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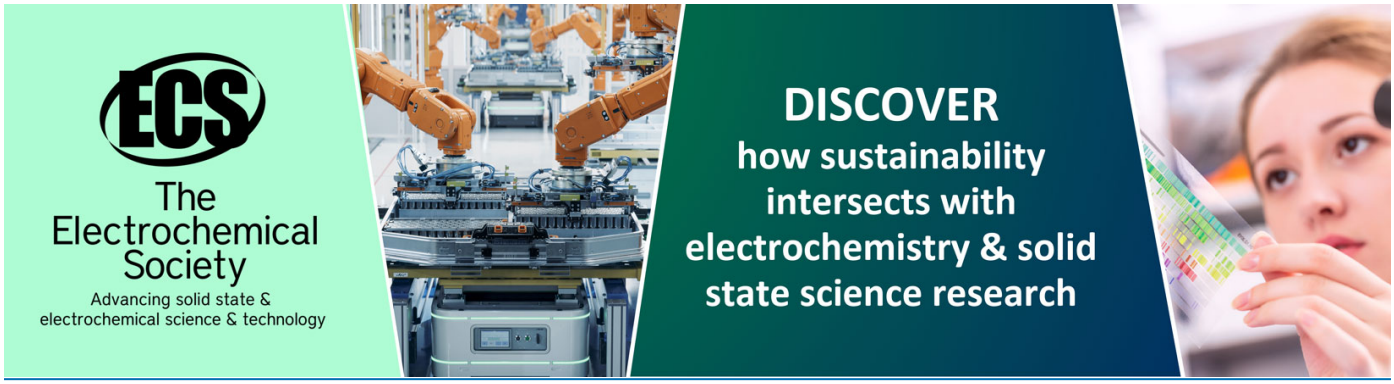

A FPGA-based software for microdosimetric data processing

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Abstract. The tissue equivalent proportional counter (TEPC) is the most accurate device for measuring microdosimetric properties of particle beams. Since microdosimetric quantities span over several decades, the electronic and acquisition chain should meet specific requirements. In order to cover the wide dynamic range of the signals generated by the TEPC, the output signal from the preamplifier is fed in parallel to three linear amplifiers which shape and amplify the signal with different gains. Very low-energy deposition events are filtered in the high-gain stage, and high-energy deposition events are processed in the low-gain stage. A new system with high acquisition performance and compact hardware was developed for this purpose. The analog-to-digital conversion is performed by a commercial acquisition system that includes a FPGA. Thanks to the FPGA a parallel high-speed acquisition on three channels can be performed. The software merges signals together from the three electronic chains and computes a real time microdosimetric spectrum giving a prompt information about the irradiation field. This acquisition system, which performs analog-to-digital conversion and signal processing at a sampling rate up to 15 MS/s, was tested by irradiating a TEPC with an Am-Be fast neutron field, an intense quasi-monoenergetic neutron beam and a 62 MeV/u helium ion beam.

1. Introduction

In the last decades, radiation therapy with ion beams has been spreading worldwide for treating cancer. With respect to conventional photon radiation therapy, better dose conformation to the target and increased sparing of the healthy tissue surrounding the tumour can be achieved with ion beams, due to the different physics of interaction of charged particles into matter. Moreover, higher LET (linear energy transfer) radiation, like carbon ions, exhibits a larger number of double strand breaks in the DNA and a higher RBE in the Bragg peak than photons and protons and is, thus, a good candidate for the treatment of radio-resistant tumours [1]. Since ionization generated in ion therapy is markedly localized and non-uniform against depth, significant variations on the radiation quality and consequently differences in the biological effectiveness across the Bragg curve are present [2]. Nevertheless, the present radiation-treatment planning procedures are based on the measurement of the absorbed dose, which is a macroscopic and average quantity that does not take into account neither the stochastics of particle interactions in the target volume nor the track structure of ionizing charged particles, which is crucial for the initiation of the radiation damage [3]. The standard dosimetric approach can be integrated with methodologies and instruments provided by microdosimetry, which aims at measuring the statistical fluctuations of the local energy imparted at the micrometric level [4].

The tissue equivalent proportional counter (TEPC) is the most accurate device for measuring the microdosimetric properties of a particle beam. Since microdosimetric quantities (i.e. specific energy and lineal energy) may span over several decades, the electronic and acquisition chains of such detectors should meet further requirements with respect to the conventional ones. In order to cover the wide dynamic range of the signals generated by the TEPC and to ensure a good resolution throughout this range, the output signal from the preamplifier is generally fed in parallel to three linear shaping amplifiers. The acquisition chain should be capable of processing and merging the signals coming from the three amplifiers. A new system with high acquisition performance, in terms of real time calculations, and compact hardware was developed for this purpose.

2. Materials and methods

Common TEPCs operate in pulse mode and record each single ionization event occurred in the sensitive volume. The interaction of an ionizing particle within the gas cavity is translated into a voltage signal distinguishable from the electron noise by exploiting a proper electronic acquisition chain. Since ionization events occurred in the sensitive volume of the proportional counter span over a very wide range, a low-noise charge-sensitive preamplifier with a dynamic range higher than 4 decades is required. Moreover, the preamplifier should be connected as close as possible to the anode wire in order to maximize the signal to noise ratio. Signals from the preamplifier are processed by a further amplification stage constituted by three linear amplifiers in parallel which shape and amplify with different gains (usually set to obtain a relative ratio of 1, 10 and 100) for covering the wide range of produced signals. In this way, very low-energy deposition events (mainly due to electrons) are filtered in the high-gain stage, whereas very high-energy deposition events (mainly due to recoil and low-energy ions), which necessarily saturate in the high-gain stage, are processed by the low-gain stage.

A typical TEPC acquisition chain is shown in Figure 1.

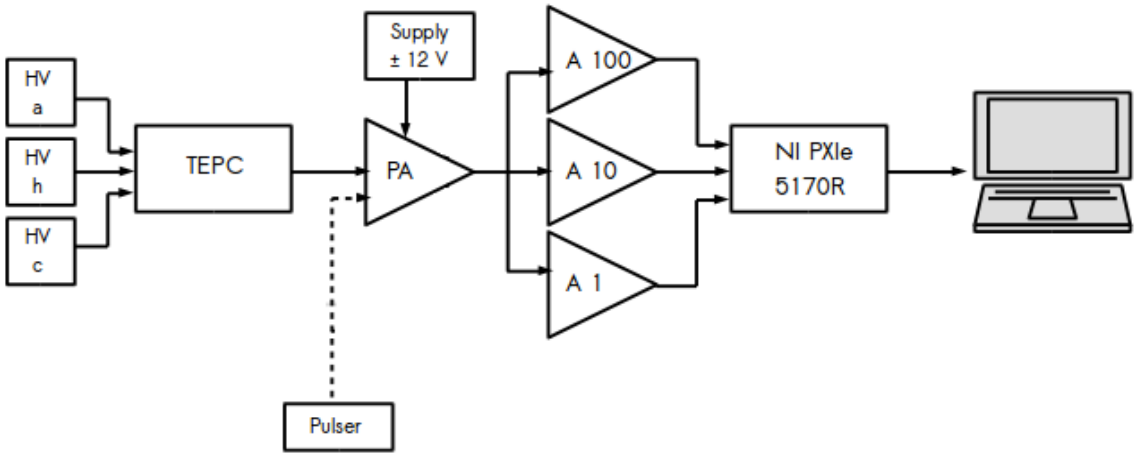

Figure 1. Block diagram of the TEPC whole electronic and acquisition chain.

The analog-to-digital conversion is performed by a commercial acquisition system produced by National Instruments, the 4 channels 14 Bit-Oscilloscope NI PXIe-5170R, which is a configurable digitizer including a user-programmable FPGA (Field Programmable Gate Array) module for the on-board signal processing. The FPGA module is an integrated circuit that contains a matrix of reconfigurable gate-array logic circuitry that is programmed via software. When an FPGA is configured, the internal circuitry is connected in a way that creates a hardware implementation of the software application. In this way, the FPGA is capable of performing high speed parallel computations

on the acquired data. The FPGA circuitry is programmed with the LabVIEW FPGA module, which belongs to the high-level LabVIEW graphical programming environment. The FPGA module also contain a built-in FIFO (First In First Out) transfer and memory read/write functions for storing data in the FPGA application. The FIFO transfer is the connecting bridge between the FPGA and the elaboration software, which gives the microdosimetric spectrum. The FIFO memory is the core of this implementation, which allows in the meanwhile a high-speed acquisition through the FPGA module and the computations needed for producing the microdosimetric spectrum. High speed is reached by decoupling the acquisition part (performed by the FPGA that stores the pulses into the memory) from the microdosimetric elaboration which is carried out by the host PC. The development of this software required several efforts in order to maintain high computation speed, since the complex calculations needed to provide the final microdosimetric spectrum affect unavoidably the final efficiency of the whole process.

3. Results

Thanks to the FPGA module a parallel high-speed acquisition on the three channels can be performed. Moreover, the implemented software can merge the three electronic chains and compute a real time microdosimetric spectrum. The developed software has a graphical interface where the user can set the acquisition parameters (e.g. sampling rate and acquisition thresholds) and visualize the microdosimetric spectrum.

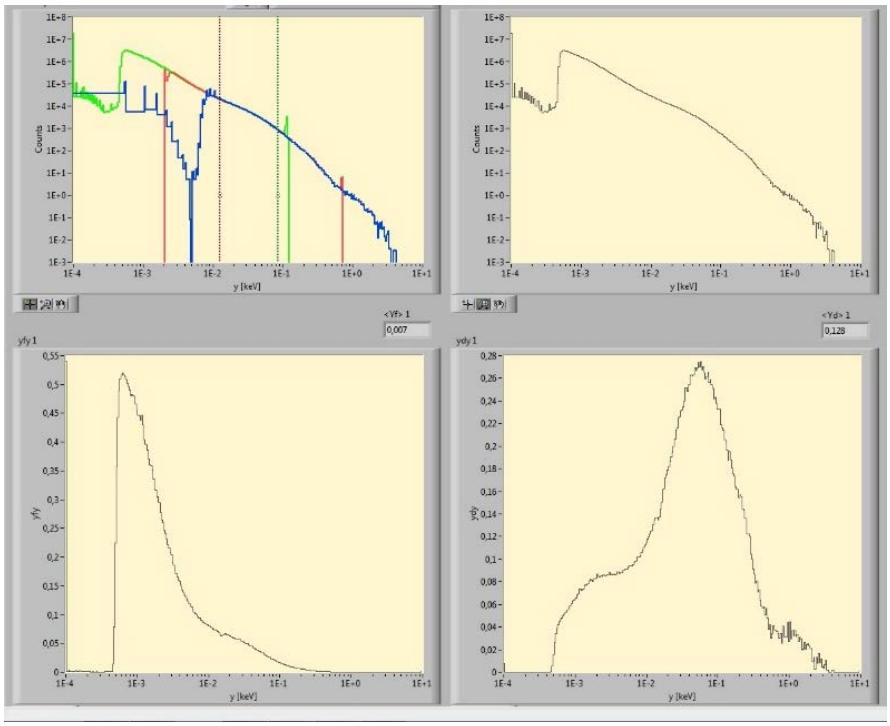

Figure 2. Software user interface in which the microdosimetric elaboration is shown. Top-left: spectra from each channel. Top-right: joint and rebinned spectrum. Bottom-left: frequency distribution yf(y). Bottom-right: dose distribution yd(y). Note that the neutron microdosimetric spectrum shown in this figure is not calibrated against lineal energy.

The FPGA software can perform analog-to-digital conversion and digital signal processing at a sampling rate up to 15 MS/s per each channel (the ADC speed is 45 MS/s). This sampling rate is enough for obtaining a good digitisation of pulses even when the shaping time of the amplifiers is set to 250 ns. This low value is mandatory for minimizing signal pile-up when the TEPC is irradiated with

intense fields (i.e. accelerator-based fields). During acquisition, the software can plot a real time microdosimetric spectrum and compute microdosimetric mean quantities (e.g. dose-averaged lineal energy) in order to obtain a prompt information about the irradiation field.

An example of real time computation on the acquired data is shown in Figure 2, where a portion of the user interface is reported. The spectra shown in the figure are obtained by irradiating the avalanche-confinement TEPC previously described [5-7] with an Am-Be neutron source at the Politecnico di Milano fast-neutron irradiation facility. The figure shows the different steps of the elaboration starting from the merging of the outputs of the three electronic chains (top-left) to the final microdosimetric spectrum (bottom-right). Further irradiations with quasi-monoenergetic neutron beams and 62 MeV/u helium ion beam were performed with this system. In particular, measurements against the helium beam showed that a real time information about the microdosimetric distribution is really useful and suitable for a first evaluation of the radiation quality of a therapeutic hadron beam.

4. Conclusions

The new FPGA-based hardware and software allow to reach a significant high acquisition speed required when measuring with intense radiation fields, since very short shaping times are mandatory in order to avoid pulse pile-up. The new acquisition software was tested by irradiating a TEPC with an Am-Be fast neutron field, an intense quasi-monoenergetic neutron beam and a 62 MeV/u helium ion beam and showed the capability of producing real time information (microdosimetric spectrum and mean quantities) about the irradiation field. Further optimization on the FPGA architecture is foreseen in order to achieve an improvement on the computation performances and to allow the implementation of other kind of microdosimeters (e.g. silicon based) in the elaboration software.

5. Acknowledgments

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6. References

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