A SOLUTION FOR DOSIMETRY AND QUALITY ASSURANCE IN IMRT AND HADRONTHERAPY: THE PIXEL IONIZATION CHAMBER.

S. AMERIO, S. CODA, U. NASTASI
Servizio di Fisica Sanitaria, Ospedale S. Giovanni A.S.
V. Cavour 31, I-10123 Torino, Italy

S. BELLETTI, B. GHEDI
Servizio di Fisica Sanitaria, Spedali Civili di Brescia
P.le Ospedale 1, I-25123 Brescia, Italy

A. BORIANO
ASP, V.le Settimio Severo 65, I-10133 Torino, Italy

R. CIRIO, A. LUPARIA, F. MARCHETTO, C. PERONI, C.J. SANZ FREIRE
Università and INFN of Torino, V. Giuria 1, I-10125 Torino, Italy

M. DONETTI
Fondazione TERA, V. Puccini 11, I-28100 Novara, Italy
E-mail: donetti@to.infn.it

E. MADON, E. TREVISIOL, A. URGESI
OIRM S. Anna, V. Baiardi 43, I-10126 Torino, Italy

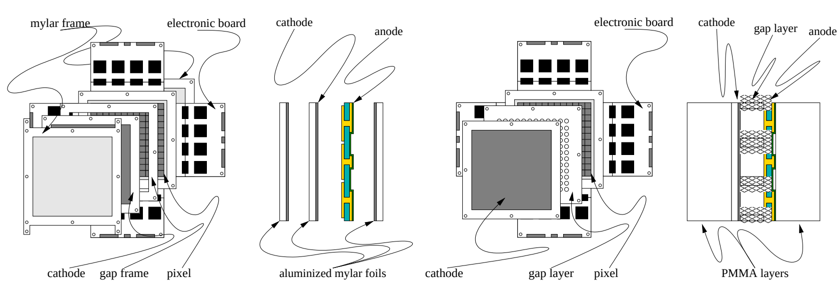
The new radiotherapy techniques require new detectors to monitor and measure the clinical field. The Intensity Modulated Radiation Therapy (IMRT) techniques like step and shoot, sliding window, dynamic wedge or scanning beam add the time variable to the treatment field. In this case the water phantom with a single ionization chamber moving inside the field needs very long measurement time. Linear arrays of ionization chambers or diodes measure the field only along a line. 2D detectors like radiographic or gafchromic film are not suitable to be used as on line detectors. We have developed, built and tested an ionization chamber segmented in pixels that measure the dose in a plane at several points. Every channel has a dedicated electronic chain that digitizes the collected charge and data from all the channels are sent to the computer that performs the data acquisition. One read out cycle is very fast allowing to measure in real time the fluency and the shape of the field. The chamber can be used in two different ways, as monitor chamber and as relative dosemeter. A description of the detector, the electronics, and test results with both photon and hadron beams will be reported.

1 Introduction

We have built a ionization chamber with the anode segmented in pixels that measure the dose released in a regular grid of points on a plane. Two different versions have been built in order to fit two different kinds of applications. Our detector, in fact, can be used both as monitor chamber and as dosemeter in a polymethylmethacrylate (PMMA) phantom. When used as a monitor chamber the water equivalent thickness of the detector is required to be as small as possible. As a dosemeter for electron and photon beams it is more important to avoid large dishomogeneity whilst the thickness requirements can be relaxed.

2 Mechanical description

The pixel chamber is a parallel plate ionization chamber where the anode is segmented in 1024 pixels and covers a total area of (24×24) cm^2. The anode was produced with the printed circuit board technology on a substrate of 100 μm thick vetronite foil, the cathode instead is an aluminized mylar foil. The front-end acquisition boards are mounted on the anode support.



(a) Thin version - exploded view

(b) Thin version - side view

(c) Thick version - exploded view

(d) Thick version - side view

Figure 1. Schematic view of the detector in the thin and thick versions.

The chamber design is characterized by a full modularity: we obtained the two versions by simply modifying the assembly. In figures 1(a) and1(b) it is shown an exploded and a side view of the monitor chamber (thin version).

Anode and cathode are glued to vetronite frames and the gas gap is defined by the thickness of another frame placed between the anode and the cathode. In application where the amount of material along the beam is not a constraint but only the density of the material (dosemeter in PMMA phantom) anode and cathode are glued to PMMA slabs few millimeters thick. In figures 1(c) and 1(d) it is shown the views of the detector (thick version). Between anode and cathode a plastic slab with a grid of holes is mounted. Every hole corresponds exactly to a pixel, creating an independent sensitive volume.

3 Front-end electronics

The front-end electronics is based on a Very Large Scale Integration (VLSI) chip that we have developed(TERA05). The electronics block diagram is shown in figure 2. TERA05 has 64 independent channels, each one consists of three stages. The first converts the input current in to a pulse train which frequency is proportional to the current itself. The charge, which one pulse correspond to, (charge quantum), it can be adjusted between 100 to 800 fC. The maximum frequency (5 MHz) limits the maximum current that can be measured: with 800 fC it is equal to 4 μA. In figure 3 current-to-frequency linearity is shown. We remark that the linearity in a very large range is better then 1%. In the second stage the pulses are counted with 16 bits wide counter. Finally, the last stage is a latch register that is used to store the output of the counter just before the read out is performed by the data acquisition (DAQ) system. A multiplexer connects the counter, selected by the DAQ , to the 16 digital output lines. 16 VLSI chips are used to acquire all the channels of the ionization chamber. The read-out frequency is 10 MHz allowing us to read the whole chamber in $\simeq$100 μs. By reading two channel at the same time and using a 32 bits wide input port the read out time is reduced to $\simeq$50 μs.

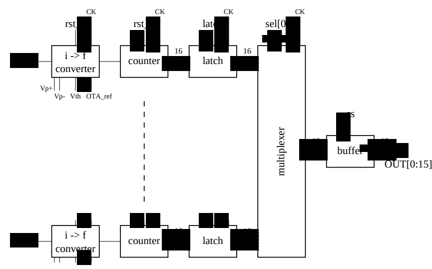


Figure 2. Block diagram of the VLSI chip.

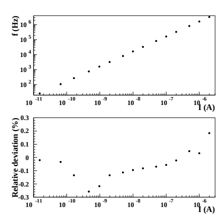


Figure 3. Linearity of current-to-frequency converter.

4 Data acquisition system

The two applications require different kinds of DAQ systems. When used like monitor chamber the DAQ has to be supervised by a more general software package which controls as fast as possible if the beam characteristics are matching to the specifications. For this reason we use a stand alone CPU that runs a real time operative system which responds with a time delay of the order of some hundred of μs. When used like dosemeter, cheaper and easy to handle solutions can be found. We choose a system based on a PCI digital input-output card housed inside a PC.

5 Test results with photon beam

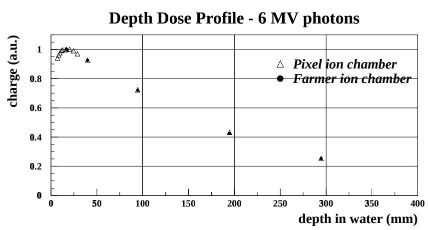


Figure 4. Depth dose profile measured in a PMMA phantom.

Tests with photon beams have been done in order to use the pixel chamber as dosemeter inside a phantom and for beam quality assurance (QA) measurements. In such application there are no DAQ time constraints, however the chamber can measure the delivered dose as a function of time. Several measurements have been performed to study the reproducibility of the response that was found to be better than 1%. Flatness and field profile measurements at different depth have been done. The results show that the pixel chamber is suited as QA instrumentation. As example, in figure 4, depth dose profile is shown and compared to a standard ionization chamber.

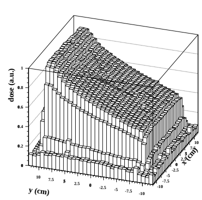


Figure 5. Relative dose in a dynamic wedge treatment.

With the chamber one can measure the relative dose in a plane across the beam and provide a complete 2D view. As an example of results we show in figure 5 the chamber response in a dynamic wedge treatment. Has to be stressed that with this system one can map the whole field at the same time, on the contrary with an array detector it would have been necessary several measurements. In applications where 2D dose as a function of time has to be monitored, the fast read out time allows to check in real time the shape and the intensity of the beam.

6 Test results with hadron beam

The chamber has been exposed to the carbon ion beam at GSI, Darmstadt, Germany. The beam delivery system can perform a finite scan over a large area. We used this capability to study the chamber as a monitor. The almost pencil beam was aimed to different positions of the chamber as is shown in figure 6. Thus we could determine the spatial resolution and the response homogeneity of the detector. The beam position has been reconstructed and compared to the position measured by an independent system. The distribution of the deviations is shown in figure 7. The resolution (r.m.s.) was found to be less than 0.2 mm when a 8.8 mm wide (FWHM) carbon ion beam was used. Response homogeneity was found in agrement with the results obtained with photon beams.

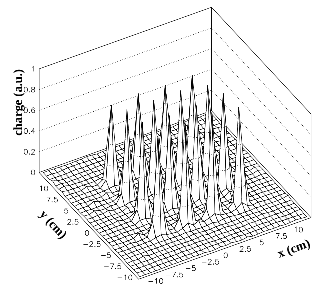


Figure 6. Relative dose as measured for a discrete spot scan.

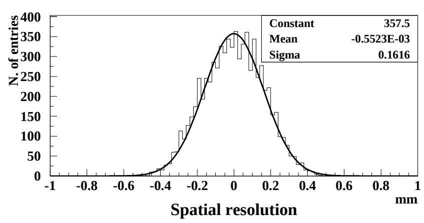


Figure 7. Spatial resolution measured with a carbon ion beam.

Acknowledgments

We wish to thank the Ion Beam Application (IBA) Louven la-Neuve, Belgium for its partial support to this research.
It is a pleasure to acknowledge the technical support and skill of the GSI Biophysics group and to thank the Laboratory for the use of the carbon ion beam.