TECHNOLOGY SELECTION FOR THE BEAM POSITION TUNING SYSTEM IN HADRONTHERAPY FACILITIES*

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Abstract

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 determined. The Beam Position Monitor (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 possible photodiodes able to read the light emitted by the scintillating fiber, and the tests performed in order to find the most suitable photodiode to measure the beam position from the variations in the beam current. The setup used for the tests comprises a Sr-90 source, which emits electrons, a scintillating fiber, converting these electrons into photons, and a photodiode, which detects the photons emitted by the fiber. The photodiodes studied have been of two types: Avalanche Photodiode (APD) and Multi Pixel Photon Counter (MPPC). In this paper both photodiodes are compared and the results are presented.

INTRODUCTION

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

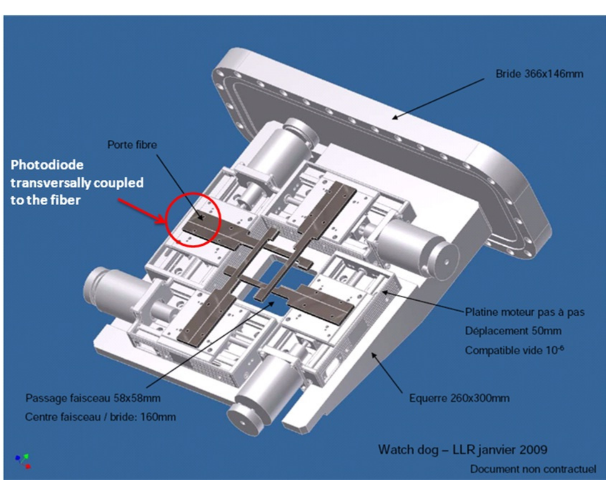

Figure 1: 3D view of the "Watchdog" BPM.

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In order to detect the light produced by the fibers when intercepting the beam, a photodiode is transversally coupled to each fiber. Differences in the particle rate intercepting the fibers left and right, and the fibers top and bottom, will generate differences in the output current of their respective photodiodes. These current differences will be related with the horizontal and vertical position of the beam.

The choice of the most appropriate photodiodes is well explained in [1].

The goal of the tests described in this report is to validate if the photodiodes chosen for this BPM are optimum devices to detect the photons leaving the scintillating fibers, and which one is the most suitable to measure the beam position from the variations in the beam current.

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. The support comprises:

- A Sr-90 source, emitting electrons with an average energy of 195.8 keV, playing the role of the beam.
- A scintillating fiber, converting these electrons into photons.
- A photodiode, which detects the photons guided by the fiber and turn them into electric current.

The Scintillating Fiber

The fiber used is a Kuraray SCSF-78 scintillating fiber made up of polystyrene [2]. It's a 0.5×0.5 mm^2 square fiber 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. For instance, 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 depends on the numerical aperture of the fiber and the refraction index of the medium right after the fiber ($n \approx 1$ for air): $NA = n \times sin\alpha \rightarrow \alpha = 33,7°$. Taking into account the emission angle, we can calculate the area of the light cone. With $d = d_0 + d_1$ the distance between the fiber and the photosensitive surface inside the photodiode, see Fig.2, we have $L = d \times \tan\alpha$. Then, the area of light conus is $Area = \pi L^2$.

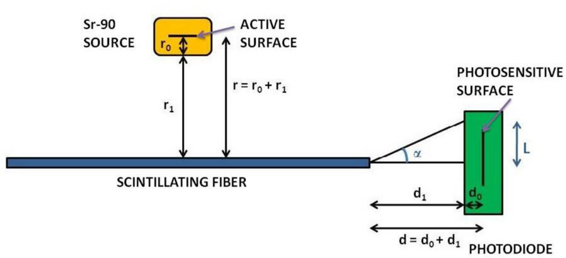

Figure 2: Geometrical proportions of the light cone emitted by the fiber.

Assuming the end of the fiber is touching the photodiode window ($d_1 = 0$), d is just the distance between the photodiode window and the photosensitive surface of the photodiode, which is d_0. 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.

- **The amplifier.**
  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 voltage supply.**
  The high voltage supply used is Keithley 2410C with $1100\,V$ maximum voltage. The MPPC needs an input voltage of $70.86 - 70.9\,V$ at $25°C$, while the APD needs $143.8\,V$ input voltage at the same temperature.
- **The oscilloscope.**
  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.

TESTS AND RESULTS

The goal of the tests is to validate if the photodiodes chosen for the "Watchdog" BPM are optimum devices to detect the photons emitted by the scintillating fiber. 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. Therefore, it is equivalent to the current produced by the photodiode. We want to know the beam position from current measurements, therefore, we are interested in studying the electron rate variation when changing the distance between the Sr-90 source and the fiber. 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 the following.

MPPC Test

Both MPPC S10362-11-100C (MPPC 1×1) and MPPC S10362-33-100C (MPPC 3×3) were measured at IFIC and VSC.

To measure the electron rate with a MPPC, we should take into account the dark counts produced when the Sr-90 source is not present. Then, first we measure the number of dark counts at a given trigger level, and after that we measure the electron rate at different distances between the radioactive source and the fiber. The range of distances is $2.5 - 42.5$ mm for the IFIC test and $1.1 - 41.1$ mm for the VSC test. We consider that the fiber is touching the photodiode window ($d_1 = 0$). The results for the IFIC and VSC tests are shown in Table 2.

APD Test

Both APD S2384 and APD S4315 were only measured at VSC, because the Sr-90 source we have at IFIC doesn't generate an output current high enough to be measured.

The APD S4315 has the same features than the APD S2384, but with the difference that the APD S4315 has a

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	-	-
d_0 (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

Table 2: MPPC 1×1 and MPPC 3×3 . IFIC and VSC Electron Rate Tests

IFIC test			VSC test	
	MPPC 1×1	MPPC 3×3	MPPC 1×1	
r (mm)	rate (s^{-1})	rate (s^{-1})	r (mm)	rate (s^{-1})
2.5	195	1035	1.1	9538
7.5	130	865	6.1	23210
12.5	55	410	11.1	22730
17.5	28	825	16.1	22515
22.5	15	725	21.1	23488
27.5	5	525	26.1	20100
32.5	5	505	31.1	16965
37.5	5	115	36.1	20400
42.5	0	0	41.1	17865

Table 3: APD S2384 and APD S4315. VSC Electron Rate Tests

VSC test		
	APD S2384	APD S4315
r (mm)	rate (s^{-1})	rate (s^{-1})
16.1	1395	920
21.1	1315	975
26.1	1825	1480
31.1	1440	1420
36.1	1585	985
41.1	1150	1025

cooling module, thus allowing us to cool down the photodiode until $-10°C$. With this operating temperature one can avoid the electronic noise due to the heating of the APD associated to its operation. Furthermore, the voltage supply of the photodiode can be reduced.

The APD doesn't have so many dark counts like the MPPC, but the measure could be distorted by the electronic noise. In order to avoid the electronic noise, we put the trigger level at 50 mV. Table 3 shows the results for distances between the Sr-90 source and the fiber in the range 16.1 – 41.1 mm.

CONCLUSIONS

This paper presents the study of the response from different photodiodes when receiving the light emitted by a scintillating fiber. The goal of this study is to select the most suitable photodiode for its operation in the "Watchdog" BPM. The following photodiode types have been studied: MPPC S10362-11-100C, MPPC S10362-33-100C, APD S2384 and APD S4315 (TE-cooled).

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 next step will be the construction of a prototype to measure the photodiodes with a particle beam.

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