MATRX: AN INNOVATIVE PIXEL IONIZATION CHAMBER
FOR ON-LINE BEAM MONITORING IN HADRONTHERAPY

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Abstract

The control of beam position and dose delivery are key issues in the treatment of tumours using hadron beams, especially in the case of active dose distribution systems. In this framework, an innovative pixel ionization chamber has been designed and constructed for 2-D control of beam position, shape and intensity. This chamber is characterized by a $21 \times 21 \text{ cm}^2$ sensitive area subdivided in 1024 pixels of $6.5 \times 6.5 \text{ mm}^2$. The 1024 channels are read-out by 8 boards based on 16 TERA06 chips. The sensitivity can be adjusted in the range 100-800 fC. The tested minimum read-out time of the full chamber is 1 ms. After some preliminary measurements with X-rays, tests have been performed on the proton beam of the cyclotron of the Joint Research Centre in Ispra, Italy. In March 2005, MATRIX has been successfully tested on several beam lines for proton-therapy at the Loma Linda University Medical Center, US. The very positive results of these tests are presented.
1 Introduction

Hadrontherapy is a technique of cancer radiation therapy based on the use of proton and carbon ion beams. Due to their characteristic ionization loss, the so called Bragg curve, and due to the fact that being charged they can be precisely directed toward a small target, hadrontherapy allows to conform the dose to the tumour volume much better than conventional X-ray radiotherapy. During a treatment, the on-line control of beam intensity, position and shape is of paramount importance in order to assure the conformity of the dose given to the patient according to the treatment planning specifications. To accurately control the clinical beams during hadrontherapy treatments an innovative pixel ionization chamber, named MATRIX, has been designed and constructed. In this paper the construction and the first beam tests of this detector are described.

2 Design and construction of the chamber

The structure of the chamber is made of five successive fiberglass frames, as shown in Figure 1. The external frames are equipped with glued mylar foils which allow to maintain the planarity of the internal cathodic and anodic electrodes in case a gas is used at non-atmospheric pressure. The sensitive volume of the detector corresponds to the air gap between the anode and the cathode foils. MATRIX is designed to have a gap of 5 mm but a different gas volume can be easily obtained by substituting the spacer. The anode and cathode foils are glued to the respective spacers using a non-conductive epoxy araldite. The gluing procedure required the construction of a special tool, designed to
Figure 2: The top side of the anode with the 1024 pixels (left). The MATRIX chamber fully assembled. The fibreglass frame and the eight electronic boards for the read-out are visible (right).

obtain a good planarity of the electrodes. The chamber is characterized by a $21 \times 21 \text{ cm}^2$ sensitive area subdivided in 1024 pixels of $6.5 \times 6.5 \text{ mm}^2$. In order to minimize the amount of material traversed by the beam, the anodic electrode is made of a thin 50 µm kapton foil, with a deposition of 17 µm copper on each side. As shown in Figure 2 (left), the pixels are located in one side of the anode foil together with a guard ring and pads for soldering the read-out connector. The other side of the anode foil contains the pixel-pad connections. Metalized holes are used to electrically connect the two sides. The fully assembled MATRIX detector is shown in Figure 2 (right). The 1024 channels are read-out by 8 electronic boards which handle 128 channels each. Each board hosts two VLSI chips, named TERA06, specifically designed for this specific application. Each chip has 64 independent channels based on a recycling integrator architecture which allows the implementation of a wide dynamic range charge-to-digital converter. Each channel is equipped with a 16-bit digital counter whose output value is proportional to the integrated charge. The sensitivity can be adjusted by varying the quantum of charge, which corresponds to one digital count, in the range between 100 and 800 fC. The maximum frequency of 5 MHz limits the maximum current for each channel to 4 µA. The linearity of the measurement of the charge has been measured to be better than 1% in a wide range. The tested minimum read-out time for all the 1024 channels of MATRIX is 1 ms.

3 Beam tests

Laboratory tests have been performed before the first beam tests. The electronic noise has been measured to be less than one count per channel per second.
Figure 3: Two-dimensional representation of the read-out of the MATRIX pixel chamber before (left) and after calibration (right) for a square shaped field.

The chamber has been irradiated with X-rays in order to verify the correct operation of all the 1024 pixels. For all these tests and the following beam tests the voltage of 400 V has been applied which corresponds to an electric field of 800 V/cm in the sensitive volume. The first beam tests have been performed at the cyclotron of the Joint Research Centre of the European Commission in Ispra (Italy) at the end of 2004. Using a proton beam of 17 MeV and approximately 5 nA, the chamber was irradiated under several conditions and different beam shapes were measured. These first beam tests showed that MATRIX was successfully designed and constructed, fulfilling all the design requirements. In March 2005, several tests have been performed on the clinical beams of the proton-therapy centre of the Loma Linda University Medical Center in California (USA). Figure 3 shows the results of the calibration procedure 2), based on three different measurements (reference, 90° rotation and one pixel shift). No assumption on the shape of the beam is used for the calibration. MATRIX has been installed in several treatment rooms equipped with horizontal beams or gantries and the full system could be dismounted and put in operation in about 30 minutes. This shows the system is highly reliable and user friendly. The two-dimensional map of several fields has been measured. As an example, a field shaped for the treatment of a prostate cancer is shown in Figure 4 (left). The Bragg peak due to the ionization loss of a 149 MeV proton beam has been measured by interposing layers of water equivalent absorber between the exit window of the accelerator and the chamber, as presented in Figure 4 (right). Several tests have been performed using the read-out speed of 1 ms for the full chamber.

The very positive results of all these beam tests show that MATRIX is an innovative detector that can be successfully used for on-line beam monitoring in hadrontherapy.
Figure 4: Two-dimensional map of a field shaped for a prostate cancer treatment (left). The Bragg peak measured for a 149 MeV proton beam (right).

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References
