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Data Acquisition System for the ^{3}He Position-Sensitive Proportional Counter Based Neutron Dosimeter

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Abstract

We present a data acquisition (DAQ) system for a three slender ^{3}He Position-Sensitive Proportional Counters (PSPC) based neutron dosimeter. The DAQ system measures the charge of the neutron-induced events, calculates the position of the events, and provides the power supply for the dosimeter. The DAQ system provides a significant support for the proof of principle.

Keywords: data acquisition, neutron dosimeter, position-sensitive counter

1. Introduction

In radiation protection, we can use the neutron energy spectrum of the neutron radiation field to calculate the neutron ambient dose equivalent. However, the neutron spectrometer is difficult to be widely used due to the complex equipment and the cumbersome measurement process, such as the Bonner Sphere Spectrometer (BSS) [1] proposed by Bramblett which consists of a series of moderator spheres with different diameters.

A neutron dosimeter is an apparatus to measure the neutron dose. It includes a detector and a data acquisition (DAQ) system. The detectors in most of the commercial neutron dosimeters have one moderator and one thermal neutron sensor, and these dosimeters cannot get a good energy response for the radiation protection use.

Toyokawa designs a neutron dosimeter [2, 3] with one spherical polyethylene moderator and three slender ^{3}He Position-Sensitive Proportional Counters (PSPC) to balance the energy response and the complexity. The dosimeter acquires all the data in one measurement. The neutron dose and ambient dose equivalent can be conveniently obtained [4]. The sphere is divided uniformly in Toyokawa's calculation.

Li proposes a novel non-uniform division method, in which the moderator sphere is divided non-uniformly into five spherical shells, to calculate the ambient dose equivalent [5]. The data from the non-uniform division method is more approximate to the BSS's data than the uniform division method.

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We design a DAQ system to support the research on the non-uniform division method. The main functions of the design are a) to measure the charge of the neutron-induced events occured during the reaction between thermal neutron and ^{3}He in the PSPCs; b) to calculate the position of the neutron-induced events; and c) to provide the power supply for the dosimeter.

In this paper, we present the design and testing of the DAQ system.

2. The principle of the neutron dosimeter

The detector in Toyokawa's neutron dosimeter consists of one spherical polyethylene moderator and three slender ^{3}He PSPCs. The PSPCs are orthogonal to each other in the moderator. In the non-uniform division method, the moderator sphere is non-uniformly divided along the radical direction into five spherical shells [5, 6, 7]. The amount of the neutron-induced events in each shell is counted.

The neutron-induced event is a reaction that a neutron reacts with the ^{3}He gas in the PSPC (^{3}He (n, p) ^{3}H). The proton and tritium ionize the working gas in the PSPC and the ions drift to the ends. The charge collected in both ends of the PSPC is proportional to the distances from the event to both ends [8, 9]. The charge is collected and integrated into voltage in the Charge Sensitive Amplifier (CSA).

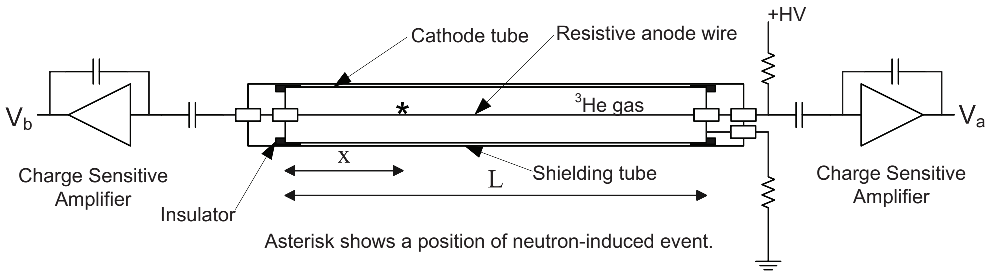

Fig. 1: Schematic of a ^{3}He PSPC

Fig. 1 shows the schematic of a ^{3}He PSPC. "*" is the position of the neutron-induced event. x is the distance from the event's position to the left end. L is the total effective length of the PSPC. V_a and V_b are the peak voltages of the output pulse produced by the CSA. The position is calculated using Eq. (1) [10]

$$\frac{x}{L} = \frac{V_a}{V_a + V_b}. \tag{1}$$

We use commercial PSPC with embedded CSA. The signal produced by the CSA is 4~6 μs in full width at half maximum (FWHM), 4 V maximum in amplitude, and 10 k/s maximum in event rate. The signals always show up in pairs at the both ends of the same PSPC.

In the DAQ system, we capture all the signals from the CSAs, pair the signals which are from the same event, and find the peak value of each signal. With the paired peak values of signals and Eq. (1), we calculate the position and count the amount of events in each shell.

3. The DAQ overview

The block diagram of the neutron dosimeter is shown in Fig. 2. The dosimeter includes a detector module and a data acquisition module. The detector module consists of one spherical polyethylene moderator, three slender ^{3}He PSPCs which are orthogonal to each other in the moderator, and six CSAs at both ends of each PSPC. The data acquisition module consists of a data acquisition board, a host computer with control and calculation software, and a power management module. The detector module gives the signal outputs to the data acquisition module, and the data acquisition module offers the high voltage and power supplies for the detector module.

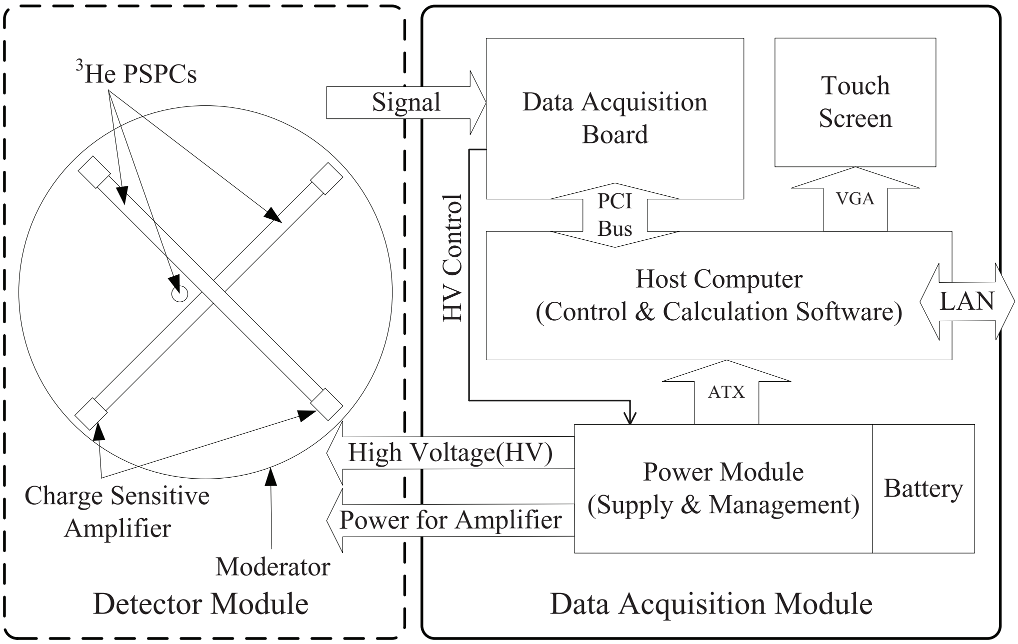

Fig. 2: Block diagram of the neutron dosimeter

3.1. The data acquisition board

The data acquisition board transfers the analog signals into digital signals with the shapers, main amplifiers, and Analog to Digital Converters (ADCs). It also pairs the digital signals with the Digital Pulse Processing (DPP) techniques in a Field Programmable Gate Array (FPGA), and finds the peak value of the events. The block diagram of the data acquisition board is shown in Fig. 3.

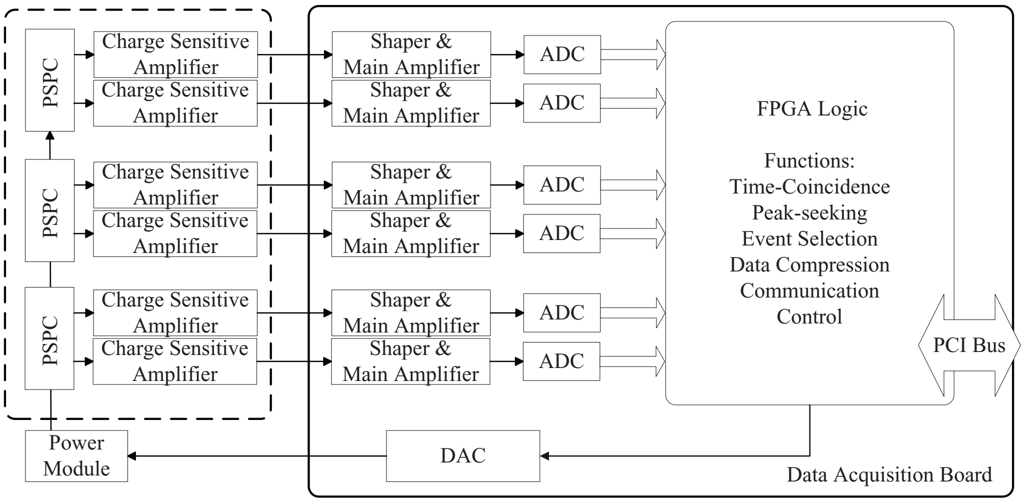

Fig. 3: Block diagram of the data acquisition board

When a neutron-induced event occurs, the CSA gives a pair of voltage signals which is 4~6 μs in FWHM and 4 V maximum in amplitude. The signals pass the shapers and main amplifiers and become signals which is 10~16 μs in FWHW and 1 V maximum in amplitude for the ADC. We use 8-bit, 100M samples per second

ADCs to digitalize the signals with a good resolution. After the data conversion, the digital signals pass into the FPGA for the digital pulse processing and data transmission.

We have digital time-coincidence and peak searching logics implemented in the FPGA. Any one of the six signals which goes over the pre-set threshold triggers the digital time-coincidence logic. The digital time-coincidence logic finds out the paired signals of each PSPC in a following time window after the trigger. The peak searching logic offers the peak values of each paired signal.

3.2. Power Management

We use a commercial Uninterruptible Power Supply (UPS) module as the core of the power management module. The block diagram of the power supply system is shown in Fig. 4.

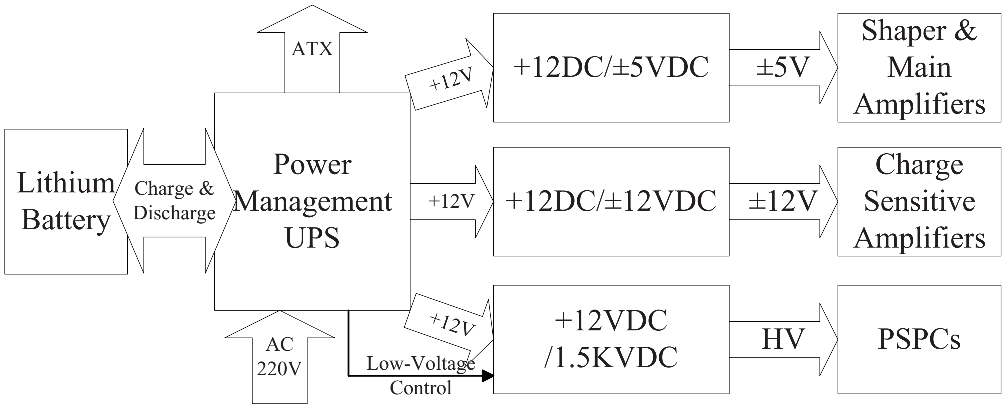

Fig. 4: Block diagram of the power supply module

The UPS module charges and discharges the lithium battery and switches between the external AC and internal DC power supplies. It offers standard ATX power supplies for the host computer and an additional +12 V power supply for the DC/DC modules. The DC/DC modules generate ±12 V for the CSAs, ±5 V for the shapers and main amplifiers on the acquisition board, and 1.5 KV adjustable high voltage for the ^{3}He PSPCs.

The power consumption is an important indicator of the portable equipment. It decides the battery life, how long the system can go without an external power supply. The total power consumption of the DAQ system is less than 40 Watts. With a fully charged 19 V, 11 Ah lithium battery, the system can work for five hours without an external power supply.

3.3. Software

We develop the software in the NI LabWindows/CVI platform which provides a friendly user interface. The software sets the parameters in both software and hardware, reads out the data from the data acquisition board via the PCI bus, and calculates the event position according to the Eq. (1). In the software, we can use uniform division or non-uniform division with different parameters. We can compare different division methods with the same position data.

The flow chart of the software is shown in Fig. 5(a), and the graphical user interface in Fig. 5(b). We provide a dynamic link library (DLL) to operate the data acquisition board, with which the users can design their own software to meet special acquisition and calculation requirements.

4. Tests

We did the electronics test and the neutron source test with our DAQ system.

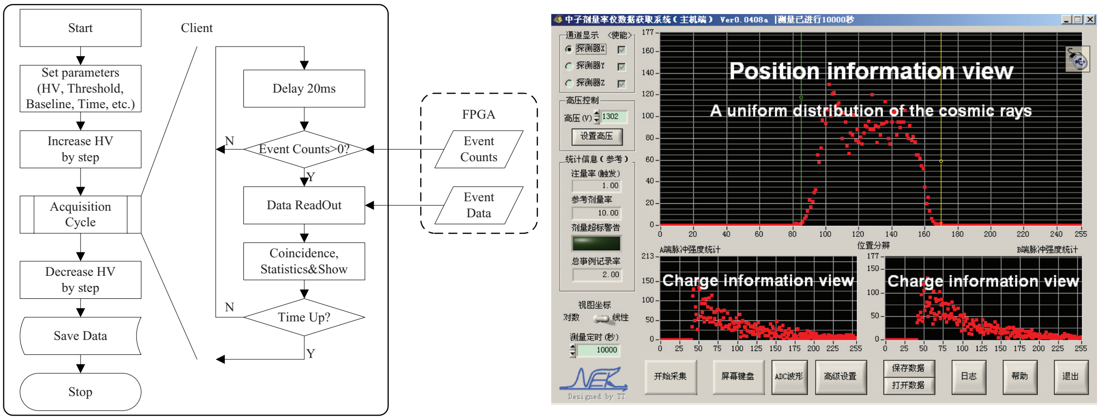

Fig. 5: (a) Software flow chart; (b) Graphical user interface

We used an Agilent 33250A signal generator and the DAQ system to perform a counting rate test. The maximum counting rate of the DAQ from the test is 49.9 kHz. The counting rate is high enough to capture all signals from the detector which has a 10 k/s maximum event rate.

We used the dosimeter to acquire cosmic rays to test the performance. Fig. 5(b) shows a distribution of the cosmic rays. Because the cosmic rays reach the detector randomly, the position of the cosmic rays-induced events should be a uniform distribution on the PSPC. In Fig. 5(b), the flat stage is the effective position range. The cosmic rays-induced events have the uniform distribution that we expected.

We took a neutron source test in Oct. 2010 in Beijing. With the response functions [7] and the position distribution from our DAQ system which is shown in Table 1, we calculated the ambient dose equivalent rate. The results are shown in Table 2 and compared with the reference values.

Table 1: Counting rate in moderator shells

Neutron source	Rate (s^{-1})	Non-uniform division shells[a] 1	2	3	4	5
^{241}Am-Be[b]	Total	596.6	634.1	512.3	288.7	112.4
	Background	157.3	177.5	178.1	117	75.3
	Net	439.3	456.6	334.2	171.7	37.1
^{252}Cf[b]	Total	195.3	214.5	179	127.9	53
	Background	48.1	60.4	67.2	70.5	40.7
	Net	147.2	154.1	111.8	57.4	12.3
Correction Factor[c]		1.00	1.01	1.05	1.08	1.61
^{241}Am-Be	Net	439.3	461.2	350.7	185.5	59.7
^{252}Cf	Net	147.2	155.7	117.4	62	19.8

[a] Shell 1 is in central. The thicknesses of shells are 3.5cm, 3cm, 2.5cm, 2cm, 1.5cm from 1 to 5.
[b] Total measure time: ^{241}Am-Be 100 seconds, ^{252}Cf 200 seconds.
[c] Due to the end effect of the PSPC.

The deviation of the measurement of the ambient dose equivalent rate varied by 24% [6], and the relative deviation in our results was within that range. Our results were reasonable and acceptable. A further analysis indicated that the high voltage of the PSPCs was not set to an optimal value and reduced the efficiency of the PSPCs. We will make a further test to optimize the high voltage.

Table 2: Neutron source test results and comparison with reference values

Neutron source		Flux ($cm^{-2}s^{-1}$)	Ambient dose equivalent rate ($\mu Sv/h$)
^{241}Am-Be	Reference	124	171
	Test Result	97.2	138.7
	Relative Deviation (%)*	-21.61	-18.89
^{252}Cf	Reference	39	54
	Test Result	29.0	41.3
	Relative Deviation (%)	-25.64	-23.52

* Relative Deviation (%)=(Test Result - Reference)/Reference*100%.

5. Conclusion

We design an easy to use data acquisition system for a three slender ^{3}He PSPCs based neutron dosimeter. The DAQ system measures the charge of the neutron-induced events, calculates the position of the events, and provides the power supply for the dosimeter. The DAQ system provides a significant support for the proof of principle.

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References

[1] Bramblett RL, Ewing RI, Bonner TW. A New Type of Neutron Spectrometer. *Nuclear Instruments and Methods*; 1960, 9(1):1-12
[2] Toyokawa H, Uritani A, Mori C, Yoshizawab M, Takeda N, Kudo K. Neutron Spectrometer with Position-sensitive Proportional Counters. *Nuclear Instruments and Methods in Physics Research A*; 1996, 381:481-7
[3] Toyokawa H, Uritani A, Mori C, Takeda N, Kudo K. A Multipurpose Spherical Neutron Counter. *IEEE Trans Nucl Sci*; 1995, NS42(4):644-8
[4] Li Taosheng, Yang Lianzhen, Chen Jun, Ma Jizeng, Hou Xueli. The Unfolding Method Analysis of a Sphere with the Multi-counters. *Nuclear Electronics & Detection Technology (Chinese)*; 2004, 24(5): 453-6
[5] Li Taosheng, Zhao Xiuliang, Fang Dong. Reasonable Study of Neutron Energy Responses for a Sphere and Three Position-sensitive Counters. *Nuclear Electronics & Detection Technology (Chinese)*; 2006, 26(5):553-6
[6] Li Taosheng, Yang Lianzhen, Ma Jizeng. Performance Test of a New Neutron Measuring Apparatus for Ambient Dose Equivalent (Rate). *Radiation Protection (Chinese)*; 2005, 25(5):283-0
[7] Li Taosheng, Yang Lianzhen, Li Dongyu. The Calculated Neutron Response of a Sphere with the Multi-counters. *Nuclear Electronics & Detection Technology (Chinese)*; 2004, 24(2):132-5
[8] Radeka V. Signal Noise and Resolution in Position-Densitive Detectors. *IEEE Trans Nucl Sci*; 1974, NS21(1):51-64
[9] Radeka V, Rehak P. Second Coordinate Readout in Drift Chambers by Charge Division. *IEEE Trans Nucl Sci*; 1978, NS25(1):46-2
[10] Uritani A, Mori C, Watanabe T, Miyahara A. Development of Position Helium-3 Proportional Counter for Thermal Neutrons with Novel Signal Readout. *Journal of Nucl Sci Tech*; 1990, 27(8):712-7