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TIMING RESOLUTION FOR AN OPTICAL FIBRE-BASED DETECTOR IN A 74 MeV PROTON THERAPY BEAM

C. Penner, C. Hoehr , C. Lindsay, TRIUMF, Vancouver, Canada
C. Duzenli, British Columbia Cancer Agency, Vancouver, Canada
S. O'Keeffe, University of Limerick, Limerick, Ireland

Abstract

A Terbium activated Gadolinium Oxysulfide (Gd_2O_2S:Tb)-filled optical fibre sensor was developed and tested as a proton therapy beam dosimeter on a 74 MeV proton beam. Tests were carried out at the TRIUMF proton therapy centre, where a passively scattered beam is used for treatment. To create a clinically relevant spread-out Bragg peak, a modulator wheel with steps of varying thickness is employed.

To determine the sensor's response in a 23 mm spread out Bragg peak, the sensor signal was sampled at depth intervals of 0.79 mm along the beam axis in a water phantom. The resulting data showed a periodic variation in the signal corresponding to the rotation of the modulator wheel and related to the depth in water of the detector. This timing resolution in the sensor response could find application in quality assurance for modulated proton beams.

INTRODUCTION

Proton radiotherapy is a rapidly growing method of cancer treatment with the number of facilities as well as treatments increasing every year [1-3]. Though proton therapy can be administered as scanning and intensity-modulated beams, some clinical proton beams, like the one at the TRIUMF facility, are passively scattered by various degraders placed in the path of the beam.

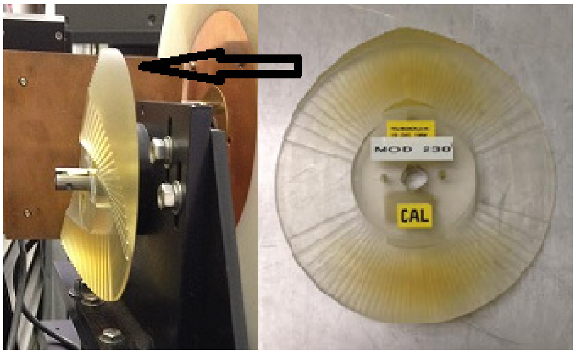

Figure 1: The 23 mm modulator wheel spreads out the Bragg Peak over an axial distance of 23 mm by creating layers of individual Bragg peaks (Fig. 2).

Proton beam degraders serve two purposes: to reduce the energy of the incoming beam to one which will peak at the desired maximum depth in tissue (in the case of TRIUMF, the far end of a tumour in the eye), and to spread the otherwise very narrow Bragg peak (BP) region into the wider spread-out Bragg peak (SOBP) to irradiate the whole tumour axially.

During proton therapy the beam is modulated by a rotating, stepped polymethyl methacrylate wheel [4] (Fig. 1). The modulator wheel creates a uniform distribution of dose over a specified depth range by superposition of BPs, each with a specific range and relative weight. .For a 23 mm SOBP (Fig. 2), the modulator wheel consists of 20 discrete steps resulting in the superposition of 20 individual BP's. The relative weight of the peaks increases with their range. For the 23 mm SOBP, the heaviest weighting is given to the peak with a range of 31 mm (labelled peak 1 in Fig 2).

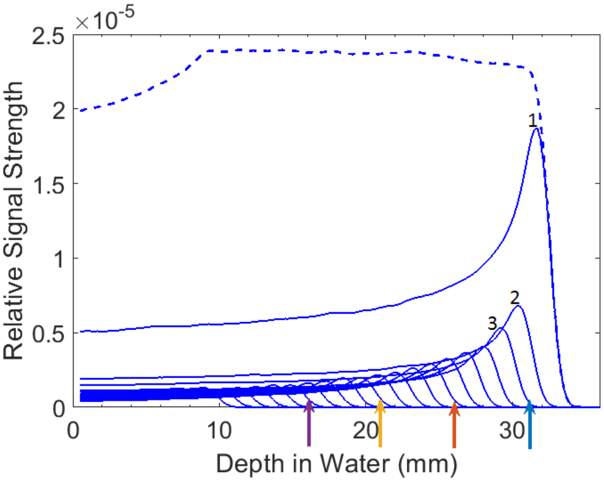

Figure 2: The spread-out Bragg peak (dashed line) shown as the sum of its multiple individual Bragg peaks. The arrows indicate the depths sampled by the fibre sensor and the corresponding data in Fig 6.

In a recent study we characterized the response of a novel scintillation optical fibre sensor (OFS) in the TRIUMF proton therapy beam [5]. The narrow Bragg peak of a pro-ton depth dose curve is best resolved with small detectors providing high spatial resolution. Optical fibre-based de-tectors can provide this, being available in sub-millimetre diameters as well as being waterproof, enabling them to be submerged in the water phantom used for beam quality assurance. Optical fibre detectors can also deliver real-time readout which has potential for in-vivo applications. Gadox has a signal decay time of 1.6 ms and is capable of resolving the x-ray pulses delivered

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by a 6 MV linac down to 0.1 ms [6]. As such, there is an effort to exploit these features and develop an optical fibre detector for use in proton radiotherapy. Here we explore the structure in the fibre signal over time, as a function of depth in a SOBP, as it relates to the rotating modulator wheel.

MATERIALS AND METHODS

The detector was fabricated from polymethyl methacrylate (PMMA) based plastic optical fibre, with a cavity micromachined at one end and Gd_2O_2S:Tb (Gadox) scintillator powder packed into the cavity (Fig. 4). The detecting end was sealed with silicone and the distal end fixed with a connector attached to a light guide which relayed the optical signal to a multi-pixel photon counter (MPPC). The MPPC is a solid-state detector that operates in Geiger mode and records data directly via USB as Microsoft Excel files. The MPPC properties were set at a threshold of 0.5 p.e (photon equivalent), and a gate time of 100 ms. The sensor was attached to a Lucite rod that was mounted on a 3-D scanning stage. A water box phantom was placed on the stage and the rod with attached sensor was positioned directly behind the 1 mm thick Solid Water™ (Gammex RMI, Middleton WI) window inside the water box (Fig. 3). Count rates for 10 000 monitor counts were collected every 0.79 mm in the water phantom from the inner surface of the window to a water depth of 39.7 mm. Monitor counts (MC) are a measure of beam output. In the case of the 74 MeV TRIUMF beam, there are approximately 10 000 MC/ 140 cGy of dose at the centre of the 23 mm SOBP.

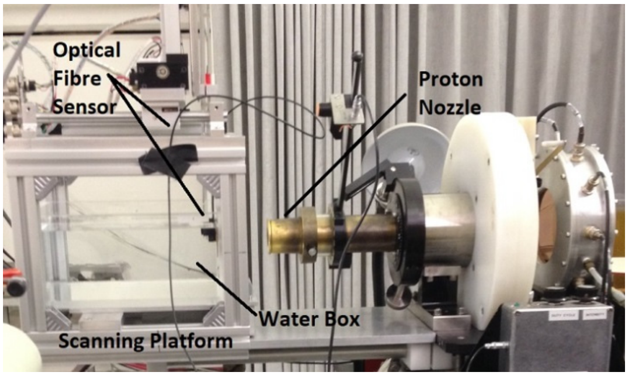

Figure 3: Optical fibre sensor setup in water phantom. The proton beam is coming from the right.

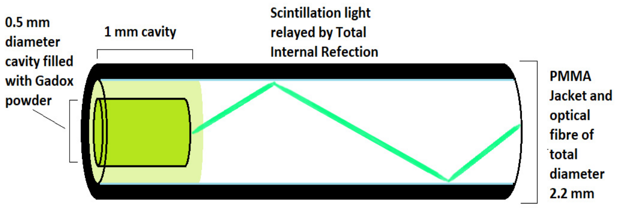

Figure 4: Dimensions of OFS.

RESULTS

The Gadox optical fibre signal as a function of depth in a 23 mm SOBP and an unmodulated BP can be seen in Fig. 5. Samples taken at the four positions indicated with arrows in Fig. 2. are shown in Fig. 6. Particularly noticeable is how, as the dwell points become deeper, the variation between highest and lowest count rates become more pronounced. It is also important to note that towards the end of the SOBP, the scintillator signal is quenched (Fig. 5), which explains why the signal with the highest variation is not also the highest signal.

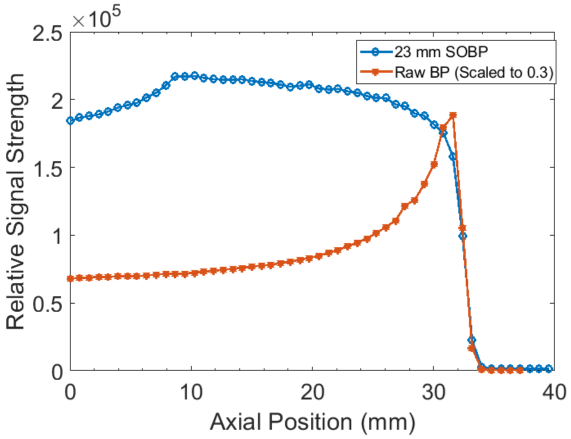

Figure 5: The Bragg peak and spread-out Bragg peak as measured by our OFS. The distal end of the SOBP is noticeably quenched (an under-response), as is typical of scintillators.

DISCUSSION

The increase in variation between maximum and minimum count rates at a given depth toward the distal end of the SOBP is aligned with our knowledge of how the SOBP is formed. At 31 mm of depth, only peaks 1,2 and 3 contribute to the signal on the detector. As the detector moves to shallower depths, more peaks are contributing to the signal and the relative weight of these peaks is more uniform. This results in reduced signal variation with decreasing depth, until at position 16 little variation is observed as predicted in Fig. 2.

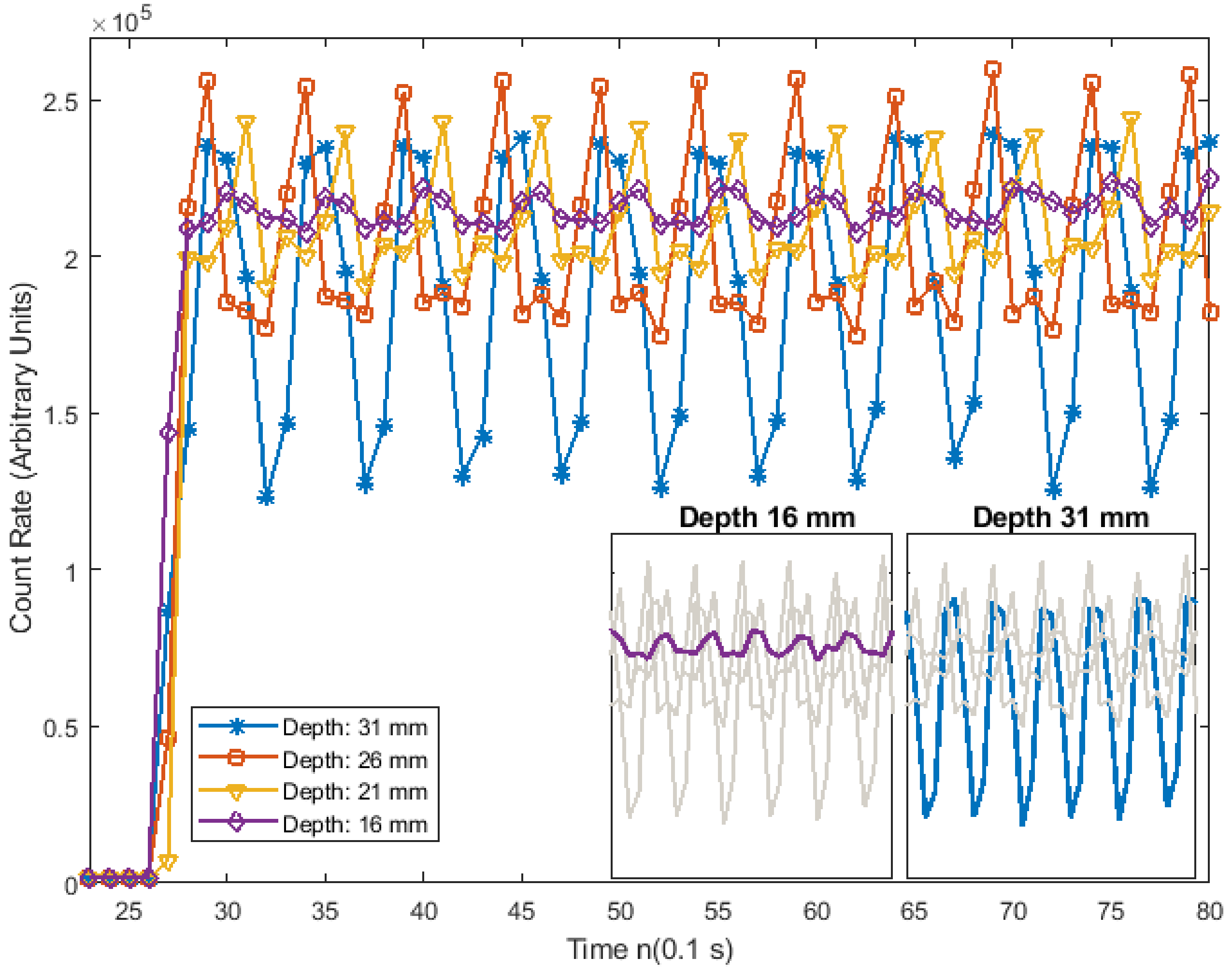

Figure 6: Signal cycles at recorded at depths in water of 16, 21, 26 and 31 mm.

CONCLUSION

The data in this study indicates that the timing sensitivity of the Gd_2O_2S:Tb scintillator and MPPC may be exploited for quality assurance testing of modulated proton beams. The fibre sensor could be used to confirm the rotational speed of the modulator wheel and the identity of the particular wheel. Since wheels designed to produce different SOBPs create a unique set of individual BPs, each wheel will produce a unique signal variation with depth. The sensor depth could also be determined from the measured variation if the wheel is known. Furthermore, applications in scanned and intensity modulated proton beams may be identified through further study.

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