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Radiation processing with the Messina electron linac

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Abstract

In the last decades radiation processing has been more and more applied in several fields of industrial treatments and scientific research as a safe, reliable and economic technique. In order to improve existing industrial techniques and to develop new applications of this technology, at the Physics Department of Messina University a high power 5 MeV electron linac has been studied and set-up.

The main features of the accelerating structure will be described together with the distinctive features of the delivered beam and several results obtained by electron beam irradiations, such as improvement of the characteristics of polymers and polymer composite materials, synthesis of new hydrogels for pharmaceutical and biomedical applications, reclaim of culture ground, sterilization of medical devices, development of new dosimeters for very high doses and dose rates required for monitoring of industrial irradiations.

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1. Introduction

In the last years a lot of applications of radiation processing were developed and several techniques used in various civil and industrial sectors involved electron and X-ray sources. Several modern machines are able to deliver electron or X-ray beams, but the best-balanced mix of compactness, reliability end versatility is represented by electron linacs. These are modular machines made up of several resonating cavities coupled together in order to form a linear accelerating structure. The number of cavities can be arbitrarily chosen so as to obtain the largest efficiency at the desired energy, while beam power can range from few kilowatt to several megawatt. Moreover, linacs are very stable machines and are able to run for long time without control nor servicing.

2. Accelerator features

The accelerating head is a standing wave structure with a resonating frequency of 2998 MHz; it consists of 9 accelerating cavities spaced out by 8 coupling cavities placed along the beam axis (see Fig. 1) [1]. The shape of the single resonating cavities has been studied and designed in collaboration with ENEA Accelerators Group (Frascati, Rome) to obtain an auto-focusing effect on the accelerated beam, a high shunt impedance (70 M/m) and a low Kilpatrick factor (1.5 for the whole structure).

The auto-focusing effect avoids the use of external magnets, while the high shunt impedance and the low Kilpatrick factor reduce the total length of the accelerating structure.

Moreover, the thickness of the cavity walls has been reduced to the minimum value needed to ensure the correct

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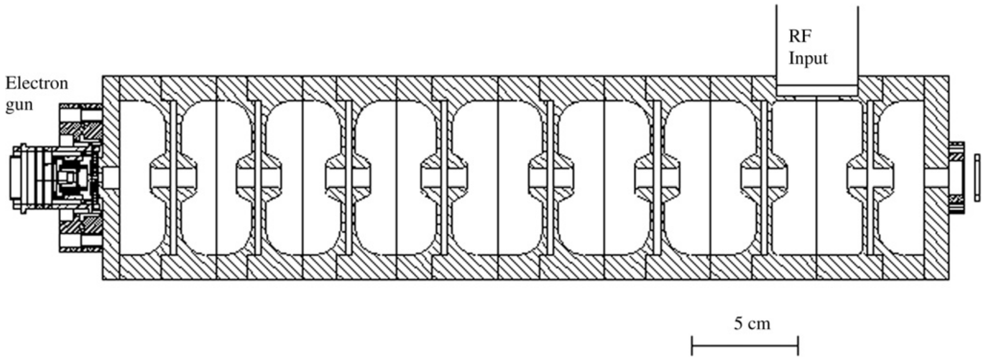

Fig. 1. Accelerating structure of the 5 MeV electron linac.

heat transfer coefficient. The structure is water-cooled, in order to reduce shape variations of the resonator due to thermal expansion. Possible small expansions are compensated by an electronic tuning system that automatically changes the Magnetron frequency to follow the resonating frequency of the accelerating structure. As a result, the linac head set up has an approximate length of 40 cm and a weight around 25 kg, which could be used to develop a compact and portable system for in situ applications, like treatment of big structures and non-portable items.

The radio-frequency generator is a magnetron with a peak power of 2.5 MW and a mean power of 2.5 kW. To reduce the size of the whole system without increasing the risk of voltage breakdowns, a simulation of all the high electric fields has been performed in order to get the optimal shape and position of the electron gun and magnetron modulators. In this way the whole machine, except for remote power supplies and control system, can be housed in a 110 cm × 50 cm × 34 cm box.

The main features of Messina University linac are summarized in Table 1.

Electron to X-ray conversion has also been performed, by bremsstrahlung process in a target placed beyond the extraction window. A multilayer converter has been studied and designed [2], optimizing all the parameters involved in the X-ray production and transport, in order to obtain a high power high energy X-beam useful for several applications.

3. Applications

The accelerator is working since the end of 2002 and has been widely used to study several topics of applied and fundamental research. In the following sections some of the results obtained in Messina will be presented.

Table 1
Accelerator parameters

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

3.1. Improving characteristics of polymers

Ionizing radiations induce strong modifications on polymer chains which can improve several characteristics of polymers and polymer composite materials.

A number of processing on several polymers such as polyester and epoxy resins, polyethylene, teflon, Perspex and PVC has been studied in Messina.

For instance, promising results have been obtained by studying ultra-high-molecular-weight-polyethylene (UHMWPE) properties. It is an interesting polymer, employed in different fields, such as medicine, microelectronics, engineering, chemistry and food industry. It shows excellent properties of bio-compatibility, electrical insulation, high mechanical and chemical resistance; nevertheless an improvement of its features can be obtained by inducing substantial modifications in polymeric chains.

By irradiating the polymer with the 5 MeV electron beam a strong de-hydrogenation has been observed; this effect can be addressed to C–H bonds breaking and formation of C=C chemical bonds, producing cross-linking effects between polymeric chains with a resulting high density carbon network, similar to graphite [3,4]. This implies a hardening and an increase of the melting temperature. At an irradiation dose of 3.2 MGy, a rise of the Young modulus by 415%, a fall down of elongation at break from 290% to 11% (see Fig. 2) and a rise of the melting temperature from 139 °C to 151 °C have been observed.

3.2. Sterilization

The chance an organism has to survive after irradiation decreases logarithmically with increasing dosages. Thus, irradiation is one of the best methods for removing all the life forms dangerous for human activities. Several applications of this effect of ionizing radiation have been studied in Messina with good results.

A method for reclaiming culture ground has been developed. By treating several varieties of grounds with electron