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Digital Readout Method for Position Sensitive Detectors

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Abstract: Efficient thermal neutron detectors with large area, two-dimensional position sensitive, high counting rate high detection efficiency and low gamma sensitivity are required to satisfy the demands for the China Spallation Neutron Source (CSNS). Compared with the traditional analog readout method, the digital readout method has the advantages of higher counting rate, smaller quantity of data transmission, simpler readout system and higher signal to noise ratio. The theoretical analysis of the digital readout method is reported in this paper. Used the raw data of GEM detector, the relationship between the position resolution and the width of the readout strip was studied. The results indicate that the digital readout method could be a good choice for the large area position sensitive detector where the requirement of position resolution is less than 4 mm, e.g. the detector of Small-Angle Neutron Scattering (SANS) diffractometer of CSNS.

Key word: digital readout method; position sensitive; GEM; neutron detector

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1 Introduction

The neutron scattering techniques have been playing a more and more important role in the medicine, biology, condensed state physics and chemistry researches, as a compensation of the X-ray. China Spallation Neutron Source (CSNS), which is under construction in Guangdong province, China, will be the first spallation neutron source in the developing countries. The Small-Angle Neutron Scattering (SANS) diffractometer, as one of the three spectrometers to be built in the first phase project, requires a thermal neutron detector in the wavelength range from 0.4 Å to about 8 Å. Such a detector should have an active area of 650 mm × 650 mm, a position resolution of 5~8 mm and a counting rate up to 5×10^4 Hz. The position sensitive neutron detector, originating from the Multi-Wire Proportional Chamber (MWPC) based on the ^{3}He convertor, have been widely used in many neutron spectrometers because of easy large area building, high detection efficiency, good n/γ discrimination and basically no radiation damage as compared to the solid state and scintillation detectors[1−3].

A MWPC neutron detector based on the ^{3}He converter with an active area of 650 mm × 650 mm is under construction for SANS in the Institute of High Energy Physics Chinese Academy of Sciences (IHEP). The neutron detection includes two processes, which are the neutron conversion as the reaction in ^{3}He+ n→^{1}H + ^{3}H + 764 keV and the ions detection. The position deviation caused by the neutron conversion is determined by the path lengths of the produced ions, which will be suppressed greatly by filling some kind of stopping gases, such as propane, butane and carbon and so on[4]. So, the position resolution of the neutron detector is mainly determined by the intrinsic resolution of the electrons detection. In the past decades, the analog readout methods such as center of gravity method,

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charge division method and delay line method were widely used for the position sensitive detectors[5−8]. The center of gravity method has the advantage of good position resolution but needs a great number of high accurate charge sensitive electronics. The charge division method and delay line method require relatively less electronics, but the position resolution decreases sharply with the area increasing[8]. The digital readout method just discriminated the threshold of each signal and gave the digital information of 0 or 1. Comparing to the analog method, the digital readout method has the advantages of smaller quantity of data transmission, high counting rate and no dependence of position resolution on the area of the detector. In order to increase the counting rate and reduce the cost of electronics, the digital readout method is considered for the detector of SANS with the lower position resolution requirement. To verify this method could meet the demands of the detector for the SANS or not, the position resolution with different widths of strips was studied and reported in the paper. By using the data of a Gas Electron Multiplier (GEM) detector[9], the event selection efficiency, quantity of data transmission and imaging accuracy with different widths of strips were studied. Finally the method was applied to a MWPC detector and some results were presented.

2 Principle of the method

When an incident particle enters the conversion area, it produces the ionized pairs. The electrons are driven by the electric field and drift into the avalanche area. A signal, approximately with a gauss distribution, is induced on the readout strips, whose center is high accordant with the avalanche position. The width (FWHM) of the induced charge distribution was dominated by the induction gap of millimeter-scale. The traditional analog method such as the center of gravity method can greatly improve the position resolution by decreasing the width of the readout strips. At the same time, a larger amount of accurate charge sensitive electronics channels will be needed and the cost will be increased. In a digital readout system, the electronics without the measurement of charge can be simplified to a large extent and each readout channel only has an amplifier and discriminator. A logic signal will be given when the strip signal exceeds the threshold. The position is considered to be the geometric center of the adjacent fired strips as shown in Eq (1).

$$X = \frac{1}{N}\sum x_i \quad , \tag{1}$$

where X is the location of the ionization, x_i is the geometric position of the strip, i is the number of the fired strip and N is the total number of the adjacent fired strips. N is inversely proportional to the setting threshold value of each channel and generally not more than three strips.

3 Analysis of results

The data of GEM detector includes the information of the accurate charge value per electronic channel and corresponding position. By setting the value of threshold in C++ code to simulate the digital readout method, the influence of the readout strip width on the position resolution was studied. Considering the single energy deposition in neutron detection, we selected the full energy peak of X-ray in the simulation. Fig.1 is the energy spectrum of ^{55}Fe X-ray in the GEM detector at atmospheric pressure and with gas mixture of Ar/CO_2 (70/30). Here, the events of Q_{sum} > 103 fC were chosen.

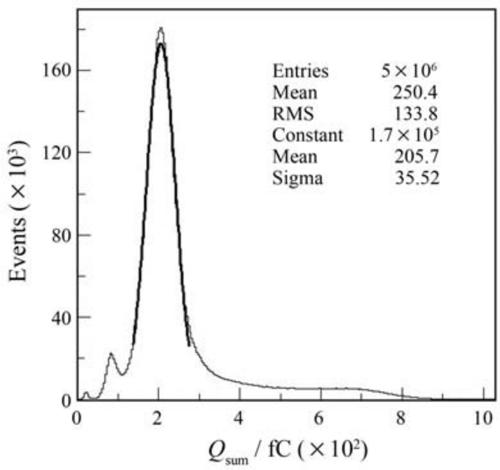

Fig. 1　Energy spectrum of ^{55}Fe X-ray in GEM detector.

3.1 Event selection efficiency

Limited to the processing technology of the PCB board under the available technologies, the readout strips cannot be too narrow. So, for some events there are only two strips fired, which will be got rid of by the center of gravity method, as shown in Fig.2. The event selection efficiency, which is defined as the ratio of the effective events to the total events, is about 89.5% by using the center of gravity method for the data.

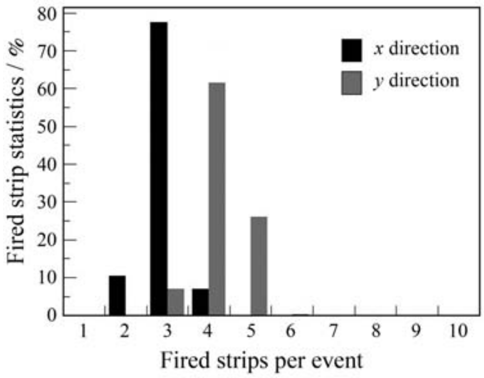

Fig. 2　The number of fired strips distribution in x and y direction.

For the digital method, the events with one fired strip or several adjacent fired strips are considered as the effective events. An appropriate threshold is very important for digital method. The fired strips in the center have high signal to noise ratio (SNR), while those at both ends have lower SNR. A high threshold will trigger only the central fired strip to get more accurate position at the cost of losing some events with small signals, while a low threshold will increase the number of fired strips and reduce the position accuracy because of the low SNR of strips at the ends. On the other hand, with low threshold selection, some events would be lost since some channels are fired by the noise in the result that all the fired strips won't be adjacent. In the simulation, the threshold for each strip was scanned from 16 fC to 50 fC in a step of 2 fC in x/y direction independently. The event selection efficiencies are shown in Fig.3. With appropriate threshold selected, 26 and 24 fC in x and y direction respectively, an efficiency of 95.8% is obtained.

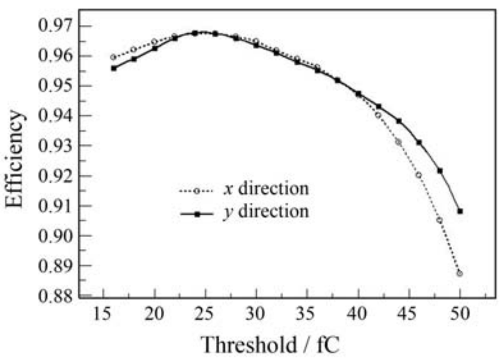

Fig. 3　Event selection efficiency as a function of threshold.

3.2　Quantity of data transmission

In the data for the center of gravity method, the trigger number, the position and charge value of each fired strip must be recorded in every event. So, a large amount of data needed, which require high data transmission rate of the DAQ system. For example, in the GEM detector, the data transmission rate is ~12 MByte/s under the counting rate of 5×10^4 Hz even though the zero-compression technique has been adopted[10]. The digital readout method, however, only needs one sign bit for each strip, i.e. N bits for N strips readout. So, it can greatly reduce the data quantity. The data transmission rate can be calculated by Eq.(3). For the GEM detector with 704 readout strips, it only needs a data transmission rate of 4.4 MByte/s, which is one third of that based on the center of gravity method. The result indicates that it could remarkably reduce the data amount with less readout strips by using the digital readout method.

$$Q(\text{Byte/s}) = \frac{N}{8}R\,, \tag{2}$$

where Q is the data transmission rate, N is the number of readout strips and R is the counting rate of the detector with unit of Hz.

3.3　Imaging accuracy with different strip widths

The widths of the readout strips in x and y direction are 751.8 and 457.2 μm respectively. In order to analyze

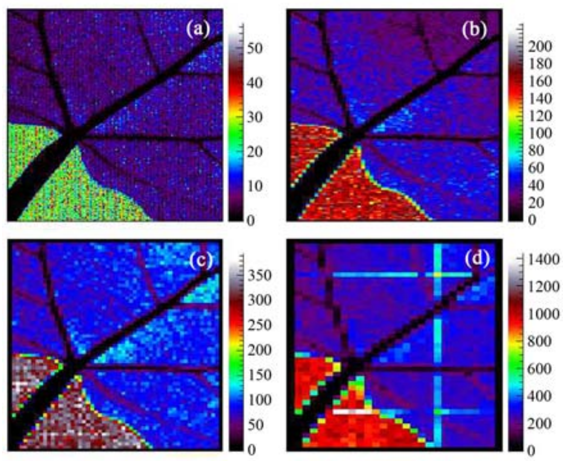

Fig. 4　The reconstructed pictures using different methods

(a) using the center of gravity method; Using the digital readout method with 751.8 μm width strips in x direction and 457.2 μm width strips in y direction (b), with 751.8 μm width strips in x direction and 914.4 μm width strips in y direction (c), and with 1 503.6 μm width strips in x direction and 1 371.6 μm width strips in y direction (d).

the influence of the readout strip width on the detector performance, the readout strips were combined together to form larger width. The imaging accuracy was calculated with the appropriate thresholds mentioned above. A part of a dehydrated leaf was put in front of the window of the GEM detector and exposed in the irradiation of the ^{55}Fe X-ray. The reconstructed image by the center of gravity method is shown in Fig.4 (a) and those by the digital readout method with different strips combinations are shown in Fig.4 (b)~(d). The results show that the increasing strip width results in the reconstructed picture becoming more and more indistinct. But in Fig.4 (b) and (c), the pictures are still clear enough to distinguish the leaf veins although the reconstructed picture is not as distinct as Fig.4 (a).

4 Application of the method to MWPC

A MWPC X-ray detector [11] with an absorber thickness of 10 mm, anode wire space of 2 mm and readout strips of 4 mm has been constructed and tested with ^{55}Fe X-ray collimated by a hole with a diameter of 1 mm and a depth of 10 mm, which is made of aluminum. The positions are reconstructed by the digital readout method.

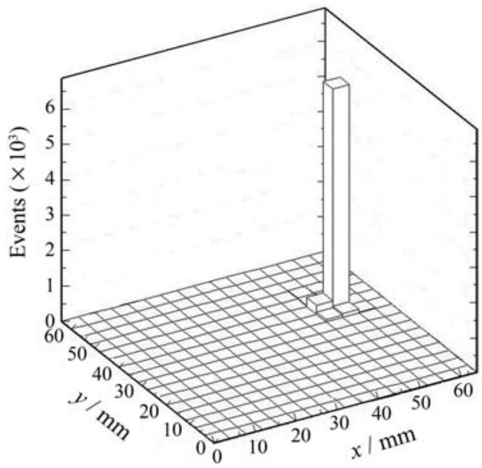

Fig. 5 Position spectrum of the MWPC detector test.

Fig.5 is the reconstructed 3D image with 93.6% and 95.0% of events falling into one position channel in x and y direction respectively. Limited to the distance between readout strips, a bin width of 4 mm is set in the picture. It shows that a position resolution (FWHM) better than 4 mm can be obtained by the digital readout method with 4 mm width strips.

5 Conclusions

The performance of the position resolution and 2D imaging accuracy by digital readout method with different widths of the readout strips were studied and compared with the traditional center of gravity method based on the data of GEM detector in X-ray test.

Due to the limitation of the readout strip width, the position resolution with the digital readout method is not very high. However, it has a great superiority for the neutron detectors whose requirement of position resolution is not high. And the detector will benefit from its less amount of data transmission, higher SNR and simpler electronics. So, for the SANS with a position resolution requirement of 5 ~ 8 mm, the digital readout method should be a good choice and the 4 mm width strip could meet the requirement.

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位敏型探测器数字法读出研究

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摘要： 中国散裂中子源(CSNS)的建造对中子探测器提出了非常高的要求，如更大的有效面积、二维位置灵敏、高计数率、高探测效率和低的γ灵敏度等。与传统的模拟读出方法相比，数字法读出具有更高的计数率，更小的数据传输量，更简单的电子学设计以及更高的信噪比。对数字法读出进行了理论计算，利用GEM探测器的原始数据分析了数字法读出的位置分辨率与读出条宽度的关系。结果表明，数字法读出对于位置分辨要求较低(小于4 mm)的大面积位置灵敏探测器是一种较好的选择，如CSNS小角谱仪探测器。

关键词： 数字法读出；位置灵敏；气体电子倍增器；中子探测器

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