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A Novel Dosimetry System for Computed Tomography using Phototransistor

C. M. M. Paschoal[a,b], M. L. Sobrinho[a], D. do N. Souza[a*], J. Antônio Filho[c], Jr.[d], L. A. P. Santos[a,b]

Abstract**—**Computed tomography (CT) dosimetry normally uses an ionization chamber 100 mm long to estimate the computed tomography dose index (CTDI), however some reports have already indicated that small devices could replace the long ion chamber to improve quality assurance procedures in CT dosimetry. This paper presents a novel dosimetry system based in a commercial phototransistor evaluated for CT dosimetry. Three detector configurations were developed for this system: with a single, two and four devices. Dose profile measurements were obtained with them and their angular response were evaluated. The results showed that the novel dosimetry system with the phototransistor could be an alternative for CT dosimetry. It allows to obtain the CT dose profile in details and also to estimate the CTDI in longer length than the 100 mm pencil chamber. The angular response showed that the one device detector configuration is the most adequate among the three configurations analyzed in this study.

Keywords**—**Computed tomography, dosimetry, photo-transistor

I. INTRODUCTION

COMPUTED tomography exams cause some of the highest radiation doses to the patients in X ray diagnosis and it represents approximately 50% of the collective radiation dose from medical radiology in European countries [9] and 70% of this dose in the United States [4].Therefore, evaluation and optimization the CT radiation doses for patients undergoing this type of examination is essential. An ionization chamber 100 mm long is the most commonly used dosimeter in computed tomography. It is utilized to evaluate the computed tomography dose index (CTDI), an important dose descriptor in CT. It was expected that 100 mm of length was able to capture the broad scatter tails of CT dose profile, providing accurate measurements of CTDI_{100} using dosimetric phantoms (CTDI weight) and CTDI_{100} free in air. However, some reports have demonstrated that the 100 mm ionization chamber, often named pencil chamber, does not collect all of the scattered photons from a single slice profile [2; 5; 6], mainly with the multi-slice CT technology that allows wider beam width. Instead of making the ion chamber even longer, some alternatives have been suggested which involves smaller detectors. For example, semiconductor devices have been used to measure dose profiles in computed tomography [1; 6; 4; 3]. In these cases, the CT dose profiles are obtained by scanning the device through the beam using multiple rotations of the X ray source. Electronic semiconductor devices have some advantages for dosimetry applications, because of their high sensitivity, small dimensions, high spatial resolution, the possibility of positioning the device within a confined space of a body or phantom and, furthermore, the ability to operate in passive or active (real time measurements) mode [7]. One point that must be observed is the geometry of a photodetector which can apparently produce a directional sensitivity in CT dosimetry.In the present work, a novel dosimetry system based in a commercial phototransistor was evaluated for CT dosimetry, this semiconductor have already been employed as radiation detectors [8]. Although the X ray tube in CT performs a full 360° rotation, equal irradiating the patient from all sides, three detector configurations based on the phototransistors were built in order to evaluate their angular response and the most situable configuration for CT dosimetry. Moreover, dose profile measurements were obtained with them and the results were compared with those obtained using a pencil chamber, which has been reported to underestimated CTDI values [2; 5; 6].

II. MATERIALS AND METHODS

The dosimetry system consists of a Flip-flop electrometer (EFF), the detector and an instrumentation computer which is used to register the measurements using DoseX® software, which controls the EFF (Fig. 1).

Fig. 1 The dosimetry system: phototransistor on a printed circuit board, the Flip-flop electrometer, a computer and the DoseX® software

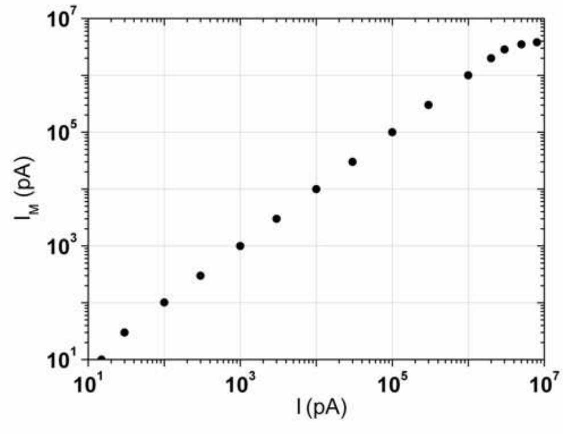

Fig. 2 Calibration curve for the Flip-flop electrometer. I_M is the measured current value and I is the conventional true value (6430 Keithley source)

C. M. M. Paschoala, M. L. Sobrinhoa and D. do N. Souzaa, L. A. P. Santos are with Departamento de Física, Universidade Federal de Sergipe, São Cristóvão-SE, Brazil(e-mail:cinthiam.paschoal@gmail.com)

M. L. Sobrinhoa is with Centro Regional de Ciências Nucleares, Comissão Nacional de Energia Nuclear, Recife-PE, Brazil

J. Antônio Filhoc, Jr are with Departamento de Energia Nuclear, Universidade Federal de Pernambuco, Recife-PE, Brazil

The Flip-flop electrometer was calibrated using a 6430 Keithley subfemtoammeter, as illustrated in Fig. 2.

The device used as the radiation detector was a commercial phototransistor (OP520 OPTEK®) which has an opaque lens package and a sensitive area < 0.5 mm^2. This system is cheap, does not require an amplifier, and provides real time measurements. A single detector array CT scanner (Toshiba Asteion) was used for all irradiation assessments. A head CT examination was chosen to test the novel dosimetry system. Measurements parameters were as follows: scan time, 0.75 s; tube kilovoltage, 120 kV; electrical current, 200 mA. Dose measurements were evaluated in a head phantom undergoing CT examination in axial mode. The phantom consisted of a PMMA (polymethyl-methacrylate) cylinder, 150 mm in diameter and 160 mm in lenght. The phantom has holes to insert the detector: one hole is located at the center of the phantom and four holes are located at the periphery, 10 mm from the surface. The phantom was positioned in a head support on the top of the patient couch, with the central hole coinciding with axis of rotation (z) (Fig. 3).

Fig. 3 Dosimetric head phantom positioned in the head support on the top of the patient couch with the detector inserted in the central hole

The dose profile in CT and directional sensitivity were evaluated using three configurations of the photodetectors: 1) a single detector device; 2) two detector devices, one soldered back to the other (Fig. 4); and 3) four detector devices soldered at right angles to one another (Fig. 5). For configurations mounted with 2 and 4 devices, phototransistors were connected in parallel to enable them to function as a single detector.

For all detector configurations, dose profiles were measured at the central hole by moving the detector (the patient couch) in small steps along the rotation axis of the scanner. The selected nominal thickness was 10 mm and dose profiles were measured over 155 mm. The distance between measuring points was set to be 10 mm, except in the central part, where a 2 mm interval was used to obtain more detail in the dose profile. Displacements were provided by programming the CT scanner after a head phantom scout view. The dose profile obtained using phototransistors was integrated along 100 and 155 mm, in order to evaluate if the length of the pencil chamber is sufficient to estimate the dose value.

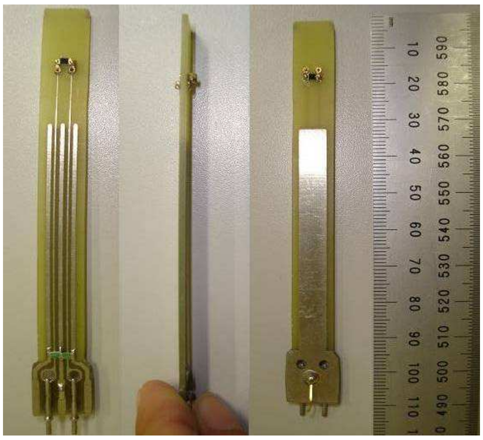

Fig. 4 Configuration with two phototransistors, one soldered back to other, mounted on a printed circuit board as a single radiation detector for CT dose profile measurements

Fig. 5 Detector configuration with four phototransistors, mounted with right angles between each phototransistor

CTDI$_{100}$ was estimated using a pencil chamber of the Accu-Pro RADCAL system with the same operating parameters as the phototransistor. However, instead of moving the detector, the ion chamber was exposed to a single scan of 10 mm of thickness in its center.

The angular response was analyzed free in air, around the longitudinal axis of the detector for different angles. Each detector configuration was placed along the rotation axis of the scanner. The angle 0° was defined as the origin and corresponds to the direction in which the longitudinal axis of the detector is parallel to the patient couch. The detector was rotated by 45° increments for a maximum rotation of 360°. The selected nominal thickness was 10 mm, in order to guarantee that the beam would cover all devices. For each angle, a set of 10 measurements were made, and the average and the standard deviation were calculated.

III. RESULTS

As can be seen in Fig. 6, it is possible to obtain details of the dose profile using the dosimetry system with phototransistor. In fact, there is still dose contribution in the dose profile tail, which extends for $x < -50$ mm and for $x > +50$ mm. Thus, the integral in this region is not zero. To enable comparison, the curves obtained from the three detector configurations were integrated along two ranges: 100 and 155 mm. The vertical bars in Fig. 6 at $x = -50$ and $x = +50$ mm delimit the range of collected charge by the phototransistor which corresponds to the dose integration region of the pencil chamber (100 mm). The results demonstrate that, for nominal beam width of 10 mm, CTDI values are underestimated by about 7 % in the central hole of the head phantom when using a 100 mm scan length compared with a 155 mm scan length. $CTDI_{100}$ value obtained using the pencil chamber was 29.2 mGy for the specified irradiation parameters (0.75 s, 120 kV, 200 mA, and 10 mm). This problem is more pronounced for multi-slice scanners, which provide wider radiation beam widths, because the scatter tails in CT dose profile become significant at larger distances. Hence, a 100 mm long pencil chamber is inadequate to cover the range of these scatter tails, in agreement with Dixon (2003) and Nachonechny et al. (2005), which further state that the current methodology should be modified. Furthermore, because 100 mm long ion chamber is already very fragile, a longer ion chamber would be even more difficult to handle. On the other side, smaller detectors allow the inclusion of the longer scatter tails and, consequentely, the integration of the CT dose profile for any scan length, through multiple rotations of the source.

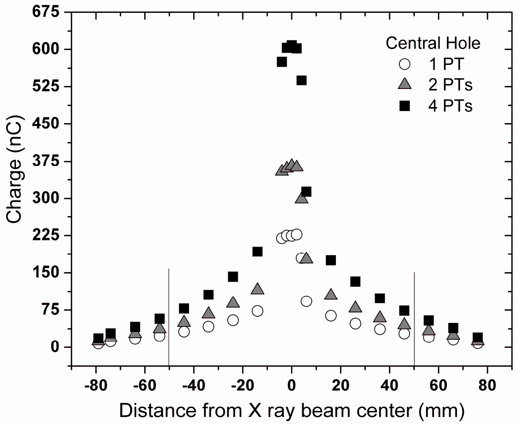

Fig. 6 Dose profiles along the central hole of the head phantom for the three phototransistor (PT) detector configurations. CT parameters: 120 kV, 200 mA, 0.75s, 155 mm scan length and 10 mm slice thickness

Following the current trend of replacement of pencil chambers for smaller detectors, the dosimetry system using OP520 phototransistor described in the present study could be an alternative, since it is cheap, small, does not require an amplifier, and provides real time measurements.

Fig. 7 shows the angular response for the three detector configurations used in this work. The directional dependence was nearly uniform, without significant variations in radiation sensitivity for all detector configurations tested.

Although the configuration with one phototransistor (detector 1) had the lowest output signal, this configuration displayed the flattest sensitivity, probably because the X ray tube performs a 360° revolution around the gantry center and uniformly irradiates the detector. The configuration with two phototransistors (detector 2) displayed some angular dependence, and as expected, the output signal was nearly twice that of the one device detector configuration. The four devices detector configuration (detector 3) yielded the highest output signal and directional sensitivity, probably because of contributions from the scattered radiation.

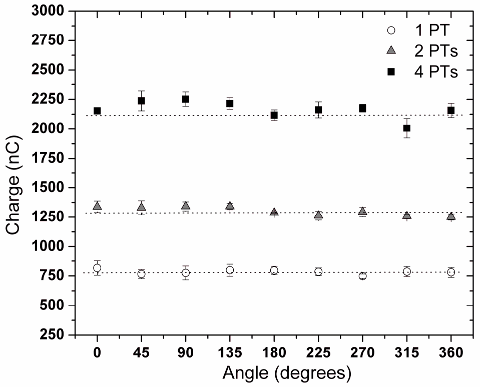

Fig. 7 Directional sensitivity of the three detector configurations analyzed for use in CT dosimetry

However, even though the other detector configurations yielded higher output signals, the one device configuration appears to be the most suitable for applications in CT dosimetry, since high accuracy measurements are required and the output electrical current of this configuration falls within the range of linearity observed in Fig. 2.

IV. CONCLUSION

The results of the present work demonstrate that the novel dosimetry system with OP520 phototransistor could be an alternative for CT dosimetry. Using this system, it is possible to obtain the CT dose profile in details and one can also estimate the CTDI in longer length than the 100 mm pencil chamber.

Angular response measurements show that the detector configuration with four phototransistors yielded the highest output signal. However, the configuration with only one phototransistor device, which yielded the lowest output signal, displayed no significant angular sensitivity. Furthermore, because high accuracy measurements are required in CT dosimetry, the one device detector configuration is the most situable for CT dosimetry applications of the three configurations analyzed in this study.

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