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Original paper

Small field characterization of a Nanochamber prototype under flattening filter free photon beams

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ABSTRACT

Introduction: Nanochambers present some advantages in terms of energy independence and absolute dose measurement for small field dosimetry in the SBRT scenario. Characterization of a micro-chamber prototype was carried out both under flattened and flattening-filter-free (FFF) beams with particular focus on stem effect.

Methods: The study included characterization of leakage and stem effects, dose rate and dose per pulse dependence, measurement of profiles, and percentage depth doses (PDDs). Ion collection efficiency and polarity effects were measured and evaluated against field size and dose per pulse. The 6_MV, 6_MV_FFF and 10_MV FFF beams of a Varian EDGE were used. Output factors were measured for field sizes ranging from 0.8×0.8 cm^2 to 20×20 cm^2 and were compared with other detectors.

Results: The 2 mm diameter of this chamber guarantees a high spatial resolution with low penumbra values. In orthogonal configuration a strong stem (and cable) effect was observed for small fields. Dose rate and dose per pulse dependence were <0.3% and 0.6% respectively for the whole range of considered values. The Nanochamber exhibits a field size (FS) dependence of the polarity correction >2%. The OF values were compared with other small field detectors showing a good agreement for field sizes $>2 \times 2$ cm^2. The large field over-response was corrected applying k_{pol}(FS).

Conclusions: Nanochamber is an interesting option for small field measurements. The spherical shape of the active volume is an advantage in terms of reduced angular dependence. An interesting feature of the Nanochamber is its beam quality independence and, as a future development, the possibility to use it for small field absolute dosimetry.

1. Introduction

The recent diffusion of SBRT and SRS treatments has increased the use of flattening filter free (FFF) beams that allow higher dose rates in order to deliver large doses per fraction in a reasonable beam-on-time [1,2]. On the other side small and non-standard radiation fields are used in the clinical practice in many centers. Measuring this kind of fields can no longer be considered only a research topic as demonstrated by the increasing number of multicentre studies [3–7]. For this reason many small volume detectors and in particular air filled ionization chambers have been developed in recent years. These chambers are generally characterized by a good energy response to low energy photons, uniform directional response, and independence of dose rate [8]. Micro and nano-chambers cannot be as small as solid state detectors but present some advantages in terms of energy independence and absolute dose measurement that make them fundamental for small field dosimetry in the SBRT scenario. Unfortunately, microchambers exhibit anomalous polarity effects that must be understood in order to have reliable measurements. Furthermore in FFF beams the ion recombination processes have to be carefully considered. In this scenario the classic methods [9] proposed to calculate the recombination and polarization correction factors should be verified. IBA has recently developed a prototype of a micro-chamber (Razor Nanochamber, IBA) with an extremely small active volume (3 mm^3) whose response was deeply investigated in this work. At our knowledge, this is the first time in which such detector is characterized.

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2. Materials and methods

A prototype of the Razor Nanochamber is an air filled micro-chamber whose outer and inner electrodes are made of Shonka (C-552) plastic and graphite respectively. While the outer case is the same than the cc01 (IBA Dosimetry, Schwarzenbruck, Germany), the active volume is much smaller (3 mm^3 against 10 mm^3) The diameter of the active volume is 2 mm. The nominal characteristics of the Nanochamber and of the other detectors used in this study are reported in Table 1.

6MV, 6MV FFF and 10 MV FFF beams from a Varian EDGE linac were considered in all measurements of this study. An IBA Bluephantom2 water tank was employed for the ion chamber measurements with a set-up fixed at SSD = 100 cm.

2.1. Stem effect and leakage

The extremely small volume of the cc003 required an evaluation of the inherent and the radiation-induced leakage. Dark current was measured over 30 min acquiring integrated measurements of 60 s each. The leakage induced by the irradiation of the chamber and of the cable was evaluated acquiring profiles along the direction of the chamber axis (i.e. horizontal position). With this setup when the chamber was entering the field (i.e. in the first part of the profile), the length of chamber and cable under irradiation was much lower than in the following measuring points enhancing eventual stem effects.

2.2. Angular response

The angular dependence was tested in air with a spherical build-up cap covering the Nanochamber positioned with the center of its active volume at the isocenter of the accelerator. The response was evaluated positioning the ion-chamber with axis both parallel and perpendicular to the beam axis. A 5 × 5 cm^2 field size was used and the angle was varied rotating the gantry every 30° covering a full rotation.

2.3. Dose, dose rate and dose per pulse dependence

The dose dependence of the Nanochamber response was studied at a fixed dose rate of 600 MU/min, in a 10 × 10 cm^2 field size. The ion chamber was positioned 5 cm deep in vertical position and its response was evaluated in a 5–2000 MU range.

Dose rate dependence was evaluated in the same set-up in a 400–2400 MU/min range with the 10 MV FFF beam.

Variation of the Nanochamber response with dose per pulse (DPP) was evaluated in the 0.18–2.2 mGy per pulse range comparing it with a plane-parallel ionization chamber following the method described in [10]. In the EDGE accelerator DPP value depends on the chosen beam energy and modality (FF or FFF). The DPP at D_{max}, in reference conditions (i.e. SSD 100 cm and field size 10 × 10 cm^2) as measured by the FC65-G ionization chamber, was 0.3 mGy per pulse for the 6 MV-FF beam whereas 0.8 and 1.3 mGy per pulse for 6 MV-FFF and 10 MV-FFF beams, respectively. In order to extend the range of available DPP values the SSD was varied from 75 cm to 125 cm. For SSD different from the reference value the collimator aperture was scaled in order to obtain always a 10 × 10 cm^2 field size at the phantom surface so to avoid any possible effect on the detector response due to the field size variation. For each available DPP value the same number of monitor units was delivered to the two ionization chambers in the same measurement conditions. Then, for each beam quality Q the ratio of the readings was evaluated correcting the PPC05 readings for ion recombination and the other influence values. The ppc05 was chosen in order to reduce the variation of ion recombination effects; in the DPP range considered in this work the PPC05 ion recombination correction factor, k_s, determined according to the IAEA TRS 398, is typically 1.0025 and deviations from this value are always within ±0.001. Moreover, in the case of PPC05 chamber, the small electrode separation (0.6 mm) ensures that the traditional two-voltage method for k_s determination still gives accurate correction factors in the dose per pulse range typical of FFF beams [11] leading to a negligible contribution of the k_s to the uncertainty of the ratio of readings (i.e. <0.05%, 1SD).

2.4. Ion collection efficiency and polarity effect

Polarity correction factors for the Razor Nanochamber were evaluated for the 3 energies used and its dependence on field size was investigated in the range 1–40 cm^2. The chamber was positioned at 3 cm depth with a SSD = 100 cm. The polarity correction factor was measured, for each field size, according to Eq. (1):

$$K_{pol}(s) = \frac{M_{+300} + M_{-300}}{2 \cdot M_{+300}} \qquad (1)$$

Saturation curves (plots of collected charge as a function of applied voltage) were obtained for the cc003 for all available beam qualities. Jaffé plots were created from the saturation curve (i.e. 1/Q vs.1/V curves) where Q is the collected charge and V is the applied voltage which was varied between +25 and +300 V. Following the method proposed by Agostinelli et al. [12], Q_{sat} was calculated as the inverse of the intercept for 1/V → 0 of the linear regression curve. The linear fit was performed considering the linear part of the plot only (i.e. low voltages).

The ion collection efficiency correction factor was introduced following the one reported by Agostinelli et al.:

$$J_s = \frac{Q_{sat}}{Q_{300}} \qquad (2)$$

J_s corrects for both recombination and excess charges and reduces to the conventional recombination factor [13] if excess charges are null.

The dependence of the ion collection efficiency on field size and on dose per pulse was evaluated over the whole range of available field sizes (1–40 cm^2) and dose per pulse values (0.02–0.2 cGy/pulse).

Table 1
Nominal characteristics of the detectors used in the study.

Detector	Type	Active volume (mm^3)	Active diameter thickness/length (mm)	Sensitive Material	Electrode Material	Sensitivity (nC/Gy)
PTW-60019 MicroDiamond	Synthetic diamond	0.004	2.2/0.001	Diamond	/	0.7–1.2
IBA-Razor	Unshielded diode	0.017	0.6/0.04	Silicon	/	6
IBA- cc003 Nanochamber	Ionization chamber	3.0	2.0/0.03	Air	Graphite	0.11
IBA-cc01	Ionization chamber	10	2.0/3.6	Air	Steel	0.4
IBA-cc13	Ionization chamber	130	6.0/5.8	Air	Shonka	4.4
IBA-ppc05	Ionization chamber	50	1.0/9.9	Air	PEEK	2

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