ELECTRON-LINAC-BASED RADIATION FACILITIES OF THE UKRAINIAN NATIONAL SCIENCE CENTER "KIPT"

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Abstract

A review is given about electron Linacs of KIPT and their some applications for research of radiation effects in reactor materials, channeling, plasma-beam interactions, geology (gamma-activation analysis of ore samples), as well as sterilization of single-use medical products, modification of polymers and semiconductors, isotope production for nuclear medicine etc.

1 ELECTRON LINEAR ACCELERATORS

Characteristic of the Ukraine economy of Today's transition period is the absence of stable situation on the radiation technology market. Considering this, it would be to good advantage to develop, build and make use of accelerators with a broad range of parameters, capable to meet the market's demands. This ideology is fundamental in the activities of "Accelerator" R&D Establishment of the Ukrainian National Science Center "Kharkov Institute of Physics&Technology", the leading organization in Ukraine in creation of electron linacs and applicable technologies. This paper gives a short survey of some electron linear accelerators and the results in the areas of applied physics and radiation technologies.

There are six electron linear accelerators at "Accelerator" R&D Establishment. The biggest one is the oldest linac in Europe LUE-2000 [1]. Three accelerators (EPOS, LU-10, KYT) are used for performing various radiation processes. There main parameters are represented in Tab.1.

1.1 Accelerator EPOS

The accelerator EPOS is a two-section linac with an extracted electron beam scanning system, built on the base of the existing equipment. EPOS has been designed to be used for radiation processing of various items, employing electron beams with energies up to 30 MeV.

The EPOS is disposed underground, horizontally, in a concrete tunnel. The accelerator layout is given in Fig. 1. The electron source is a diode-type gun with a lanthanum hexaboride (LaB_6) heated cathode. Electron beam (5.5 mm diameter, current up to 3A) is formed in the source upon application of 80 kV-pulsed voltage to the cathode from the HV-modulator (MG). While passing the bunching cavity (B), the beam is chopped up into separate bunches. Electron acceleration takes place in a disk-loaded waveguide (DLW) that has a homogeneous structure, the structure's a/b ratio being 0.14, with the phase shift per cell $\pi/2$, and the phase velocity equal to the speed of light. In order to suppress the beam breakup instability in the disk-loaded waveguide, thin radial cuts were made in them [2]. At the input end of the first section (AS1) there is a certain length (30 cm) with a lower wave phase velocity [3], providing the capture of more than 50% of the injected electrons. Temperature inside the DLW (37±0.5)C is self-maintained during the operation modes.

Tab.1 Basic Linacs Parameters

	EPOS	LU-10	KYT
Energy range, MeV	10 -30	8-18	8-14
Operation energy , MeV	20	12	9
Frequency, MHz	2797.2	2797.2	2797.2
Number of sections	2	1	1
DLW length, m	3.05	3.05	1.23
Number of klystrons	2	2	1
RF-pulse width, μs	5	4	5
RF-power input, MW	10	10	10
Current-pulse width, μs	4	3.5	4
Repetition rate, pps	50	300	300
Average current, μA	150	1000	800
Maximum Bsf, Hz	3	3	3
w×l, cm	1 x 30	1 x 30	1 x 30

The rf-power input, needed for electron acceleration, is provided by two KIU-12AM-type klystrons, the first of which operated in the self-exiting mode, and the second one is excited from the first klystron [4].

RF-power from each klystron (K) - up to 10 MW- is fed through a rectangular waveguide into the DLW. The klystrons work in a pulsed mode triggered by two klystron modulators (MK) with the parameters that are given in [5].

The beam focusing is performed by two short magnetic lenses (FL1 and FL2), two DLW-coaxial solenoids (FS1 and FS2) and two quadrupole lenses (QL1 and QL2).

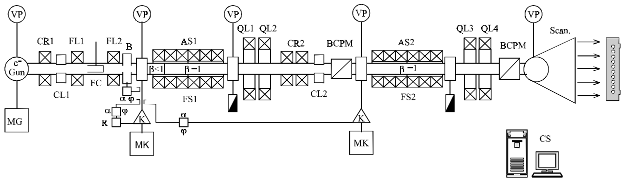

Figure 1: EPOS layout

Electron beam extraction is made through a Ti-foil 50 microns thick. In order to enlarge the irradiation area a beam scanning system (BSS) is installed at the acceleration exit, providing for beam sizes (w×l) up to the value (1×30) cm [6], the beam scanning frequency (Bsf) being 3 Hz.

Control over EPOS operation is performed by a computer-automated system, providing for the monitoring of parameters of beam and modulators, their lock-up when the assigned mode of operation is off, as well as magnetic component current adjustment and amplitude-phase tuning.

1.2 Accelerator LU-10

The LU-10 single-section electron Linac was commissioned in 1987 [7]. Up to mid-1993 it had operated with KIU-53 klystron, producing electron beam with output energy E≅10 MeV and average current I≅ 500 μA at a repetition rate F=150 Hz. In 1993 a necessity arose to increase beam energy and output power. Our studies [5] gave a reason to believe that a scheme of adding up the rf-power output from both KIU-12 klystrons should provide for a reliable operation of the accelerator and required beam parameters at F=300 Hz and the input operation power P≅(12÷13)MW from each of the two KIU-12 klystrons. A schematic layout of the accelerator LU-10 is given in Fig.2.

Since 1994 at the LU-10M research has been going on in basic and applied areas of radiation damage physics, radiation technologies and pharmaceuticals sterilization. The facility is equipped with a suspended conveyer belt, a load/unload and storage from for various items for a mass-scale radiation processing, and devices for target irradiation by large doses with necessary cooling.

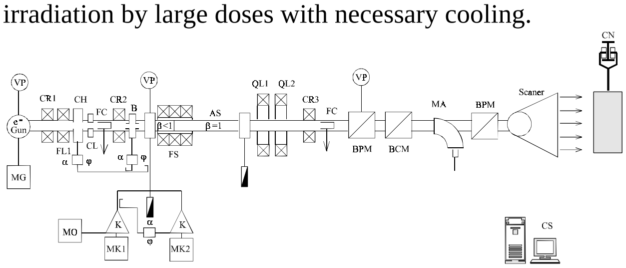

Figure 2: LU-10 layout

Accelerator has a sufficiently high long -lasting stability of beam parameters, with the 24-hour mean variations in beam energy and current not more ±1,5%. The accelerator is equipped with metrologically licensed devices [8] for energy spectrum measurements and monitoring of average and pulsed beam current.

1.3 Accelerator KYT

The KYT has been operating in NSC KFTI since September 1993 [9]. KYT consists of electron linac with the scanning and electron beam extraction device, cooling and control systems. KYT produces 8-10 MeV electron beam with power up to 10 kW and is meant for performing various radiation technological processes including sterilization of medical articles. A schematic layout of the accelerator KYT is given in Fig.3

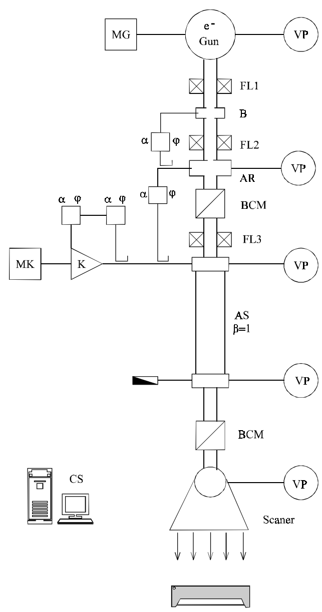

Figure 3: KYT layout

The injector is designed to inject a well-bunched (20°), well-collimated and sufficiently accelerated (E>300 keV) beam of electrons into the accelerator section. The injector consists of an electron gun, a prebuncher (B),a accelerating resonator (AR) and two magnetic thin lenses (FL1 and FL2). . The electron gun which operates at ~25 kV is of diode type with oxide cathode ∅ 15 mm.

The accelerating structure (AS) consists of the disk-loaded waveguide and input and output couplers. The disc-loaded waveguide operates at f=2797 MHz in 2π/3 mode and consists of constant impedance landings connected via four transition cells (quasi constant gradient structure).

The scanning and electron beam extraction device consists of a scanning magnet and a special system with an air-cooled exit foil.

2 APPLIED PHYSICS AND TECHNOLOGIES

A series of experiments has been carried out on LU-2000 accelerator to simulate radiation damage in reactor materials [10]. It was shown that electron beam with energy up to 300 MeV and beam current 80 μA produces on the irradiated area 3.5 x 10 mm a radiation flux (e,γ) equivalent to a fast neutron flux (E_n>0.1MeV), up to $2\cdot10^{15}$ n/cm^2. This interaction will accumulate He, as a reaction product, for example in Ni and Cr, higher approximately by two orders of magnitude, then in a fast neutron reactor. This fact allows to employ electron linacs in order to simulate, very rapidly, the phenomenon of high-temperature radiation embrittlement in advanced materials. Besides, research work on our accelerators produced important results in the studies on radiation defect aggregation in metals and high-temperature superconductors [11], as well as in the studies on electron channeling in single crystals [12].

Sterilization. Radiation processing of medical products, pharmaceutical and raw materials calls for electron and bremsstrahlung with the upper energy spectrum range $\leq$ 10 MeV and absorbed radiation dose range 5-25 kGy. LU-10 is well equipped to provide such conditions, being also outfitted with robotics for remote-control target material installation in the radiation area. For sterilization radiation dose being 25 kGy, and average material density up to 0.2 g/cm^3, the facility shall provide the yield up to 4 m^3/h with the production cost (for big batches) near \$ 35 / m^3 .

Semi-conductor modification. A technology has been developed for electron flux treatment of semiconductor devices and chips for Ukraine's electron industry. By way of radiation-induced defect implantation and silicon doping with Al in (γ,n) reactions, one can obtain a programmed modification of lifetimes of secondary charge carriers and on improved semiconductor device performance.

Polymer modification. With an aim of a obtaining heat-shrinking items, mainly polyethylene-based, a technology developed for their treatment in the bremsstrahlung radiation field. The characteristic range of irradiation doses various polyethylene brands and items is 50...150 kGy.

Utilization of rubber wastes. Some rubbers (mainly, butylcaoutchokc-based) can be re-cycled to new applications by way of preliminary radiation-induced devulcanization. It is achieved by electron irradiation to the dose up to 100 kGy of the wastes that have been preliminary cold-worked. The resulting product can be utilized as a raw material for fabrication of construction, water-resistant and roofing materials, and also to make tires and radioengineering materials. The ecological importance of this technology are significant.

Medical radionuclides. The most widely used radionuclide on the appropriate nuclear medicine market is ^{99m}Tc. In 1996 we mastered a technology of environmentally pure production of ^{99m}Tc, using a high-current linac bremsstahlung in the reaction ^{100}Mo(γ,n)^{99}Mo $\rightarrow$^{99m}Tc. The first experimental ^{99m}Tc yield has been successfully accomplished. The appropriate spectrometric and radio pharmaceutics studies confirmed its good quality [13].

Activation analysis. The inherent capabilities of a high-current linac, outfitted with an appropriate converter, to generate bremsstahlung radiation access a wide range of incident power and gamma-radiation energy with the needed radiation field dimensions have been applied to develop some systems for element activation express-analysis of ore samples and technological raw materials for rare - and precious metal inclusions. One of advantages of this technique is a capability of fast determination of element concentration at the level 0.1g/t in samples of irregular ores, weighing 1 kg and more with the yearly analysis flow up to 10^4-10^5.

Irradiation metrology. The above applied research and technologies call, as a rule, for a rigorous control over incident irradiation characteristics. This can be achieved by equipping each radiation facility with a necessary diagnostic channel set. Calibration of such sets is done, using a reference measurement complex, created jointly by "Accelerator" Establishment and Mendeleev Institute of Metrology (St.Peterburg, Russian) [14].

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