Pulsed 5 MeV standing wave electron linac for radiation processing

L. Auditore, R. C. Barnà, D. De Pasquale, A. Italiano, A. Trifirò, and M. Trimarchi*
Istituto Nazionale di Fisica Nucleare, Gruppo Collegato di Messina and Dipartimento di Fisica dell' Università–Messina, I-98166 Messina, Italy
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Several modern applications of radiation processing require compact and self-contained electron accelerators. To match these requirements, a 5 MeV, 1 kW electron linac has been developed at the Dipartimento di Fisica (Università di Messina) and will be described in this paper. This standing wave accelerator, driven by a 3 GHz, 2.5 MW magnetron generator, has an autofocusing structure and will be used to study several applications of radiation processing.

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I. INTRODUCTION

In recent years, radiation processing has been rapidly growing in various fields of industrial production and scientific research as a safe, reliable, and economic technique. In particular, for several applications, such as polymers chemistry, sterilization, or food irradiation, electron treatment represents a very powerful and environmental friendly alternative to other industrial techniques [1].

A 5 MeV electron linear accelerator can be successfully used to perform radiation processing. In fact, this energy is large enough to assure a good penetration depth of electrons in several materials and consequently to obtain a proper distribution of radiation dose in depth for a lot of treatments. At the same time, this energy is low enough to avoid activation phenomena in the treated materials.

Furthermore, the compact structure of an autofocusing accelerator of this energy is very suitable to develop a transportable system for industrial radiography and x-ray tomography.

II. ACCELERATOR FEATURES

The accelerating section shown in Fig. 1 is a biperiodic structure operating in $\pi/2$ mode. It has been designed, in collaboration with the ENEA Accelerators Group (Frascati, Rome), by means of the SUPERFISH and PARMELA codes, in such a way as to obtain an autofocusing structure, to avoid using external focusing magnets, thus noticeably minimizing the accelerator dimensions [2]. For this structure the shunt impedance is 70 $\mathrm{M}\Omega/\mathrm{m}$, and the measured value of the coupling coefficient β is 1.35.

Major features of the 5 MeV accelerator are summarized in Table I. The autofocusing effect has been obtained by combining a low injection energy ($\leq$ 15 keV) with a slow rise time of the electric field in the first accelerating cavity, which the length is greater than the standard one. It follows that the first cavity exerts an intense bunching and a strong focusing on injected electrons that will reach the center of the following cavities after the radio frequency peak, thus experiencing a further focusing [3].

A 10^{-8} mm Hg vacuum is maintained in the structure by a small ionic pump. External cavity walls have been machined in such a way as to contain ducts to allow for the water cooling of the structure.

rf power is supplied to the accelerating structure by a magnetron generator through the waveguide, connected to the 8th cell by a vacuum window with a ceramic insulator. Matching of the magnetron load is assured at a low repetition rate by 5 MW peak power ferrite insulators. A separated electromagnet provides to the magnetron generator a magnetic field ranging from 100 to 157 mT.

The pulse forming circuit shown in Fig. 2, charged through an inductance [4] and triggered by a hydrogen-filled ceramic thyratron, supplies to the magnetron a 45 KV, 90 A pulse, shown in Fig. 3. The 1:4 pulse transformer provides the proper bias to the magnetron filament.

Accelerated electrons are extracted from the resonator through a thin Ti foil (50 μm thick, Ø12 mm), which

TABLE I. Accelerator parameters.

Energy (MeV)	3.5–5.5
Peak current (mA)	200
Repetition rate (Hz)	1–300
Pulse duration (μs)	3
Peak power (MW)	1
Average power (kW)	1
rf frequency (GHz)	2.997
Structure type	SWOAC
Operating mode	$\pi/2$
No. accelerating cavities	9
Magnetic lenses	NO
Length (cm)	40
Weight (kg)	25
Beam aperture size (mm)	12

*Electronic address: marina.trimarchi@me.infn.it

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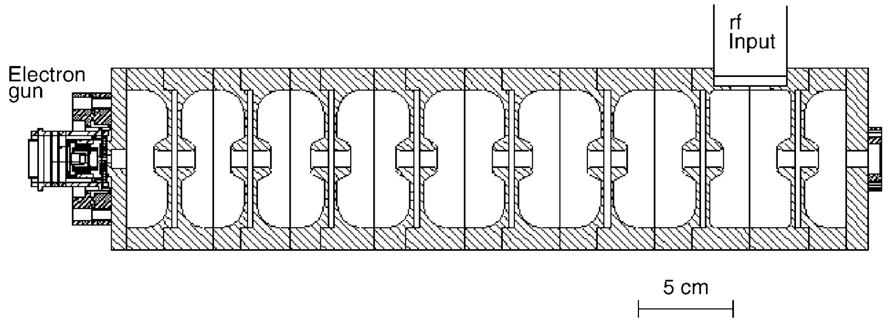

FIG. 1. Accelerating structure.

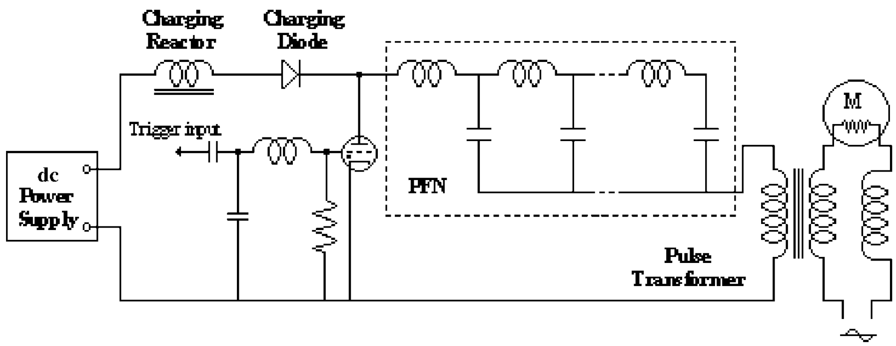

FIG. 2. Resonant-charge pulse forming circuit scheme.

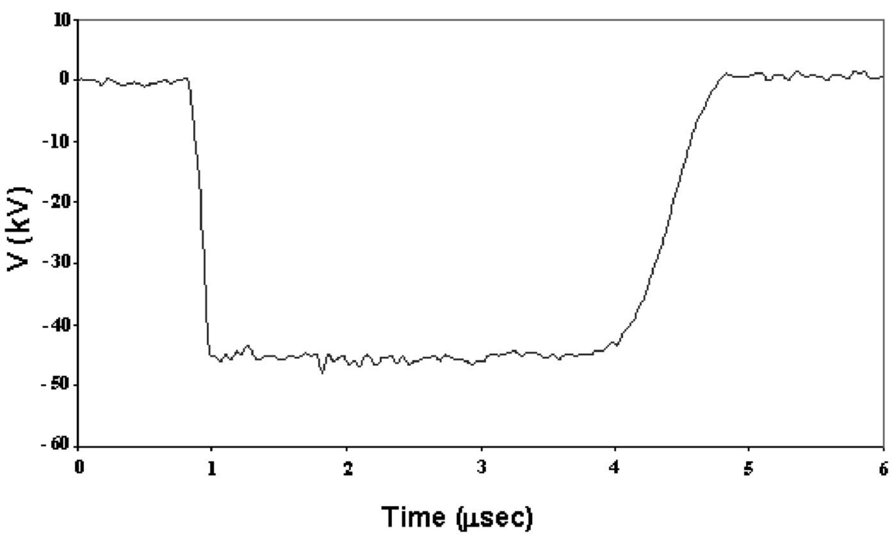

FIG. 3. Typical pulse shape.

thermal stresses have been studied by means of the ANSYS code. A proper water-air cooling system has been designed to assure correct heat dispersion on the titanium surface, avoiding damages due to the thermal power left by the collimated electron beam spot. Furthermore, the 50 μm thickness has been chosen in such a way that electrons feel a little divergence in traversing the titanium foil, and, at the same time, it assures a safe rigidity of the exit window.

III. ELECTRON INJECTION

The electron injector, shown on the left side of Fig. 1, is directly connected to the accelerating structure, so that the first accelerating cavity acts as the injector anode.

The injector consists of a rhenium-oxide emitting cathode with a properly shaped electrode, which focuses the beam in the first accelerating cavity, in a well-defined point, properly chosen to obtain autofocusing [3,5].

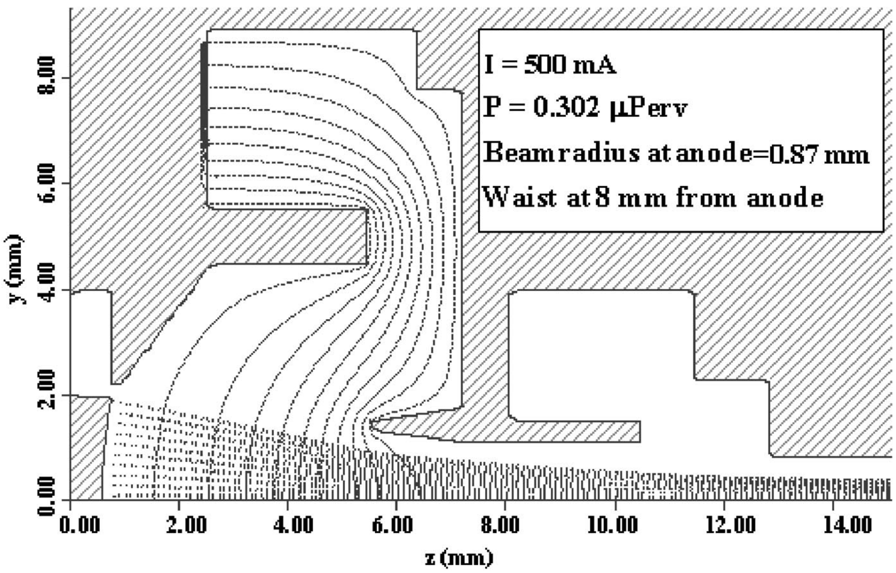

FIG. 4. Cathode simulated by EGUN.

Electron gun features have been accurately studied by means of the EGUN code (see Fig. 4). A compact pulse forming circuit has been developed for the cathode, similar to that developed for the magnetron, providing a 13 KV, 10 A, 4.5 μs pulse, and the proper heating current to the cathode.

IV. BEAM DYNAMICS

Results of the beam dynamics calculations as the computed accelerating field distribution along the accelerator structure, the electron energy spread, and the radial beam distribution are shown in Fig. 5–7, respectively [3].

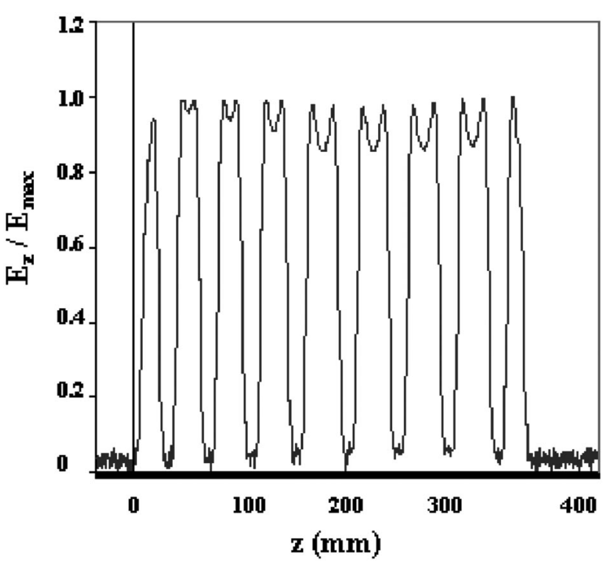

FIG. 5. Electric field distribution on the z axis.

The electron beam spot has a $\approx$ 4 mm diameter, measured at a 5 cm distance from the titanium exit window.

In order to check the beam broadening with distance, spot sizes obtained with a 1 mm diameter collimator have been recorded on gafchromic films at 1, 5, and 10 cm distances, as shown in Fig. 8(a).

In agreement with theoretical simulations, the surface dose distribution, obtained by measuring the optical density of irradiated gafchromic films, is uniform over a 1 cm diameter spot at a 10 cm distance [6].

The maximum electron peak current, measured at a 5 cm distance by means of a Faraday cup, is $\approx$ 200 mA, and the corresponding pulse shape is shown in Fig. 8(b).

Electron beam energy has been measured as a function of the magnetron rf power. Figure 9, in which energy

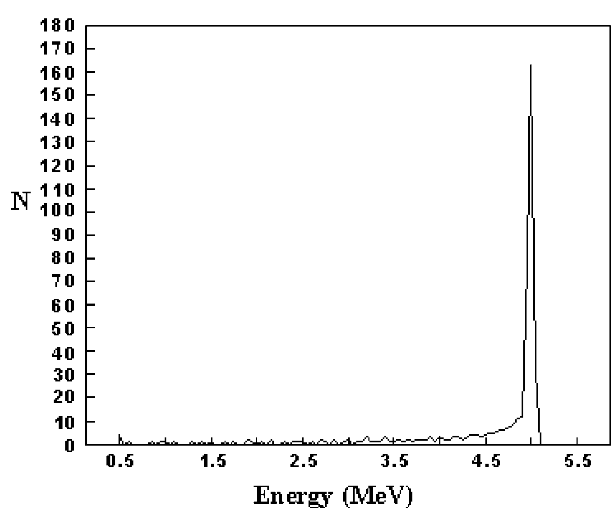

FIG. 6. Computed energy distribution.

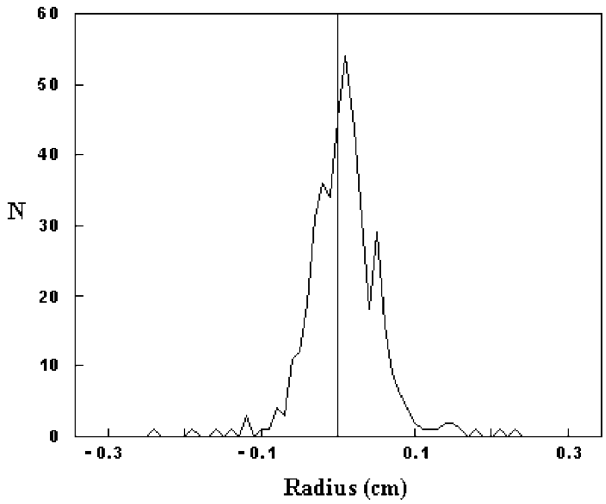

FIG. 7. Computed radial distribution.

measurements performed at the maximum peak current are reported together with the theoretical curve, shows that energy can be varied between 3.5 and 5.5 MeV.

V. CONCLUSIONS

A compact and reliable 5 MeV electron accelerator has been developed, with a particular autofocusing structure. For this accelerator, pulse frequency can be varied ranging from 1 to 300 Hz, thus allowing the study of a great number of different applications of radiation processing.

In particular, by substituting the magnetron with a klystron and the ferrite insulator with a 4-port circulator, it will be possible to study also some industrial applications requiring a very high power.

Furthermore, the very compact structure of this accelerator makes it very suitable to develop a system for

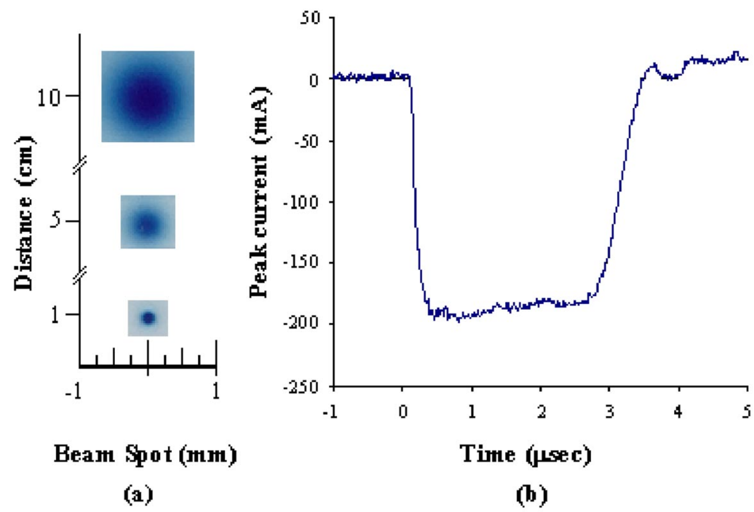

FIG. 8. (Color) Electron beam features.

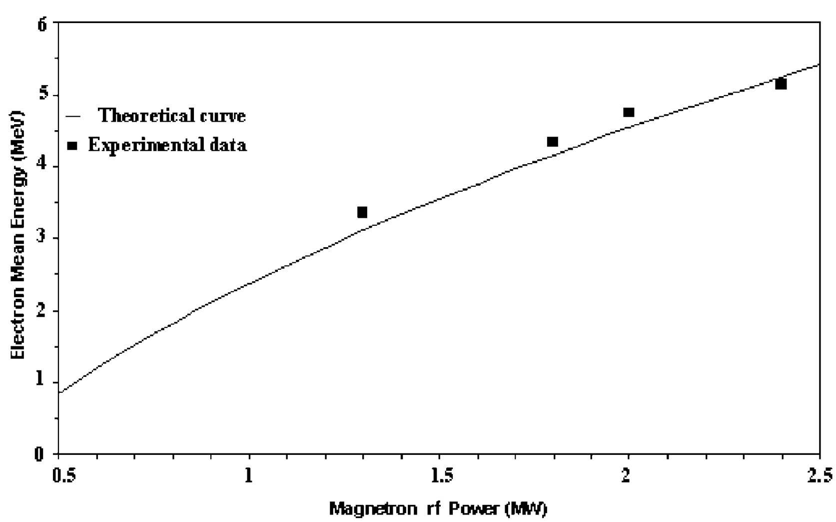

FIG. 9. Beam energy vs rf power.

in situ treatments as industrial radiography or x-ray tomography.

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