DIAGNOSTICS METHODS FOR THE MEDIUM ENERGY PROTON BEAM EXTRACTED BY THE TOP IMPLART LINEAR ACCELERATOR

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Abstract

One of the most important challenges in any therapy is maximizing the curative effectiveness while minimizing the side effects; in cancer radiation therapy this trade-off essentially translates into delivering the highest dose to tumour and acceptable, possibly negligible dose to normal tissue. Due to the basic physics of proton interactions with matter, the proton-therapy may offer a better effectiveness/side-effect ratio respect to conventional radiation therapy, especially when the tumour is close to vital organs.

The Italian TOP IMPLART project aims to develop the first proton linear accelerator for cancer radiotherapy. A 150 MeV proton LINAC is under construction at the ENEA Frascati research center: currently the machine is composed by a 7 MeV injector operating at 425 MHz and four 3 GHz linear accelerating modules (SCDTL-type) producing a proton beam of 35 MeV.

Operational procedures are defined through measurements by different monitor types placed along the beam line. The injected current in the high frequency segment of the accelerator is measured by a Fast Current Transformer (FCT) at the entrance of the SCDTL modules and the pulsed current of the accelerated beam is measured by a second FCT, placed in air, at the exit. The proton beam shape and intensity are characterized by two Ionization Chambers, a Synthetic Single Crystal Diamond detector and a Faraday Cup. In this work, a systematic study of the properties of the current TOP-IMPLART proton beam is performed under different operating conditions of the machine, aimed at its optimization for the ultimate therapeutic use.

INTRODUCTION

Many cancers are treated by radiation either exclusively or in combination with other therapies. Thanks to the peculiar interaction with matter, protons and heavy ions may deliver higher dose to tumour (larger tumour control) and simultaneously reduced or negligible dose to healthy tissue (smaller normal tissue complication) respect to conventional (gamma/electron) radiotherapy. While heavy ions generally offer higher radio biological effectiveness, protons have a better intrinsic conformal capability.

TOP IMPLART is a proton LINAC devoted to intensity modulated protontherapy under construction in the ENEA Frascati Research Center in collaboration with the Italian Institute of Health (ISS) and the National Institute of Cancer of Rome [1].

The architecture of the machine is fully linear to be a facility more functional and accessible than the circular accelerator and at lower impact in radio-protection.

The low frequency injector, capable of a 2 mA, 7 MeV proton beam, is followed by the low energy beam transport (LEBT) line, hosting a vertical extraction segment and matching the 3 GHz acceleration line composed by side coupled drift tube linac (SCDTL) modules.The protons are extracted from a Duoplasmatron source (typical extraction voltage of 28 kV) and are focused without energy changes by an einzel lens, whose voltage can be used to change the output charge, and then are injected first into a radio-frequency quadrupole and next into a drift tube linac accelerating the particles to 3 MeV and 7 MeV respectively. The following LEBT is composed by two couple of focusing quadrupoles among which a dipole is placed to bend vertically an extraction beam line devoted to low energy experiments with small samples [2].The first four SCDTLs constitute the medium energy acceleration section (MEAS) running until 35 MeV in 5 m. This whole segment is powered by a single 10 MW peak power klystron in a 4 μs pulse.

The accelerator has been commissioned with a typical repetition frequency of 10 Hz upgradable to 25 Hz. Recently a solid state modulator has been installed increasing the accelerator capacity in terms of repetition frequency up to 100 Hz [3]. In order to guarantee the safety of the patient and the effectiveness of the treatment, the beam transverse shape, direction and intensity shall be continuously and redundantly monitored right before its delivery. Actually the TOP-IMPLART proton beam doesn't have yet an energy suited to the clinical applications; however it is employed in a series of irradiation campaigns for satellite experiments oriented toward the exploration of new applications [4-6].

Therefore the characterization measurements presented below are important not only for the accelerator commissioning during its realization but also for the proper use of the machine even at medium and low energies.

DIAGNOSTIC DESCRIPTION AND MEASUREMENTS RESULTS

The four SCDTLs run horizontally and accelerate the particles from 7 MeV to 11.6, 18, 27 and 35 MeV in sequence (Fig. 1).

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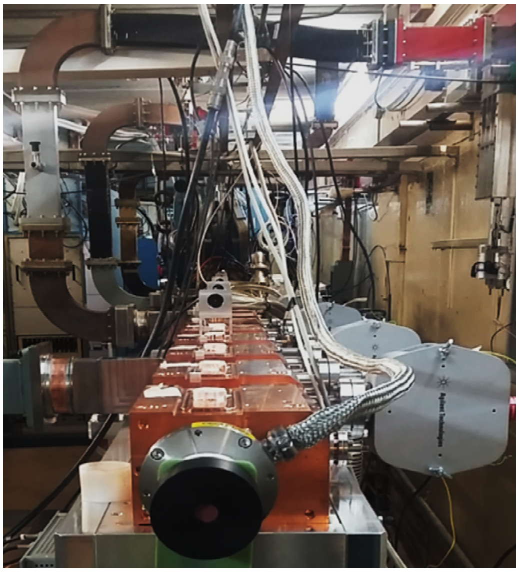

Figure 1: View of the MEAS of the TOP-IMPLART accelerator and its exit.

A first FCT (Fast Current Transformer) produced by BERGOZ is placed before the MEAS and measures the input current [7]. The proton beam exits in air through a 50 µm Ti window and then there are a second FCT and an integral ionization chamber (IIC), both joined to the extraction segment, devoted to measure the output charge.The IIC works in a range from 1 pC to 100 pC, not entirely covered by the FCT [3], and is used during the irradiations to turn-off the beam when a preset amount of particle charge is reached.

Other characterization tests in terms of beam shape and intensity have been done by a double (XY) multistrip ionization chamber and a synthetic single crystal diamond dosimeter described in detail in the following paragraphs. These detectors are placed on movable supports aligned with the accelerator at variable distance between 25 and 100 cm. Figure 2 shows the scheme of the different types of diagnostics and the Faraday cup used to measure all particles at the end of the delivering line.

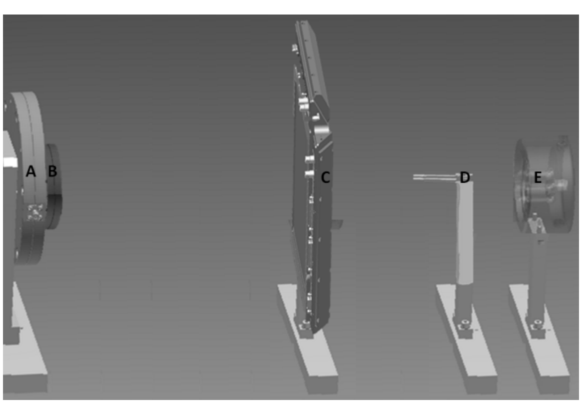

Figure 2: Scheme of the geometrical setup and positioning of the beam measuring instruments of the delivered beam in air: A= FCT, B= IIC, C= Multistrip Ionization Chamber, D= synthetic single crystal diamond, E= Faraday Cup.

Multistrip Ionization Chamber

A small scale multistrip ionization chamber [8] that measures the beam current spatial density has been developed by ISS, and after having been preliminary characterized [9] it is becoming part of the beam diagnostics.

The prototype has an anode-cathode gap of 2 mm, an active area of 7×7 cm^2 with a single cathode plane consisting of x and y strips with pitch of 0.875 mm and a pad-like pattern, adopted to maximize the field uniformity while minimizing the overall chamber thickness down to 0.16 mm water equivalent. The dedicated electronics may automatically and quickly (order of ns) adapt its trans-impedance gain to the input instant charge collected on each strip.

The ionization regime has a large plateau between 250 V and 450 V with a constant sharing between the x and y strips (Fig. 3).

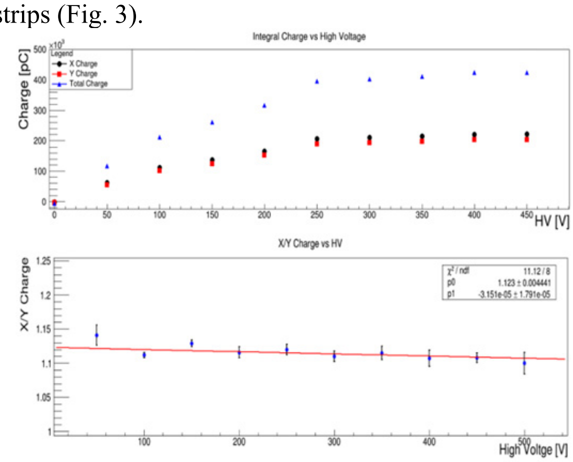

Figure 3: Top: total charge collected by the x and y strips as a function of the chamber bias current. Bottom: x and y axis charge ratio; the red line represent a linear fit. The about 10% greater collected charge along x is related to the slightly larger size of the x strips respect to the y ones.

The chamber is able to monitor each beam pulse charge intensity and its x and y cross section parameters as shown in Figs. 4 and 5 where the beam intensity and position is forced to change by means of the einzel lens in the injector. Beam intensity profile evolution can also be monitored in detail as presented in Fig. 6.

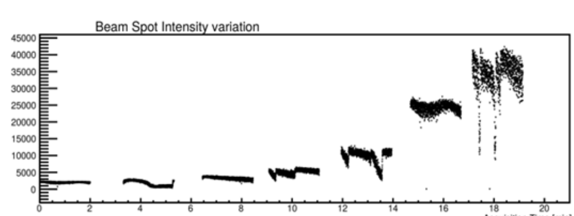

Figure 4: Total charge recorded on the chamber, for each beam pulse (single point in plot) while the beam intensity is changed on purpose. The unit on the y axis is arbitrary.

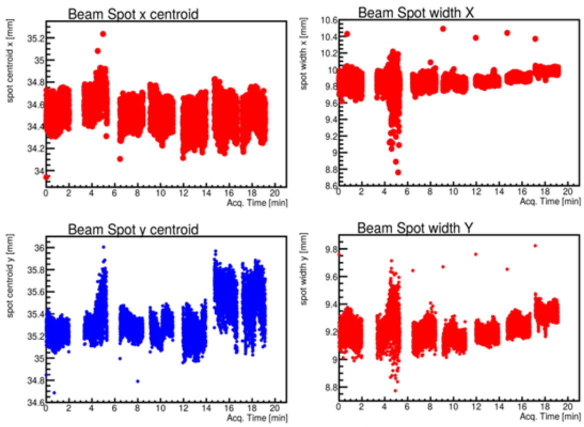

Figure 5: Beam x and y cross section synthetic parameters (centroid and width) corresponding to the same conditions of Fig. 4.

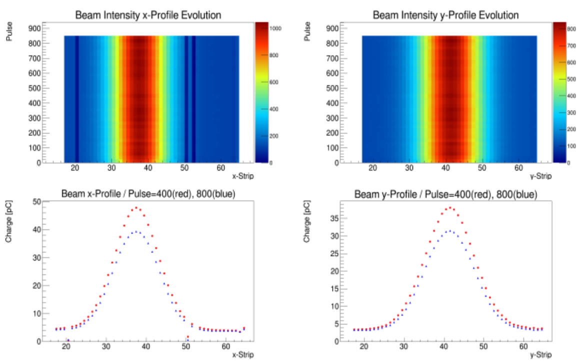

Figure 6: Beam Intensity x and y profiles versus all pulses (upper plots) and for two predefined pulses (lower plots).

A detailed calibration campaign is ongoing to assess the chamber accuracy and precision which have been preliminarily estimated to be less than 9% (which can be corrected by cross calibration) and 1% respectively [9].

Synthetic Single Crystal Diamond

The synthetic single crystal diamond detector (SCDD) was fabricated at the University of Rome "Tor Vergata" laboratories in the framework of a commercial collaboration with PTW-Freiburg company. The SCDD is currently commercialized worldwide as microDiamond (type 60019), and it has been assessed as a high performance dosimeter for different radiation qualities (photon and electrons, as well as proton and carbon ion beams).

The device consists of a multilayered synthetic single crystal p-type diamond/intrinsic diamond structure fabricated by microwave plasma enhanced chemical vapor deposition process on a commercial low-cost single crystal diamond substrate (3.0×3.0×0.3 mm^3). It operates as a Schottky barrier photodiode with no external bias voltage applied. The detector sensitive volume is about 0.0038 mm^3 (~ 2.2 diameter × 1µm thick), and, according to manufacturer specifications, the reference measurement point was assumed to be at the center of the top SCDD plate surface, 1 mm below detector tip [10].

The SCDD was used for dose measurements at different distances from the TOP-IMPLART accelerator. The characterization of the beam and its dose rate was made varying the current of protons per pulse in the range 1-25 µA and varying the einzel lens voltage between 24 kV and 29 kV as shown in Fig. 7. A PTW Unidos E electrometer, remotely controlled, was used for charge readings.

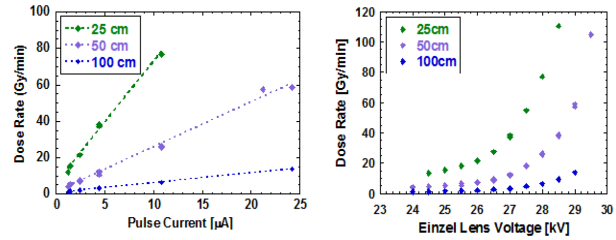

Figure 7: Proton dose rate vs the pulse current (uA), left, and vs the einzel lens voltage (kV), right, measured by the synthetic single crystal diamond.

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