developed in two modifications. In the first version cassettes with packages to be irradiated are placed on the transport system in the irradiation chamber one by one (discrete process). Such a modification of the facility has been manufactured and delivered to the customer (the Kasel Associates Industries Inc, USA) and is successfully operated nowadays; all design parameters are provided.

The second modification of the machine is intended for continuous irradiation of a large batch of products, which are put into the irradiation chamber on the transport system through a labyrinth with an additional radiation shielding. The development of such a machine is still in progress.

In all the machines of the 3rd generation the computer control system is built on the basis of Octagon Systems 6000 controllers and an Advantech host computer. The control system is updated as far as the machine is updated and can be modified at the customer's request.

Nowadays, works on the updating of systems for variation of energy of electrons are underway.

S-band accelerators for a beam power up to 25-30 kW are under design.

Works on increasing the beam diameter at the scanning system output are also in progress.

REFERENCES:

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[2] M.F. Vorogushin, Yu.N. Gavrish et al., "3 MeV Linac Based Facility for Electron Beam Processing", Atomnaya Energiya, v. 95, №1, p. 44