1. Introduction

The characterisation of radiation fields in radiology is crucial for a nation’s critical infrastructure and the improvement of dosimetry monitoring of medical staff. Energy-resolving hybrid pixel detectors have unique properties for the characterisation of radiation fields and provide a significant new technology for radiation protection. In this work we study the response of two hybrid pixel detectors, Timepix [1] and Dosepix [2], to beam qualities recommended by the International Electrotechnical Commission (IEC) for medical applications. Specifically, we use the reference beam qualities RQ85, RQ79, and RQ99[3]. This work is the first phase of a project that aims to measure the scattered radiation in a medical CT scan room.

2. Measurement instrument: hybrid pixel detector

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In 1965, inventor Gordon Moore stated that the number of transistors on an integrated circuit doubles every two years. In fact, the number of transistors on the circuits of a chip has increased much faster than Moore predicted, increasing by a factor of 10,000 every two years, to around 3 billion transistors on a chip today.

Hardware evolution and advances in chip design have given us chips that perform new functions, such as performing complex calculations and controlling our cars. These chips are used in computers, mobile devices, and other electronic devices.

3. Measurement technique: time-over-threshold (ToT)

When an ionising particle or photon impinges on the sensor, the absorbed energy creates electronic- hole pairs through the photoelectric effect. The generated charge induces a signal in the associated pixel frontend electronics. This signal is amplified into a voltage pulse whose height and width are proportional to the energy absorbed by the sensor.

The circuits compare the voltage pulse to an analogue threshold voltage which is set above background noise and low energy signals. An event is considered to have occurred if the pulse width corresponds to the time-over-threshold (ToT). The pulse duration provides a digital measurement of photon energy.

4. Timepix and Dosepix

Timepix and Dosepix are energy-resolving hybrid pixel detectors that use time-over-threshold (ToT) to measure X-ray energy. Both systems are portable, using a USB connection to a laptop for power and control. Both systems need 2000 frames to construct an absorbed X-ray spectrum offline.

5. Measurement setup

We placed the Timepix and Dosepix detectors side by side, perpendicular to a Toshiba KXO-80G X-ray generator with a tungsten anode. We measured the spectra of five consecutive 1-second X-ray pulses, using the tube voltage: 69 kV (RQ85), 92 kV (RQ97) and 124 kV (RQ99), and also varying the tube current to study the influence of flux on the measurements.

6. Measurement results

Figure 6 shows the raw spectra measured by Dosepix placed directly in front of the primary beam without any additional filtering or collimation. The shapes of the left parts of the spectra nicely represent the spectra absorbed in silicon (see simulation results below). However, at high fluxes, “pileup” occurs when multiple photons impinge on the same sensor segment during the time to process a photon (of the order of a few μs). This overlap results in a single combined ToT count. While the ToT value remains proportional to the total energy of the beam, the ToT spectrum becomes contaminated with multiple photons that do not provide individual ToT measurements.

Regardless of the pileup issues, the measured spectra demonstrate the potential to use Dosepix and Timepix to provide new information for radiation measurements. We can, for example, see the effects of characteristic X-rays from the 124 kVp spectra of Dosepix (Figure 6, bottom left). Moreover, if we only consider the spectrum above a threshold, e.g. 50 counts, the intersection of the spectrum with the count threshold provides an indication of the X-ray tube settings (Figure 6, bottom right). Although Dosepix is better suited for the measurement of spectra, when operated in photon counting mode, Timepix can be used to measure beam intensity (Figure 7).

7. Simulation results

To independently validate our measurement results, we simulated the interaction of the X-ray beam with the materials of the various detector components: 300 μm Si sensor, Cu bump bonds and materials of a printed circuit board. We used Geant4 [5] to simulate the radiation interactions and an additional simulation framework to model charge transport by drift and diffusion. Figure 8 shows the simulated X-ray interaction spectra. Overlaid with the spectra measured by Dosepix, Note that the simulations study purely the absorbed energy spectra and do not include models of the ADC circuits. We compare the energy spectra below the maximum beam energy, the measured spectra are in very close agreement with the simulated absorbed energy spectra.

8. Conclusions and future outlook

In this work, we have demonstrated the feasibility of using the energy-resolving hybrid pixel detectors, Dosepix and Timepix, to measure X-ray information. Characterisation of the energy response of these two detectors, and development of detailed simulation models of X-ray interactions with the detector materials, are vital steps in the process to accurately reconstruct spectra impinging onto the detectors and assess the radiation field. The ability to measure X-ray spectra with Dosepix and Timepix with Timepix gives us a potential new tool for the quality assurance of X-ray medical imaging systems. The measurement of the spectra of scattered radiation gives us a new tool for the radiation protection of patients and medical staff.

Our next steps are to resolve the effects of pileup in our measured spectra, and to measure the radiation scattered by patients undergoing medical imaging. To demonstrate these next steps, Figure 10 shows X-rays scattered by a water phantom. For these measurements, pileup may no longer pose a problem as the scattered flux is much lower than the flux of the primary beam.

Acknowledgements and works cited

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References

[4] 70% of the dose is absorbed in the water phantom.

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