A BEAM POSITION SYSTEM FOR HADRONTHERAPY FACILITIES*

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Abstract

Essential parts of the needed instrumentation for the beam control in Hadrontherapy accelerators are the Beam Position Monitors (BPM). The measurement of the beam position in Hadronterapy accelerators become more important at the secondary transport lines towards the patient room where this parameter must be completely determined. The BPM described in this paper is a new type of BPM based on four scintillating fibers coupled to four photodiodes to detect the light produced by the fibers when intercepting the beam. We present here the study of the different photodiodes able to read the light emitted by the scintillating fiber, the tests performed in order to find the most suitable photodiode to measure the beam position from the variations in the beam current, the mechanical design and the acquisition electronics.

INTRODUCTION

The control of the beam position is essential in Hadrontherapy accelerators, especially at the secondary transport lines towards the patient room where this parameter must be completely determine. The Beam Position Monitor (BPM) described in this paper named as ”watchdog” is a new type of BPM based on four scintillating fibers coupled to four photodiodes to detect the light produced by the fibers when intercepting the beam. We present in the first section the technology selection and the experimental tests for different types of photodiodes. In the second section we present the detailed mechanical design and in the third section the electronic acquisition system.

TECHNOLOGY SELECTION AND EXPERIMENTAL TEST OF THE DIFFERENT PHOTODIODES

The Experimental Setup

The experimental setup used for the photodiode tests consists of two parts. The first part is formed by the support fixing the fiber, the photodiode and the radioactive source. The second part is the electronics needed to feed the photodiode and to collect the electric signal at the output of the photodiode. A detailed study could be found in [1].

The Scintillating Fiber The fiber used is a Kuraray SCSF-78 scintillating fiber made up of polystyrene [2]. The fiber is square (0.5×0.5 mm^2) with single cladding and doped core (color centers), which emits photons at 450 nm wavelength. The fiber yield, i.e. the number of photons at one end of the fiber produced on average by a MIP (Minimum Ionizing Particle), is 15.5.

The Radioactive Source The radioactive source used for the tests is a Sr-90 source, emitting electrons with 195.8 keV average energy. The tests have been carried out at IFIC (Instituto de Física Corpuscular) and VSC (Val Space Consortium), with a different Sr-90 source nominal activity: 9×10^3 Bq and 37×10^6 Bq, respectively.

The Photodiode The Hamamatsu photodiodes selected for these tests are of two types: Multi Pixel Photon Counter (MPPC) and Avalanche Photodiode (APD), see Table 1 [3]. All the properties summarized in Table 1 have been considered for the selection of the photodiodes needed for our purpose. The effective area determines the photodiode area sensitive to photons. Knowing the area of the cone light leaving the end of the fiber, we can estimate whether the whole cone is detected by the photodiodes or not.

The emission angle of the fiber (α) depends on the numerical aperture (NA) of the fiber and the refraction index of the medium right after the fiber ($n \approx 1$ for air): $NA = nsin\alpha \rightarrow \alpha = 33,7°$. Taking into account the emission angle, we can calculate the area of the light cone. With d the distance between the fiber and the photosensitive surface inside the photodiode we have then, the area of light conus is $A = \pi L^2$ with $L = d \tan \alpha$.

Assuming the end of the fiber is touching the photodiode window d is just the distance between the photodiode window and the photosensitive surface of the photodiode. The results of the photodiode area illuminated by the light conus leaving the fiber are summarized for each photodiode in Table 1.

The Electronics The photodiode is supplied by a high voltage supply. When the photodiode detects light, it produces an electric signal that is amplified by an amplifier. After being amplified the signal is collected in the oscilloscope, which allows us to measure either pulse and rate level.

Due to the fact that the fiber just emits 15 photons per MIP, the photodiode has a very low output current. Because of this, we need signal amplification in order to get a pulse signal large enough to be measured by the oscilloscope. The amplifier we used is a transimpedance amplifier (V/A) with a gain range from 10^2 to 10^7. The gain used for the tests was 10^3 for the MPPC and 10^6 for the APD. The high voltage supply used is Keithley 2410C with 1100 V maximum voltage. The MPPC needs an input voltage of

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Table 1: Features of the Different Photodiodes Tested

	MPPC S10362-11-100C	MPPC S10362-33-100C	APD S2384	APD S4315
Effective area (mm^2)	1	9	7	7
Pixels number	100	900	-	-
Spectral response (nm)	320-900	320-900	400-1000	400-1000
Peak sensitivity (nm)	440	440	800	800
Efficiency	0.74	0.74	0.13	0.13
Gain (at 25°C)	2.40×10^6	2.40×10^6	60	60
Operating voltage (V)	70.86	70.90	143.80	143.80
Dark counts (cps)	1×10^6	12×10^6	-	-
Effective distance (mm)	0.5	0.45	1.4	1.9
Light conus area (mm^2)	0.35	0.28	2.74	5.04
Sensitive surface (mm^2)	1	9	7	7
Illuminated area (%)	35	3	39	72

$70.86 - 70.9\,V$ at $25°C$, while the APD needs $143.8\,V$ input voltage at the same temperature. The oscilloscope used is Agilent, and it has 2.5 GHz maximum frequency and $20\,GSa/s$ sampling rate. With the oscilloscope we can see the pulses and measure their peak voltages, FWHM, rise time, etc. We can also integrate the pulse to get the charge deposited by the photodiode, so the number of photons emitted by the fiber can be reproduced. Furthermore, we can measure the pulse rate or pulse frequency.

Experimental Tests and Results

The goal of the tests was to validate if the photodiodes chosen for the "watchdog" BPM are optimum devices to detect the photons emitted by the scintillating fiber and to study the response of the photodiodes under input current variations. This is performed by measuring the electron rate. The electron rate is the number of electrons per unit time emitted by the photodiode when it detects photons. This is equivalent to the current produced by the photodiode.

To know the beam position from current measurements, we have to study the electron rate variation when changing the distance between the Sr-90 source and the fiber, r in Table 2. To do this, we change the Sr-90 source position and count the pulses at a 20 ms window time in the oscilloscope. The trigger level of the oscilloscope is used to minimize dark counts in the MPPC case, and to minimize the electronic noise in the APD case. The results for the electron rate obtained for each photodiode are presented in Table 2.

We could conclude from the results that all of the photodiodes studied are able to detect the low light level emitted by the fiber, just 15.5 photons/MIP. However, the MPPC S10362-33-100C saturates because the area illuminated by the cone light is 3% of the total area, corresponding to 27 pixels, less than the 31 pixels needed to avoid saturation. Furthermore, we can expect saturation of the MPPC S10362-11-100C when exciting the scintillating fiber with a beam. Then, the APD type could be the most suitable photodiode for the "watchdog" BPM.

THE MECHANICS

The "watchdog" BPM configuration is based on four scintillating fibers tracking the beam by means of four movers to determine the beam position in the horizontal and vertical planes. The beam consists of 1×10^8 protons with a $1.5 - 25$ mm rough radius.

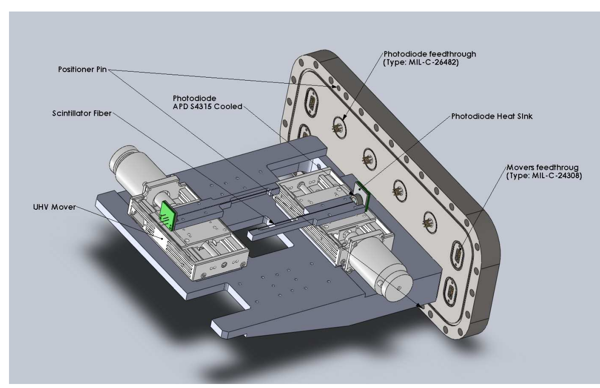

Figure 1: 3D view of the 1st prototype of the "watchdog" BPM.

The watchdog components are assembled on a base plate. This base plate is attached to a rectangular flange with four screws and two positioner pins. The first prototype will be assembled with only two movers, but the device is ready to set up the whole system with four movers, as shown in Figure 1. The prototype is designed to test the different types of photodiodes proposed. Each mover has 50 mm travel and they are ready to work in vacuum conditions. The movers have a stepper motor with 5 μm resolution and kapton insulated wires.

The flange has eight feedthroughs in order to connect the photodiode as well as the movers. Four circular feedthroughs (one per photodiode) are used for the photodiode signal. They are welded on the flange and we used plug connector type MIL-C-26482 on the air side

Table 2: Photodiodes Electron Rate Tests at IFIC and VSC

IFIC test			VSC test		VSC test		
	MPPC 1×1	MPPC 3×3	MPPC 1×1		APD S2384	APD S4315	
r (mm)	e$^-$rate (s^{-1})	e$^-$rate (s^{-1})	r (mm)	e$^-$rate (s^{-1})	r (mm)	e$^-$rate (s^{-1})	e$^-$rate (s^{-1})
2.5	195	1035	1.1	9538	16.1	1395	920
7.5	130	865	6.1	23210	21.1	1315	975
12.5	55	410	11.1	22730	26.1	1825	1480
17.5	28	825	16.1	22515	31.1	1440	1420
22.5	15	725	21.1	23488	36.1	1585	985
27.5	5	525	26.1	20100	41.1	1150	1025
32.5	5	505	31.1	16965			
37.5	5	115	36.1	20400			
42.5	0	0	41.1	17865			

and weld/crimp pins on the vacuum side. The other four feedthroughs are used for the movers control (one per mover). They are welded on the flange too and plug connector SubD 9 pins (MIL-C-24308) in the air side and weld/crimp pins on the vacuum side are used. The flange with the detection and mover system are in a box that keep the whole device under vacuum. To assembly the box and the flange thirty-two M8 screws are used as well as two positioner pins to ensure the correct position and assembly.

The scintillator fiber will be glued on a support that is attached to the movers carriage. The support has a housing to host the photodiode and to hold it together with the PCB. The PCB is a special type able to work under vacuum conditions.The PCB and the photodiode are joined to the support by two screws and two positioner pins in order to ensure the centered and alignment of the photodiode with the scintillator fiber.

THE ACQUISITION ELECTRONICS

Figure 2 shows the electronic scheme read-out system and mover control for the 1st watchdog BPM prototype. This scheme has only two-channel but can extended straightforward to four channels. This setup and its elements are chosen to be as configurable as possible being oriented to the study and evaluation of the different photodiodes response with a proton beam as well as getting the best suited operation parameters for the final design of the read-out and function electronics. The six signals needed for each channel are driven through a 6-pin MIL connectors and its pin-out corresponds to the bias voltage, V_B , and the light signal current, I_L. In the photodiode with cooling four more signals are needed which corresponds to the Peltier current circuit I_{P+}, I_{P-}, and the temperature sensor circuit, I_{T+}, I_{T-}. The light current signals from the photodiodes are converted to voltage in the amplifier. In the amplifier box are implemented two independent transimpedance amplifiers having four I/O channels with 6-pin MIL connectors for extending to the 4-channel of the watchdog. At the end the signals are acquired in a oscilloscope for posterior analysis. The others elements are the power supply, the temperature and movers control blocks.

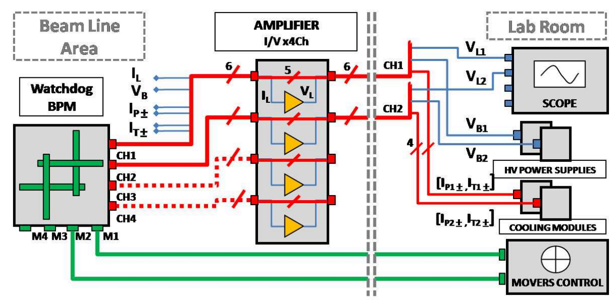

Figure 2: Electronic scheme for the 1st prototype of the ”watchdog” BPM.

CONCLUSIONS

This paper presents the technology selection of the different photodiodes, the mechanics and the electronic acquisition system of the ”watchdog” BPM. The next step will be the construction of a 1st prototype to be tested with a proton beam.

AKNOWLEDGMENTS

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