# A 5 MEV ELECTRON LINAC FOR RADIATION PROCESSING

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## *Abstract*

In recent years, the employ of radiation processing is rapidly growing in various fields of industrial treatments and scientific research as a safe, reliable and economic technique [1]. To match the requirements of several applications, a 5 MeV, 1 kW electron linac has been developed at the Dipartimento di Fisica (Università di Messina), in collaboration with the ENEA Accelerators Group (Frascati, Roma). This self- containing standing wave accelerator is driven by a 3 GHz, 2.5 MW Magnetron and has been designed to obtain an autofocusing structure.

For this accelerator, compact pulse forming circuits have been properly developed to power the magnetron and the cathode, and the pulse frequency can be varied ranging from 1 to 300 Hz, thus allowing the study of several applications of radiation processing. Main features of the accelerating structure, as well as beam spot dimensions, surface dose distribution and electron beam energy range will be described.

## ACCELERATING STRUCTURE

The accelerating section, shown in Fig. 1, is a standing wave on axis coupled structure operating in the $\pi$/2 mode. It has ben designed, in collaboration with the ENEA Accelerators Group (Frascati, Roma), by means of the SUPERFISH and PARMELA codes, in such a way as to obtain an autofocusing structure, to avoid external focusing magnets, thus noticeably minimizing the accelerator dimensions [2]. The shunt impedance obtained for the structure is 70 M$\Omega$/m. Major features of the 5 MeV accelerator are summarized in table 1. 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 length is greater than the standard one. It follows that the first cavity exerts an intense bunching and a strong focusing effect on injected electrons, which will reach the centre of the following cavities after the radio frequency peak, thus experiencing a further focusing [3].

Table 1: Accelerator parameters

| | |
|---|---|
| Peak Current | 200 mA |
| Pulse duration | 3 $\mu$sec |
| Repetition Rate | 1-300 |
| Peak Power | 1 MW |
| Average Power | 1 KW |
| RF Frequency | 2.997 GHz |
| Structure type | SWOAC |
| Operating mode | $\pi$/2 |
| N. Accelerating Cavities | 9 |
| Magnetic Lenses | NO |
| Lenght | 40 cm |
| Weight | 25 Kg |

A $10^{-8}$ mmHg vacuum is mantained in the structure by a small ionic pump. External cavity walls have been machined in such a way as to contain ducts 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 $8^{th}$ 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 magnetic field ranging from 100 to 157 mT is provided to the magnetron generator by a separated electromagnet. A 45 KV, 90 A pulse is supplied to the magnetron by the pulse forming circuit shown in fig.2, charged through an inductance [4] and triggered by a hydrogen-filled ceramic thyratron. The 1:4 pulse transformer also provides the proper bias to the magnetron filament.

Accelerated electrons are extracted from the resonator through a thin Ti foil (50 $\mu$m thick, Ø 12 mm), 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 from the titanium surface, avoiding damages due to the thermal power deposited by the collimated electron beam spot. Furthermore, the 50 $\mu$m thickness is a compromise between the need of a low electron divergence in traversing the titanium foil and a safe rigidity of the exit window.

## ELECTRON INJECTION

The electron injector, shown on the left part of fig.1, is directly connected with the accelerating structure, so that the first accelerating cavity acts as the injector anode.

Electron gun features have been accurately studied by means of the EGUN code (see fig.3). A compact pulse forming circuit has been developed to power the electron gun with a 13 KV, 10 A, 4.5 $\mu$s pulse, and providing the proper heating current to the cathode.

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].

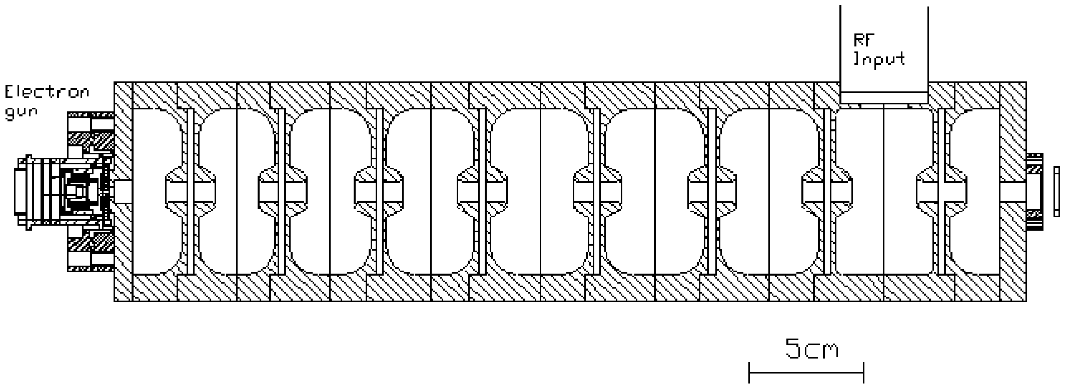

Figure 1: Accelerating structure.

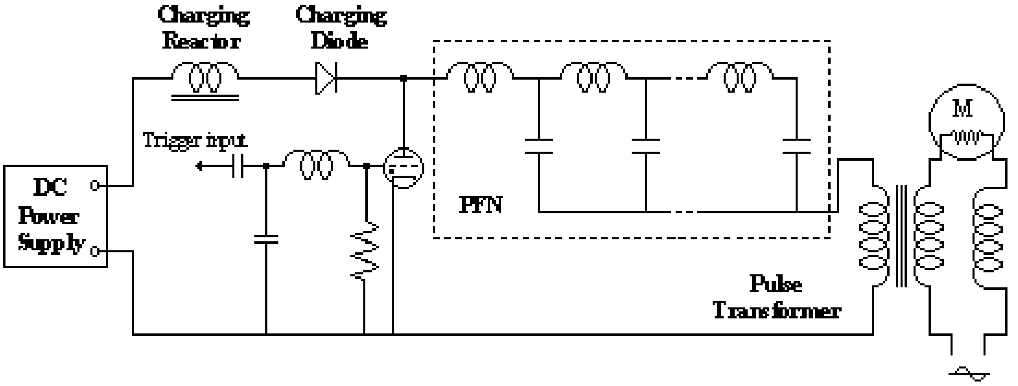

Figure 2: Resonant-charge pulse forming circuit scheme

## BEAM DYNAMICS

At the entrance of the first cavity, the electric field accelerates or decelerates injected particles depending on their starting phase, so determines an intense bunching.

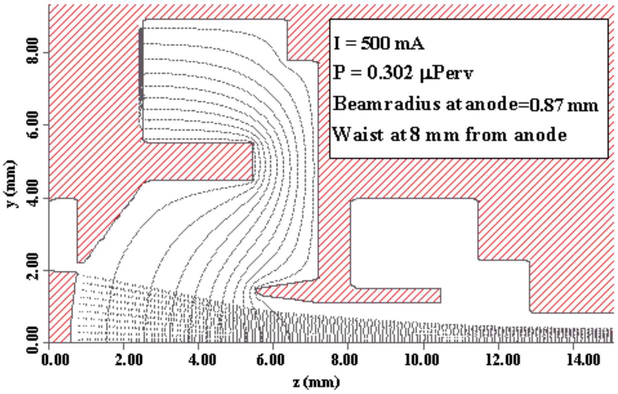

Figure 3: Cathode simulated by EGUN.

A decelerating electric field also determines a radial dispersions of the bunches, but in the first cavity the electric field rises slowly and the dispersion is not so strong. Combining the slow rise time of the electric field, with a length greater than the standard one it is possible to obtain also a strong radial fucusing in the second part of the cavity.

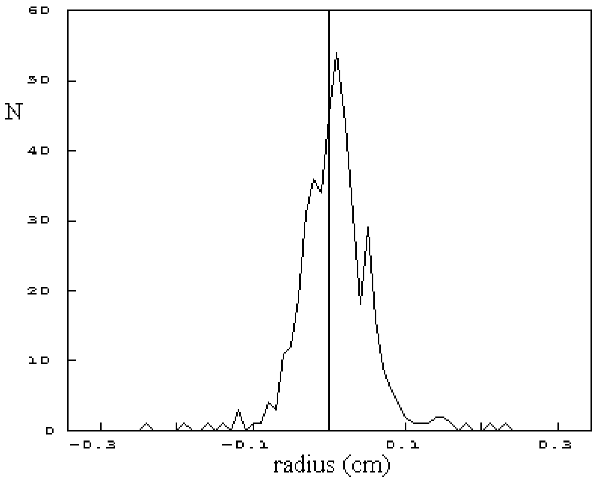

Figure 4: Computed radial distribution

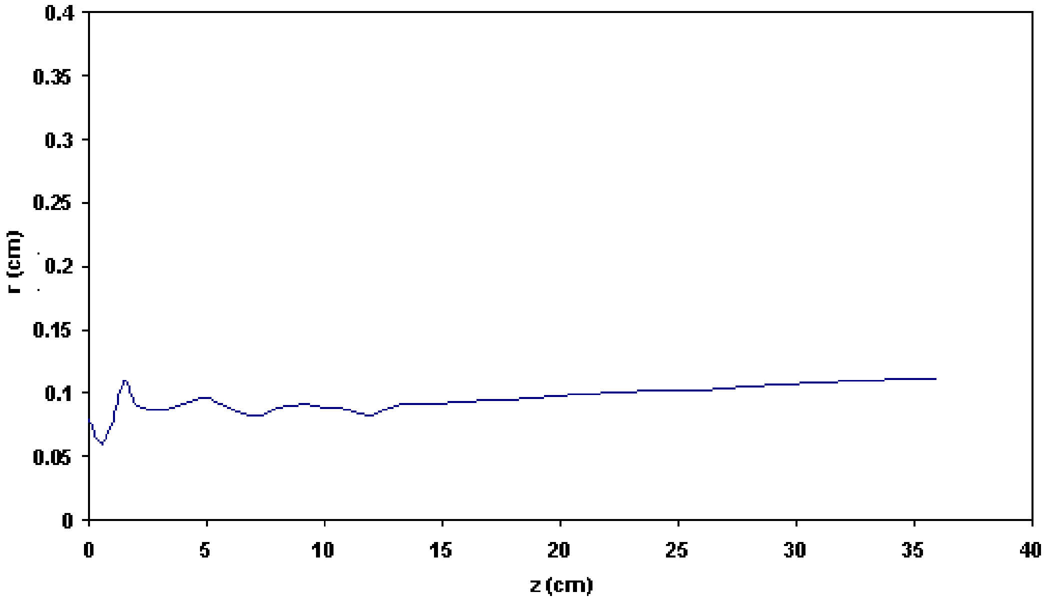

Figure 5: Theoretical simulation of beam dimension along the accelerating structure.

The bunches so focused leave the first cavity with a phase sligthly greather than $\pi$ and reach the center of the following cavity after the radiofrequency peak, thus experiencing a negative mean component of the radial electric field. In such condition bunches reach the end of the structure without appreciably spread neither in radial direction, nor in axial one. Fig. 4 and 5 show the computed radial distribution of the beam at the end of the linac and the radial dimension of the beam along the accelerating structure [3]. At the end of the linac we measured a spot size of 2mm, in good agreement with theoretical simulations.

The maximum electron peak current, measured at a 5 cm distance by means of a faraday cup, is $\approx$ 200 mA. Electron beam energy has been measured as a function of the magnetron RF power at the maximum peak current. Results are reported in fig. 5 together with the theoretical curve and show that energy can be varied between 3.5 and 5.5 MeV.

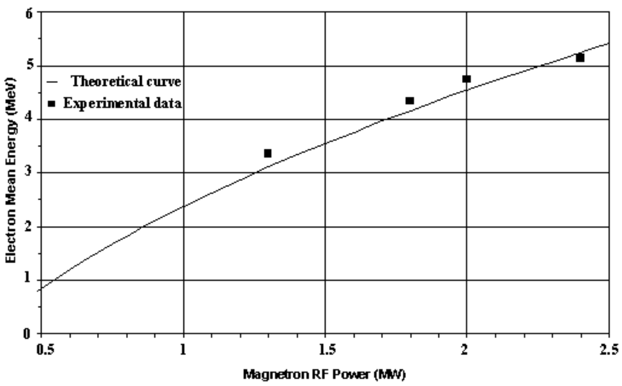

Figure 6: Beam energy vs rf power.

## CONCLUSIONS

A compact and reliable 5 MeV electron accelerator has been developed, 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. Furthermore, the very compact structure of this accelerator make it very suitable to develop a transportable system for 'in-situ' treatments as industrial radiography or X-ray tomography.

## REFERENCES

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