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LINEAR ELECTRON ACCELERATOR FOR RADIATION TECHNOLOGIES WITH BEAM PARAMETERS VARIED IN WIDE RANGE

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Abstract

We present the overview and beam parameters measurements results as well as the operational experience with the S-band pulsed linear electron accelerator with beam energy in the range of 5-10 MeV and maximum beam power of up to 15 kW. The possibility of adjusting the beam parameters in a wide range, provided by the design and control system of the accelerator, allows to use the accelerator in a wide variety of radiation technologies.

INTRODUCTION

Linear electron accelerators with the energy up to 10 MeV and beam power up to 50 kW are widely used in various radiation technologies. In the cases, when the specifications of the products being processed making use of the same installation are significantly changed, in order to optimize the radiation process it is necessary to have the possibility of on-line adjustment of the accelerated beam parameters. For example, during the radiation processing of the food products the mass-per-unit-area thickness of the products and the required dose can vary multi-fold; this requires for the several-fold change of beam power and value of dose for one beam pulse. The adjustment of the accelerated beam power with respect to the mass-per-unit-area thickness of the products enables not only to ensure the required uniformity of the dose distribution by the depth, but also to save the electric power to the considerable extent with proper design of the accelerator RF power supply system. The adjustment of dose being delivered to the products per one beam pulse enables to change the dose from hundreds of Grays to tens of kilo Grays with ensuring the uniformity of dose distribution along the surface and with high efficiency of the process.

ACCELERATOR DESCRIPTION

The linear accelerator described earlier in [1] has been installed in the centre for antimicrobial processing of products of vegetable and animal origin by the stream of accelerated electrons [2]. The photo and schematic view of the accelerator are given in Fig. 1, main parameters are presented in table 1.

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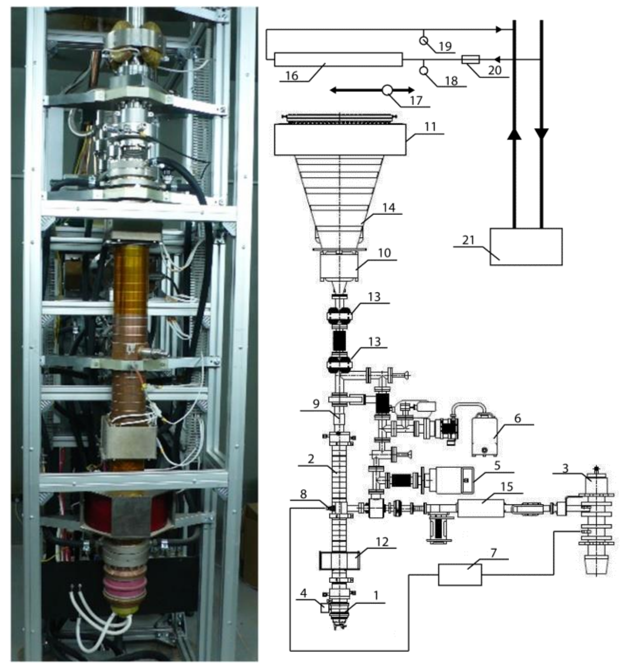

Figure 1: Photo and schematic view of the accelerator. 1 – electron gun, 2 – accelerating structure, 3 – klystron, 4, 5, 6 – vacuum pumps, 7 – low power RF unit, 8 – RF antenna, 9 – beam current monitor, 10 – scanning magnet, 11 – correcting magnet, 12 – solenoid, 13 – quadrupole lenses, 14 – scanning chamber, 15 – circulator, 16 – beam absorber 1, 17 – beam absorber 2, 18, 19 – temperature sensors, 20 – flow meter, 21 – chiller.

Table 1: Accelerator Parameters

Range of beam energy regulation	5-10 MeV
Pulsed beam current	400 mA
Range of beam power regulation	1-15 kV
Range of pulse duration regulation	4-12 µs
Range of pulse repetition rate regulation	50-400 Hz
Range of beam scanning width regulation	40-60 cm
Range of scanning frequency regulation	1-30 Hz
Operating frequency	2856 MHz
Maximum power of klyastron, pulse/average	6 MW/25 kW
Wall plug efficiency	>20%

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In order to implement the accelerator operation modes with different energies of the accelerated electrons it is necessary to have the possibility of smooth adjustment of the power being supplied from the klystron to the accelerating structure. The most energy-efficient adjustment of the output power of the klystron is achieved by means of changing its cathode voltage with maintaining the input RF signal at the optimal level. Matching of the accelerating structure with feeding waveguide is performed by means of choosing of the optimal beam current with the help of voltage adjustment on the control electrode of the three-electrode electron gun.

During commissioning period we did measurements of the accelerated beam parameters, for the purpose of calibration. The following auxiliary elements shown in Fig. 1 were used: beam absorber 15 in the form of isolated thick-wall copper tube of rectangular section cooled by water, and beam absorber 16 – isolated steel cylinder of small diameter that is moved along the output deflecting flange remotely.

METHODS

The average beam power, $\bar{P}$, released in the absorber 15 (Fig. 1), is measured by means of precise calorimeter CALEC ST II, with the temperature sensors PLH 100/105 CE M and flow meters AMFLO MAG Smart DN15. In order to measure the beam pulse current I oscilloscope is used, to which the signal is sent from the precise 50 Ohm resistor that connects absorber with ground.

When determining the average beam power it is taken into account that during the interaction of accelerated electrons with the absorber wall the bremsstrahlung radiation is generated, main part of which leaves the absorber. Also the significant part of the beam energy is taken away by the electrons reflected from the absorber. The latter process contributes also to the measured beam current. In order to take into account these factors the process of beam interaction with absorber was modeled making use of GEANT4 library. Calculated dependence of the beam power and charge leakage on the electron energy is shown on Fig. 2.

Average beam energy is calculated as per formula $\bar{E} = \bar{P}_{corr}/\bar{I}$, where $\bar{I} = I_{corr} \times \tau \times f$ is average current, $\bar{P}_{corr}$ and I_{corr} are average beam power and pulsed beam current corrected with the use of data from Fig. 2, τ is the pulse duration and f is pulse repetition rate.

Also the efficient energy of the accelerated electrons is estimated by standard method based on measurements of depth-dose distribution curves in Al according to [3]. For this purpose the multi-layer target made of Al and radiochromic film DEX B3 with operating range of the measured doses 10-50 kGy was used.

Finally, the third method of evaluation of the beam energy and energy spectra is the use of scanning magnet as a spectrometer. In order to implement this possibility the precision measurement of the magnetic field map was done and, the relation of coils current, deflection angle and electron energy was determined. The spectrum measurement is carried out with the fixed coils current by means of measurements of the beam current distribution beyond the exit window with the help of movable absorber 16 (Fig. 1) or radiochromic film.

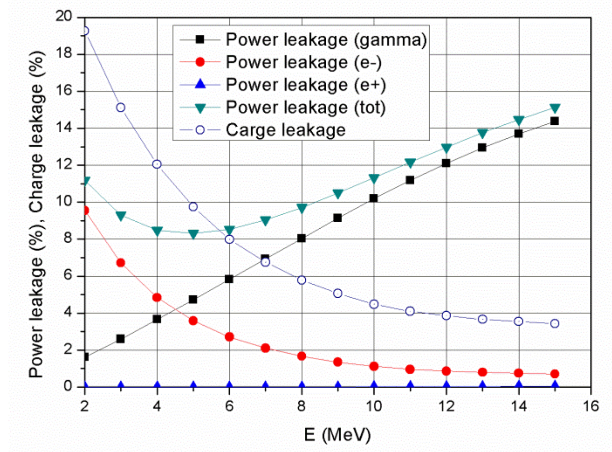

Figure 2: The dependence of the beam power and charge leakage on the electron energy due to the bremsstrahlung, secondary electrons and positrons.

RESULTS

As it was noticed above, the main parameters that determine the accelerator operation mode are voltages on klystron cathode and on control electrode of electron gun. For the solid-state modulator from ScandiNova used in our accelerator, the amplitude of high-voltage pulse coming to the klystron cathode is determined by the charge voltage of primary circuit U_{HVPS}. The dependence of pulse power $P = \bar{P}_{corr}/\tau \times f$ and beam energy $\bar{E}$ on the selected operation mode of the accelerator is shown on Fig. 4, where $U_{C.E.}$ is gun control electrode voltage. From the figure it can be seen that maximum power of 4.25 MW is achieved with the energy of 8.5 MeV. For the maximum possible duty factor of our equipment equal to 0.4%, the average power in this mode achieves 17 kW.

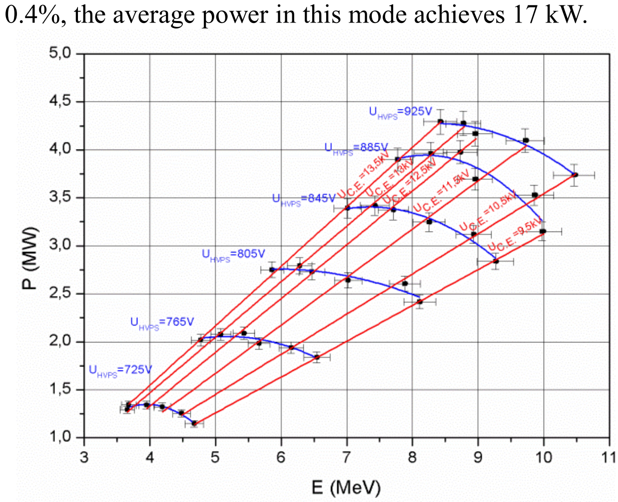

Figure 3: The relation of pulsed beam power and beam energy for the selected operation mode of the accelerator. U_{HVPS} is the charging voltage of modulator, $U_{C.E.}$ is the electron gun control electrode voltage.

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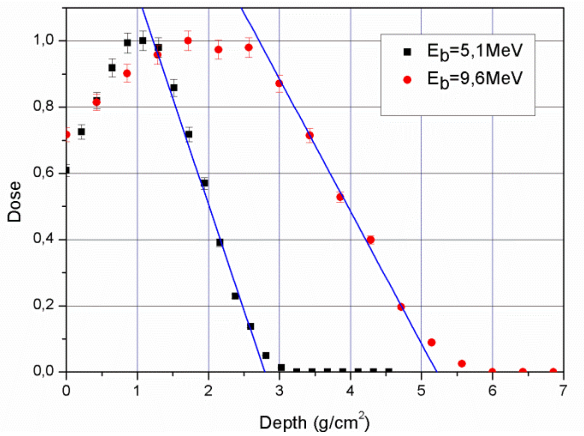

Figure 4: Measured dose - depth distribution in Al. Set energies are 5 MeV and 10 MeV.

The results of the absorbed dose - depth distribution in the Al measurements with radiochromic film are given in Fig. 4. The beam energies were set to 5 MeV and 10 MeV according to calibration based on average beam power and pulsed current measurements described above. Results of two types of beam energy measurements are in rather good agreement.

The spectra measured with the scanning magnet for several modes of the accelerator operation are shown in Fig. 5. For the mode with maximum energy the spectrum is measured both with the movable absorber and with the radiochromic film. The spectrum width is determined mainly with energy resolution of the "spectrometer". The vertical line mark the result of energy measurement with two methods described above. It is seen that the results are in good agreement.

The beam energy measurement results were used to calibrate signal of RF detector, to which the signal from the RF antenna installed in the accelerating structure comes. The signal from RF detector is used for continuous monitoring of the beam energy during the accelerator operation.

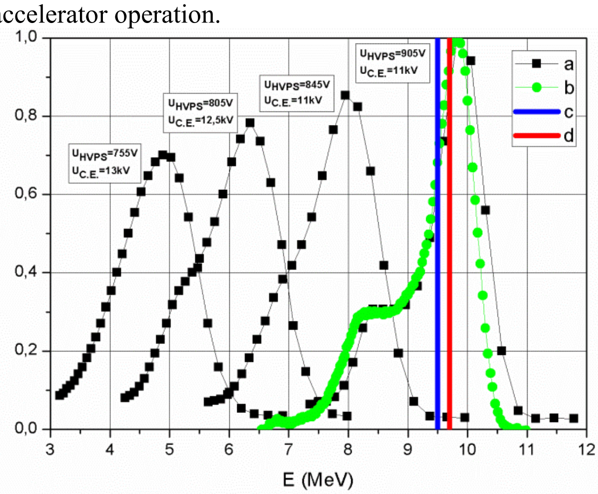

Figure 5: The beam spectra measured by the absorber 16 (Fig. 1) (a), by radiochromic film (b), beam energy from dose-depth distribution measurement (c) and from average power and pulsed current measurements (d).

PRACTICAL USE

In order to ensure the convenient and efficient operation of the accelerator on the basis of the above-described measurements of the accelerated beam parameters, we have developed the algorithm enabling on the basis of the parameters of the products being irradiated (i.e. required dose, dimensions and weight of the box) to determine the accelerator operation mode parameters, ensuring the maximum capacity of the complex with the minimum energy consumption. Besides, the remote control of the accelerator operation via Internet and continuous record of beam main parameters and mode parameters to a server are ensured.

CONCLUSION

The presented results demonstrate wide capabilities for flexible adjustment of energy and power of accelerated beam. In combination with the beam scanning system and conveyor that is a part of the complex, the accelerator enables processing of the products with effective thickness from 0.1 g/cm^2 up to 8.1 g/cm^2 with maximum efficiency, delivering the dose starting from 0.8 kGy.

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