PARTICLE BEAM CHARACTERISTICS VERIFICATION FOR PATIENT TREATMENT AT CNAO

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Abstract

At Centro Nazionale di Adroterapia Oncologica (CNAO) in Pavia, Italy, a synchrotron has been built to treat tumor with protons and ions delivered with a full active delivery system. Several pencil beams with appropriate energy are steered in sequence to the right positions inside the tumor volume covering it totally. Beam characteristics have to be deeply known in order to be able to deliver a safe patient treatment.

Dose Delivery system, composed by beam monitoring and scanning magnets, manages the treatment with high precision in real time.

Beam characteristic are studied by means of several detectors and verification systems in the treatment room to guarantee the quality of the treatment. Quality is checked in terms of pencil beam characteristics and characteristic of the overall dose in the treatment fields.

INTRODUCTION

At CNAO a full active scanning delivery system is used. A treatment planning system (TPS) is used to calculate how to cover the entire tumor volume using a very large number of beam spots. Every spot is characterized by the particles energy, the particles number and the position where has to be placed. All spots with the same energy are grouped in slices and a synchrotron cycle is used to generate a beam with the right energy and dimension. With a couple of scanning magnets the beam is sent in the right position and when the requested particles number is delivered for the first spot the beam is moved in the following spot position. When the last spot belonging to a slice is delivered the beam extraction is stopped and a new synchrotron cycle is generated. The sequence continues slice by slice until all spots are delivered.

The control of the treatment is done in real time by the Dose Delivery system. It is composed mainly by the monitoring system, that measure the beam intensity and position, and the scanning system.

DOSE DELIVERY SYSTEM

The dose delivery system is based on an electronic crate that is shown in Fig. 1.

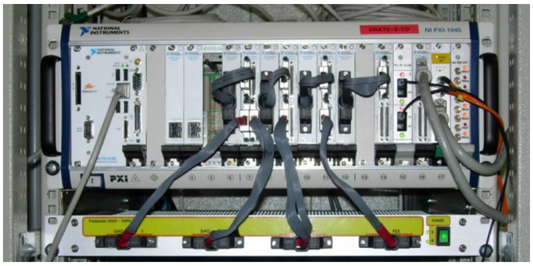

Figure 1: The electronic crate of the Dose Delivery.

The controller manages the connection with the synchrotron control system and the electronic cards to load all information needed to treat a single slice. During the beam extraction phase the cards work independently from the outer world to assure maximum speed and reliability. Data acquisition programs run on Field Programmable Gate Array (FPGA) exchanging data with memory cards where data from TPS are stored. An important role is played by the interface with the timing system that synchronizes dose delivery with several events on the accelerating cycle. A FPGA card controls the scanning magnet power supplies directly via an optical connection. A new reference can be sent every 25 µs.

Five ionization chambers are divided in two completely independent boxes to monitor the beam intensity and position. These boxes are placed on the beam nozzle that is shown in Fig. 2.

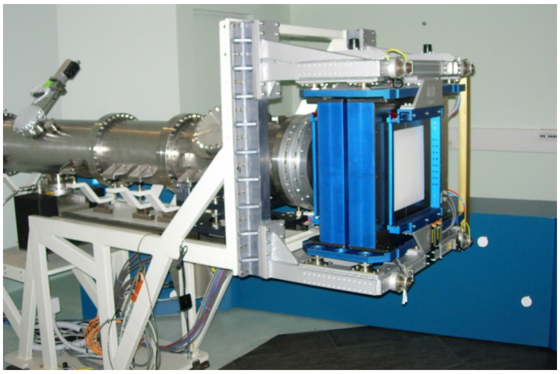

Figure 2: The CNAO nozzle.

Two chambers with a large electrode measure the beam intensity at 1 MHz. Two chambers have teh collecting electrodes divided in 128 strips giving, at a rate of 10 kHz, the x and y position of the particle beam. The last ionization chamber is divided in 1024 pixels to measure the real 2D distribution of the particles delivered during the treatment.

The monitor acquisition system is based on electronic chips, TERA06 and TERA08, that convert the collected charge in digital data. A differential transmission system is used to send to the FPGA boards on the electronic crate these data.

Calibration curves are used to convert the charge on number of particles. The calibration take in account the pressure and the temperature of the gas and the beam energy.

BEAM CHARACTERISTICS

Some of the measured beam data have been implemented into the TPS (Siemens Syngo RT Planning) for calculation of patient treatment plans. In particular depth dose distribution in water for different energies, have been measured mainly using PTW Freiburg PEAKFINDER Water Column. The water column is an electronically controlled device to position an ionization chamber behind a height-adjustable water column. The dosimetry components required for dose measurements are two ionization chambers model Bragg Peak of about 8 cm in diameter. One as a moving field chamber and one as reference mounted in front of the device. The high resolution of the device (down to 10 µm) guarantees a very precise Bragg peak position determination. Figure 3 shows an example of depth dose for different proton energies between 117.54 MeV/u and 173.12 MeV/u. The agreement between measurements (circles) and the simulations allow the use of the simulated curves to populate the TPS for all beam energies.

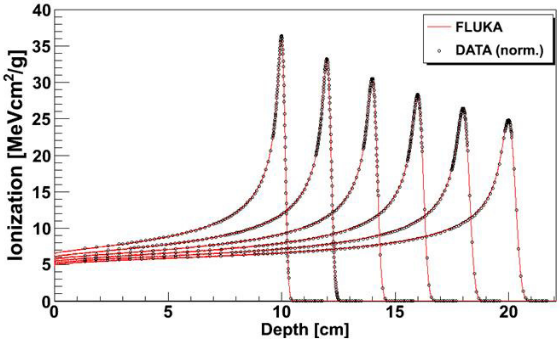

Figure 3: Bragg Peak measurement.

Other beam characteristics to be implemented into the TPS is the beam spot size in term of FWHM in air and eventually in water for different energies and at different depth (isocenter, before the isocenter (in air) and also beyond the isocenter in water). GAFCHROMIC® EBT2 dosimetry Films are very suitable for this kind of measurement. They are water resistant, self-developing, having also a very high spatial resolution and dose range.

EBT2 are also employed to measure homogeneity of delivered regular fields like squares of different dimension varying spot dimension and/or grid sizes. Figure 4 shows a scanned film analyzed by a commercial software: dose level are showed in a colored scale.

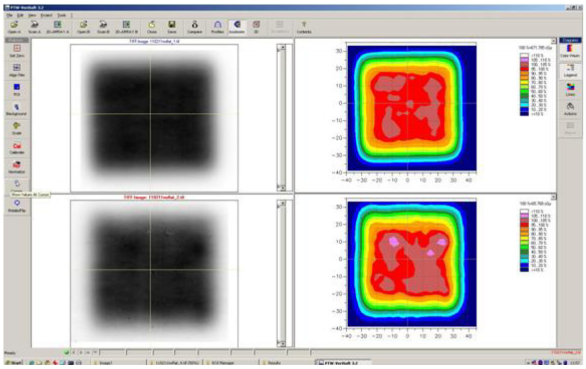

Figure 4: Uniformity of a square scanned field.

Beam spot profile in water has been measured with a PTW-Pinpoint ionization chamber, placed on a motorised arm in a water phantom. The main characteristic of this dosimeter consists in its very high spatial resolution and its reduced sensitive volume (0.03 cm^3) that make it suitable for scanning beam. Figure 5 shows the spot beam X profile at different depth in water. Data measured with Pinpoint chambers (circles) and MC simulation clearly agree.

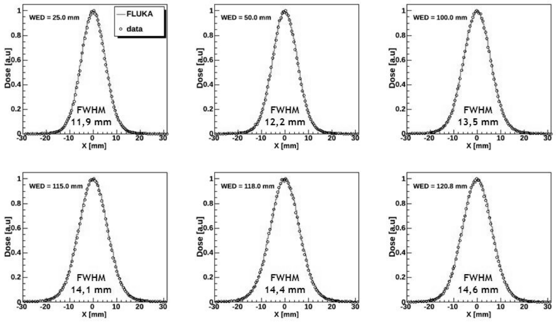

Figure 5: Pencil beam profile at different depth.

For absolute dosimetry in water, is particularly used PTW-Freiburg waterproof Farmer-type ionisation chambers. It can be placed in a motorised water phantom or in a water equivalent slab phantom (RW3 Phantom). Absolute dose in water is measured at the depth in water of the plateau level of the depth dose distribution (i.e. 2 cm). in order to be able to calibrate the beam monitor system and let it to deliver fields with the desiderate dose.

Pristine Bragg Peak will not be useful in tumour treatment if they were not shaped to cover the entire tumour volume. To achieve this goal, pristine Bragg Peak of different energies are superimposed to create the so called Spread Out Bragg Peak (SOBP). Radiochromic films and both Farmer-type and Pinpoint ionisation chambers are used for the determination of dose in the SOBP volume, of its geometrical dimension and internal lateral, vertical and longitudinal homogeneity.

CONCLUSIONS

The commissioning of the technical part of the CNAO system for hadrontherapy is complete for the proton part and is in progress for the carbon ion part. The permission to start with the experimental medical part has been obtained and the medical activities are about to start.

The validation of the beam and of its spreading, measurement and modelling of beam characteristics to be used in treatment planning and periodic machine qualification are a fundamental part of the usage of a hadrontherapy facility. The results obtained so far are in good agreement with simulations which gives confidence on the quality of the dose distribution.