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A multiplex readout method for position sensitive boron coated straw neutron detector

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ABSTRACT

A 1 m × 1 m boron coated straw neutron detector is expected to be used to build the small-angle neutron scattering (SANS) instrument of the Compact Pulsed Hadron Source (CPHS) in Tsinghua University. A multiplex readout method based on summing circuits in columns and rows is studied for this large area position sensitive detector. In this method, the outputs of charge sensitive preamplifiers are combined by columns and rows at two ends of the detector, and then the shaped signals are sampled by flash ADCs. With the position reconstructed algorithm implemented in FPGA which analyzes the charge division and column and row number of signals, the 3-D position information of neutron events can be obtained. The position resolution and counting rate performance of this method are analyzed, and the comparison to the delay-line readout method is also given. With the multiplex readout method, the scale of readout electronics can be greatly reduced and a good position resolution can be reached. A readout electronics system for a detector module which consists 4 × 10 straw tubes is designed based on this method, and the test with neutron beam shows an average 3-D spatial resolution of $4 \times 4 \times 6.8\ \text{mm}^3$.

1. Introduction

Due to the shortage of ^{3}He gas [1], the alternative neutron detectors are being studied widely all over the world recently [2]. The boron coated straw (BCS) neutron detector has acceptable detection efficiency and good position resolution [3] and can be used to build the small-angle neutron scattering (SANS) instrument. A 1 m × 1 m BCS neutron detector is expected to be used for the SANS instrument of the Compact Pulsed Hadron Source (CPHS) in Tsinghua University [4] and the method to read out the thousands of position sensitive straw tubes in the detector should be studied. In this paper, a multiplex readout method based on summing circuits in columns and rows (named a SCR multiplex readout method) is introduced and the theoretical performance is analyzed. Based on this method, readout electronics for a BCS detector module are designed for evaluation, and the test result with neutron beam in CPHS is shown.

2. Boron coated straw neutron detector

The 1 m × 1 m BCS neutron detector used for CPHS is composed of straw tubes which are proportional counters with a length of 1 m and a diameter of 4 mm. The straw tube is coated by $^{10}B_4C$ on the inner wall, and neutrons can be captured by the $^{10}B_4C$ layer with a reaction $n + {}^{10}B \rightarrow {}^{7}Li + \alpha$. With large thickness of ^{10}B-enriched $^{10}B_4C$ layer, a single boron coated straw tube could have a maximum thermal neutron efficiency of about 10% [5].

To increase the neutron efficiency of the BCS detector, multiple layers of straw tubes are required, typically 8 layers of the straw tubes could get a thermal neutron efficiency of about 40% [6]. The efficiency of the BCS detector with 8 layers of straw tubes is lower than the efficiency of ^{3}He tubes which can reach to 90% or more, but is acceptable for the SANS instrument of CPHS. The 1 m × 1 m BCS neutron detector is assembled by multiple detector modules and each detector module has independent readout electronics.

3. Existing readout method for BCS detector

The readout electronics based on charge division method for a position sensitive ^{3}He tube [7] could be used to read out a single boron coated straw tube, and there will be two channels of independent readout electronics on the both ends of the straw tube. For the 1 m × 1 m BCS detector with 8 layers of straw tubes, the total number of readout electronics channels will reach to about 4000 which is quite large, so the readout method to reduce the scale of readout electronics should be studied.

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There are many kinds of position sensitive detectors such as MWPC [8], GEM [9], GMSD [10] and scintillator detector [11] that have readout methods which can deal with a large number of pixels. Most of the position sensitive detectors are 2-D position sensitive, but the BCS detector is 3-D position sensitive, so the readout method for BCS detector has some differences. If a neutron is detected by the BCS detector, there will be only one straw tube in the layers of straw tubes that generates signal, and this feature is unique from detectors which detect charged particles and gamma rays.

Delay-line readout method shown in Fig. 1 is designed for BCS detectors by Proportional Technologies and a 3-D position resolution of $4 \times 4 \times 7$ mm^3 is achieved [13]. In this method, the row and column number of the straw tube which has a neutron event occurred in can be found by analyzing the relative time difference between signals on both ends. The longitudinal position of the neutron event can be measured by analyzing the difference of the signal amplitudes caused by the charge division between the two ends. We studied on this method [12] and found a problem that

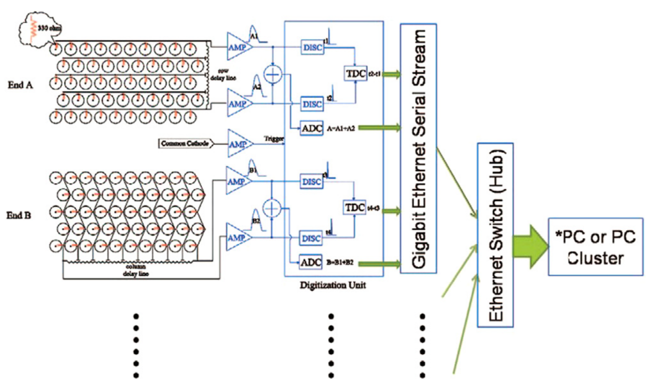

Fig. 1. Readout structure of delay-line readout method [13].

the longitudinal position resolution would become worse quickly with the increase of the straw tube number in the detector module (The reason will be shown in Section 4.3.), so an alternative multiplex readout method for the BCS detector is designed and described below.

4. SCR multiplex readout method for BCS detector

4.1. Readout structure

Taking a detector module which consists 4 rows and 4 columns of straw tubes for example, the structure of readout electronics is shown in Fig. 2. In the center of each tube, there is a resistive anode wire and both ends of the anode wire are connected to preamplifiers with high voltage blocking capacitors. High voltage is supplied to one end of the anode wire with a resistor. At one end of the detector module (end A), the outputs of preamplifiers in a column are combined to one column signal by an analog multi-inputs summing circuit. At the other end of the detector module (end B), the outputs of preamplifiers in a row are combined to one row signal. All column signals and row signals are shaped by CR-RC4 shapers and then sampled by the ADCs on the DAQ board. The neutron hit position can be found by processing the ADC generated data by the FPGA in which a position reconstructed algorithm is implemented.

The structure of data processing logic in FPGA is shown in Fig. 3. Each ADC channel has a threshold comparator and only if two signals at both ends rise above the threshold at the same time then an event will be triggered by the coincidence trigger generator. The event will be processed by the processing module and there are independent processing modules to process the events occurred in different rows and columns at the same time. In the processing module, the waveforms of the signals are analyzed to throw away the accumulated events and the amplitudes of the

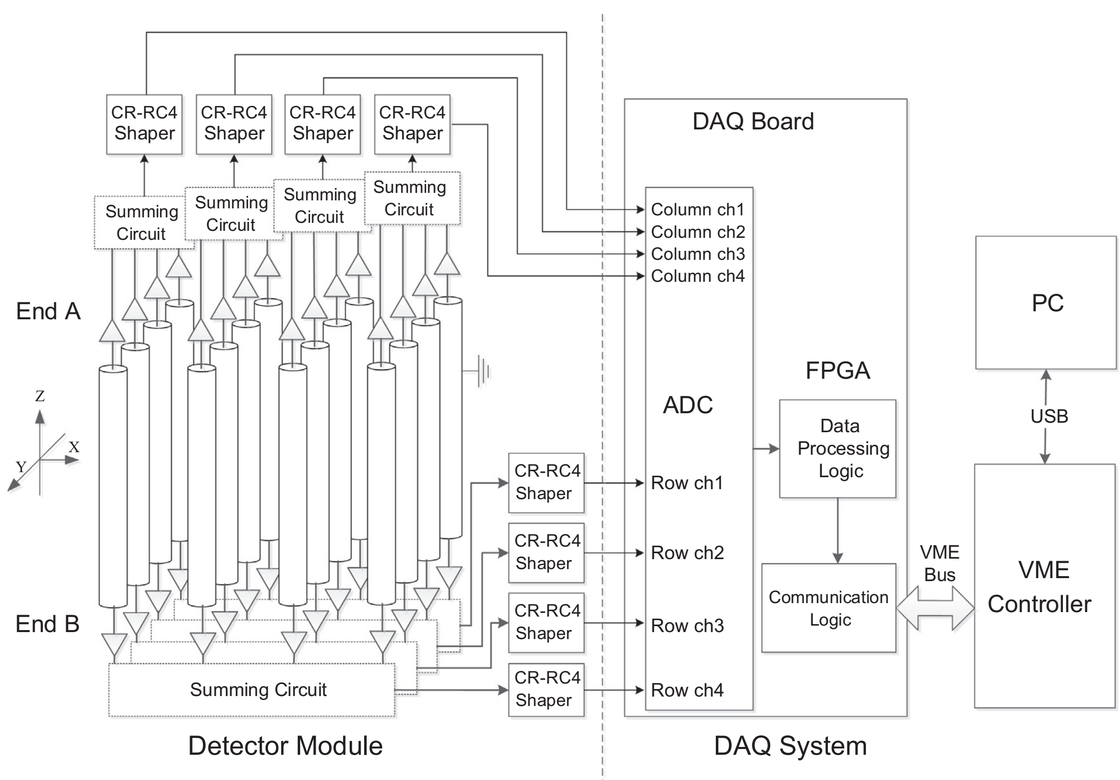

Fig. 2. Readout structure of the SCR multiplex readout method.