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THE 5 MeV ELECTRON LINAC FOR RADIATION PROCESSING IN MESSINA

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Abstract

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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1 INTRODUCTION

In recent years, radiation processing is rapidly growing in various fields of industrial production and scientific research as a safe, reliable and economic technique.

In particular, for several applications, 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.

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

2 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 auto focusing structure, to avoid using external focusing magnets, thus noticeably minimizing the accelerator dimensions [2].

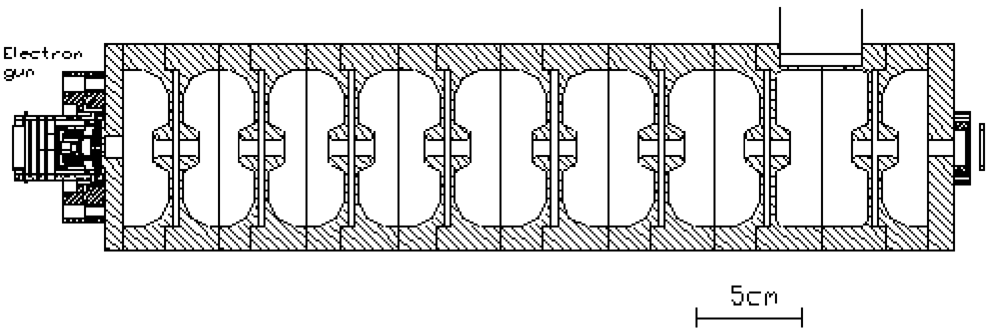

FIG. 1: Accelerating structure.

Major features of the 5 MeV accelerator have been summarized in table 1. The autofocusing effect has been obtained by combining a low injection energy (< 15 keV) with a slow rise time of the electric field in the first accelerating cavity , which 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 centre of the following cavities after the radio frequency peak, thus experiencing a further focusing [3].

A 10^{-8} mmHg vacuum is maintained in the structure by a little ionic pump.

RF power is supplied to the accelerating structure by a Magnetron generator through the waveguide, connected to the 8^{th} cell by a vacuum window with ceramic insulator. Matching of the Magnetron load is assured at 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.

TAB. 1: Accelerator parameters.

PARAMETERS OF THE ACCELERATING STRUCTURE	
Energy (MeV)	3.5 – 5.5
Peak current (mA)	200 mA
Repetition rate (Hz)	1-300 Hz
Pulse duration (μsec)	3
Peak power (MW)	1
Average power (kW)	1
RF Frequency (GHz)	2.997
Structure type	SW OAC
Operating mode	π/2
N. accelerating cavities	9
Magnetic lenses	NO
Length (cm)	40
Weight (kg)	25

A 45 KV, 90 A pulse, shown in fig.3, is supplied to the Magnetron by the pulse forming circuit. This circuit, shown in fig.2, is charged through an inductance, to optimise the charge efficiency [4].

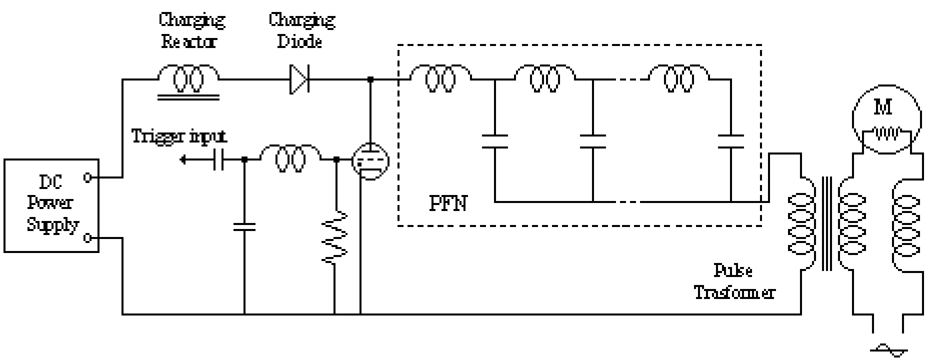

FIG. 2: Resonant–charge pulse forming circuit scheme.

The 1:4 pulse transformer acts as an impedance coupler between the pulse forming network and the Magnetron, and provides the proper bias to the magnetron filament.

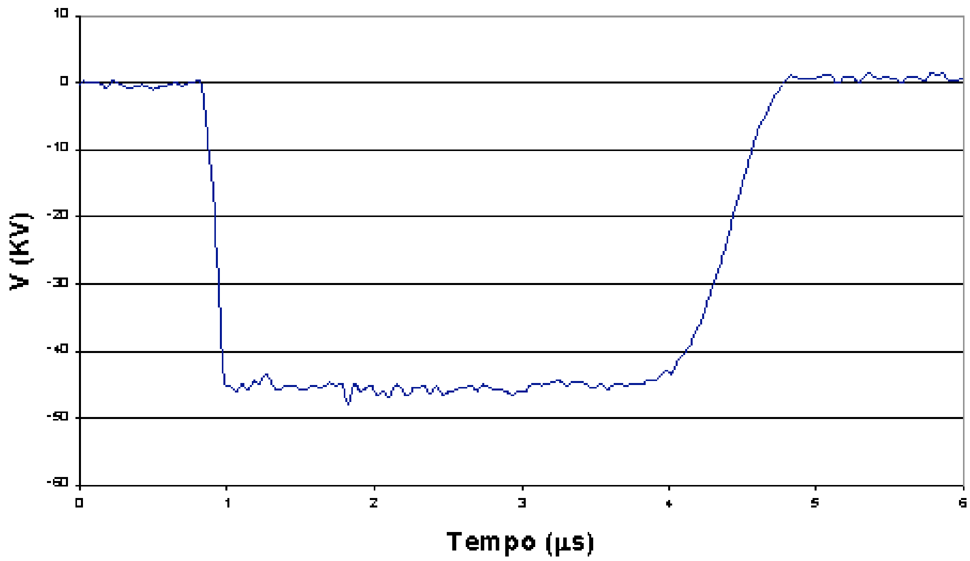

FIG. 3: Typical pulse shape.

The requirements of low resistance, stability to temperature variations, rapid time-closure and the need to achieve the proper repetition rate have suggested the use of a hydrogen–filled ceramic Thyratron as a switch for the pulse forming network.

Accelerated electrons are extracted from the resonator through a thin Titanium foil (50 μm thick), which 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 in it by the collimated electron beam spot. Further, the 50 μm thickness has been chosen in such a way as electrons feels a little divergence in traversing the titanium foil, and, at the same time, it assures a safely rigidity of the exit window.

3 ELECTRON INJECTION

As shown in fig.1, electron injector is located on the left part of the accelerating structure, directly connected with it, so that the first accelerating cavity acts as the injector anode. The electron injector consists of a Rhenium – Oxide emitting cathode with a properly shaped Pierce electrode, which focuses the beam in the first accelerating cavity, in a well defined point, properly chosen to obtain autofocus [5].

The shape of the Pierce electrode, and its distance from the anode have been accurately studied by means of the EGUN code (see fig.4).

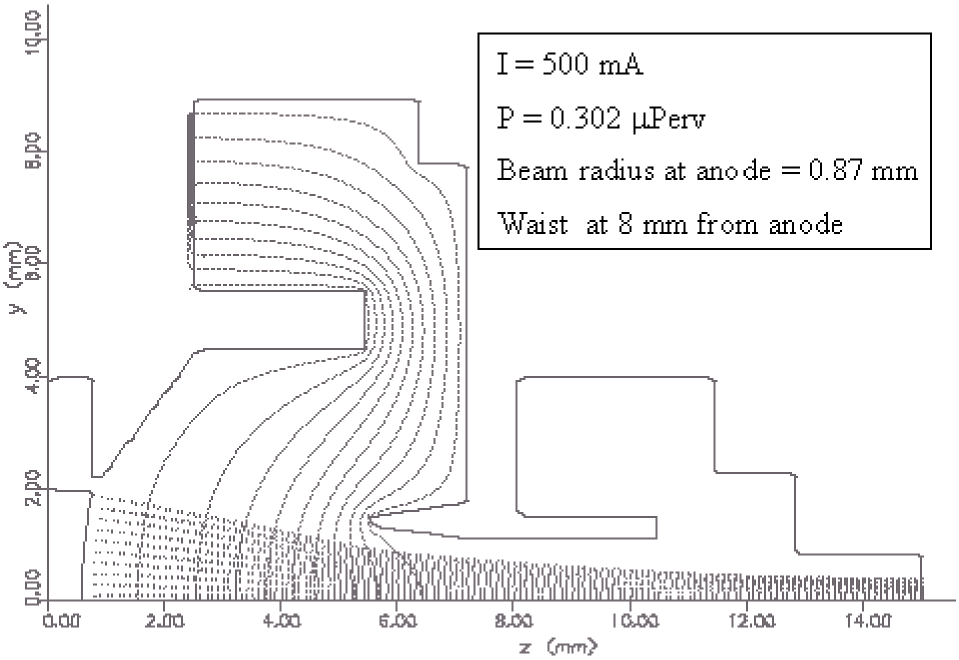

FIG. 4: Cathode simulated by EGUN.

A compact pulse forming circuit has been developed for the cathode, similar to that realized for the Magnetron, providing a 13 KV, 10 A, 4.5 μs pulse, and the proper heating current to the cathode.

4 BEAM DYNAMICS

The electron beam spot has a 4 mm diameter, measured at a 5 cm distance from the Titanium exit window. Spot diameters obtained with a 1 mm- diameter collimator for 1, 5 and 10 cm distances, are shown in fig. 5A. In agreement with theoretical simulations, the surface dose distribution is uniform over a 1 cm – diameter spot at a 10 cm distance [6].

The electron peak current, measured at a 5 cm distance by means of a faraday cup, is ~200 mA, and the corresponding pulse shape is shown in fig.5B.

Electron beam energy has been measured as a function of the Magnetron RF power. Fig.6, in which energy measurements are reported together with the theoretical curve, shows that energy can be varied between 3.5 and 5.5 MeV.

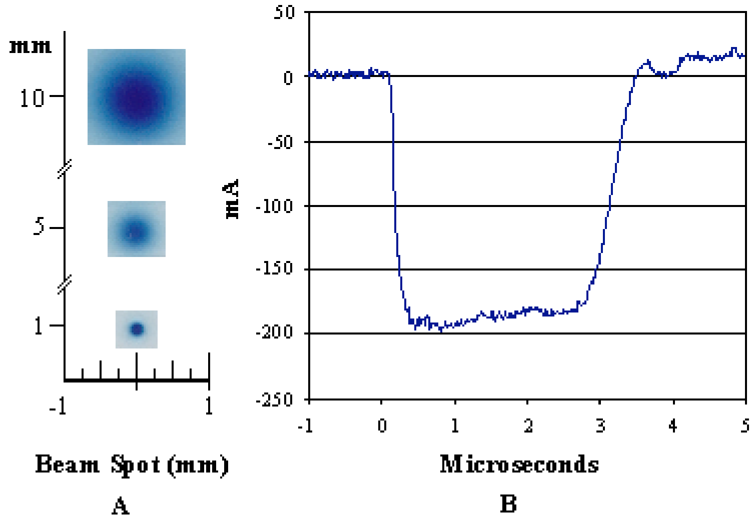

FIG. 5: Electron beam features.

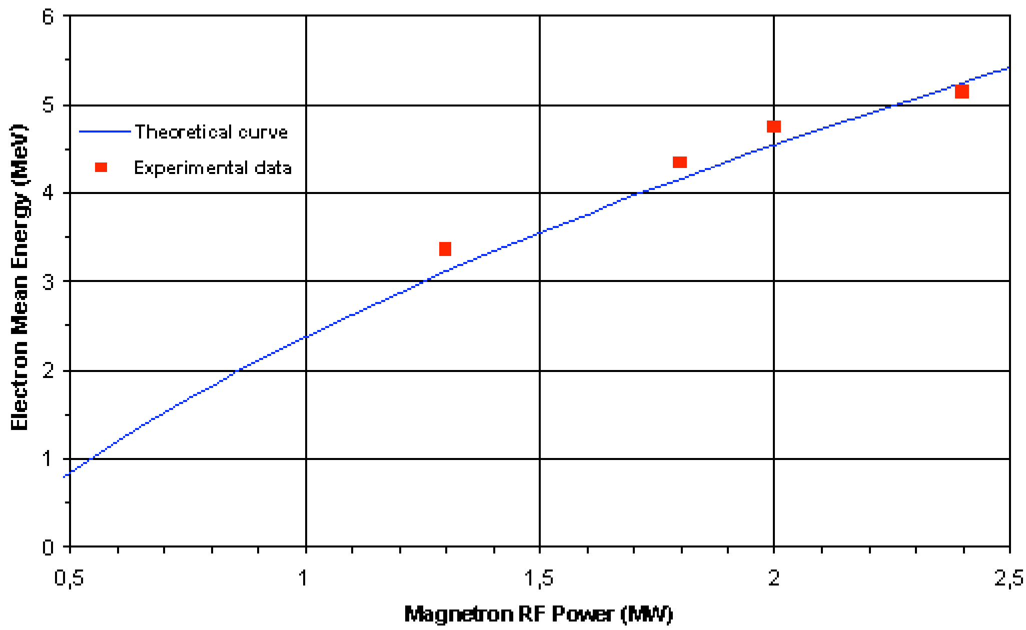

FIG. 6: Beam energy Vs RF power.

5 CONCLUSIONS

A compact and reliable 5 MeV electron accelerator has been realized, with a particular auto focusing 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.

Further, the very compact structure of this accelerator make it very suitable to realize a system for 'in-situ' treatments as industrial radiography or X-ray tomography.

6 REFERENCES

[1] R. J. Woods and A. K. Pikaev, Applied Radiation Chemistry – Radiation Processing (John Wiley & Sons, Inc 1994);
Radiation Technology for conservation of the environment (proceedings of the Zacopane symposium, Poland, 8-12 sept 1997);

[2] S. Ramo, J.R. Whinnery, T. Van Duzer, Fields and Waves in Communication Electronics (John Wiley and Sons, Inc);

[3] L. Picardi, C. Ronsivalle, A. Vignati, RTI – INN (92) - 20

[4] P. W. Smith, Transient electronics - Pulsed Circuit Technology (John Wiley & Sons, Ltd 2002)

[5] W. B. Herrmannsfeldt, Electron Trajectory Program , SLAC – Report 226, 1979

[6] W. L. Mclaughlin and M. F. Desrosiers, Rad.Phys.and Chem. **46**/4-6, 1163 (1995)