The role of a microDiamond detector in the dosimetry of proton pencil beams

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Abstract

In this work, the performance of a microDiamond detector in a scanned proton beam is studied and its potential role in the dosimetric characterization of proton pencil beams is assessed. The linearity of the detector response with the absorbed dose and the dependence on the dose-rate were tested. The depth-dose curve and the lateral dose profiles of a proton pencil beam were measured and compared to reference data. The feasibility of calibrating the beam monitor chamber with a microDiamond detector was also studied. It was found the detector reading is linear with the absorbed dose to water (down to few cGy) and the detector response is independent of both the dose-rate (up to few Gy/s) and the proton beam energy (within the whole clinically-relevant energy range). The detector showed a good performance in depth-dose curve and lateral dose profile measurements; and it might even be used to calibrate the beam monitor chambers—provided it is cross-calibrated against a reference ionization chamber. In conclusion, the microDiamond detector was proved capable of performing an accurate dosimetric characterization of proton pencil beams.

Die Rolle eines microDiamond-Detektors in der Dosimetrie von Protonen-Nadelstrahlen

Zusammenfassung

In dieser Arbeit wird die Leistung eines microDiamond-Detektors in einem gescannten Protonenstrahl untersucht und es wird bewertet, welche Rolle dieser Detektor bei der dosimetrischen Charakterisierung von Protonen-Nadelstrahlen haben kann. Die Linearität des Detektors mit der Dosis und die Abhängigkeit des Ansprechvermögens von der Dosisleistung wurden getestet. Die Tiefendosiskurve und das laterale Dosisprofil eines Protonen-Nadelstrahls wurden gemessen und gegen Referenzdaten verglichen. Zusätzlich wurde untersucht, inwiefern sich die Monitorkammer des Strahls mittels des Diamant-Detektors kalibrieren lässt. Es zeigte sich, dass das Detektorsignal linear zur Wasserenergiedosis ist (bis herab zu wenigen cGy). Das Ansprechvermögen ist unabhängig sowohl von der Dosisleistung (bis zu einigen Gy/s) als auch der Energie (innerhalb des gesamten klinisch relevanten Bereichs) der Protonen. Der Detektor war gut zur Messung von Tiefendosiskurven und Querprofilen

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geeignet, und er kann sogar zur Kalibrierung der Monitorkammer verwendet werden – vorausgesetzt, er wurde gegen eine Referenzkammer kreuz-kalibriert. Zusammenfassend zeigt sich, der microDiamond-Detektor ist für die präzise Dosimetrie zur Charakterisierung von Protonen-Nadelstrahlen geeignet.

Keywords: Microdiamond detector, proton therapy, radiation dosimetry

Schlüsselwörter: Microdiamond-Detektor, Protonentherapie, Strahlungsdosimetrie

1 Introduction

The dosimetric characterization of a proton pencil beam requires three experimental measurements: (i) a relative depth-dose curve, (ii) relative lateral dose profiles and (iii) an absolute determination of the absorbed dose to water (D_w) at a reference point, i.e. reference dosimetry. Depth-dose curves should be measured in water [1] and, in the case of proton pencil beams, they are typically measured with a large-diameter plane-parallel ionization chamber [2]. Lateral dose profiles are typically measured with high spatial resolution 2D-detectors—such as radiochromic films [3,4] or a scintillating screen coupled to a CCD camera [4,5]—or with a small volume ionization chamber [3,6]. Finally, reference dosimetry is described in IAEA TRS-398 [1] and it should be performed in water with a cylindrical or a plane-parallel ionization chamber.

In this work, we studied the performance of a synthetic single-crystal diamond (SSCD) detector (microDiamond Type 60019, PTW-Freiburg, Freiburg, Germany) in a scanned proton beam and we assessed its potential role in the dosimetric characterization of proton pencil beams. The microDiamond detector is based on a SSCD-detector developed at Rome "Tor Vergata" University laboratories. The dosimetric properties of early SSCD-detector prototypes have been investigated—by some of the authors of this work—in photon [7] and electron beams [8]. Also, SSCD-detectors have been shown to be suitable for intensity modulation radiation therapy [9] and volumetric modulated arc therapy [10] treatment dose verification. Furthermore, an early prototype of the current commercially-available microDiamond detector has been tested in high-energy scattered proton beams at the Loma Linda University Medical Center [11]. In their work, the authors reported promising results for the relative dosimetry of scattered proton beams.

In this work, we studied the performance of a commercial version of the microDiamond detector in a scanned proton beam. Although the interactions of protons with matter are independent of the delivery technique (scattering or scanning), scanned beams have some particularities with respect to scattered beams (e.g. much higher dose rates) which could potentially have an influence in the response of the detector. Therefore, based on the results of Ref. [11], in this work we expanded on the following:

1. We tested the linearity of the detector response with the absorbed dose, down to doses one order of magnitude lower than Ref. [11].
2. We tested the dose-rate dependence of the detector up to (instantaneous) dose-rates two orders of magnitude higher than Ref. [11].
3. We measured depth-dose curves at a lower energy than Ref. [11] and we determined the proton water-equivalent thickness of the detector entrance window.
4. We measured the lateral dose profile of a single pencil beam in air, with two different detector configurations.
5. We studied the feasibility to calibrate the beam monitor chamber with a microDiamond detector.

2 Materials and methods

In this work, we tested two commercially-available microDiamond detectors. The microDiamond detector differs from early SSCD-detector prototypes in the housing and encapsulation materials. The working principle, detection mechanism and technology of SSCD-detectors are described in detail in Ref. [12]. In the commercial microDiamond detector, the sensitive volume is a SSCD disc of 1.1 mm radius and 1 μm thickness. The axis of the disc coincides with the detector axis. According to the manufacturer, the (photon) water-equivalent thickness of the entrance window is 1 mm. The reference point of measurement is therefore defined on the detector axis, 1 mm below the detector surface. For a detailed description of the microDiamond technical specifications, see the manufacturer website [13].

In what follows, we describe the different tests and measurements we performed with the microDiamond detector.

2.1 Dose linearity

A desirable characteristic of a radiation detector to be used in relative dosimetry is the proportionality of its signal with the absorbed dose at the point of measurement, within the