Nuclear Instruments and Methods in Physics Research A 717 (2013) 44–50

Contents lists available at SciVerse ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Neutron/gamma discrimination employing the power spectrum analysis of the signal from the liquid scintillator BC501A

X.L. Luo *, Y.K Wang, J. Yang, G. Liu, C.B. Lin, Q.Q. Hu, J.X. Peng

Department of Instrument Science and Technology, College of Mechatronics and Automation, National University of Defense Technology, Changsha, China

ARTICLE INFO

Article history:
Received 24 August 2012
Received in revised form
2 April 2013
Accepted 2 April 2013
Available online 10 April 2013

Keywords:
n/γ discrimination
Power spectrum
Liquid scintillator
Reference-pulses

ABSTRACT

A digital method for the discrimination of neutron and γ-ray events based on analyzing the power spectra of the signals from a BC501A liquid scintillator detector was presented and investigated in this paper. In order to evaluate the feasibility of this novel pulse shape discrimination method, a 5GSample/s 8-bit oscilloscope was used to acquire waveforms for n/γ discrimination. Furthermore, the performance of this novel n/γ discrimination method was compared with that of a widely used method called *the reference-pulses method* which averaged a large number of neutron and γ-ray pulses to obtain the reference-pulse as the criterion for n/γ discrimination. The results showed that the proposed method performed well over *the reference-pulses method*, which was verified by the considerable decrease in the error rate of n/γ discrimination and the improvement of the Figure of Merit.

1. Introduction

Liquid scintillators are widely used in fast neutron detection because of their excellent pulse shape discrimination (PSD) properties and fast timing performance. In most cases the accurate discrimination between neutrons and γ rays is essential since liquid scintillators are sensitive to both neutrons and γ-ray photons [1]. Over the past few decades many PSD techniques for n/γ discrimination, which are based on the principle that the decay rate of the light output of a liquid scintillator depends on the radiation types, have been developed and studied. The traditional methods of n/γ discrimination, including the rise-time method [2,3] and the charge-comparison method [4,5], exploit analog techniques which require dedicated analog electronic modules with complex circuits and poor stability. The rise-time method implies the determination of the time at which the integrated light output reaches a certain fraction of its maximum, while the charge-comparison method implies essentially the determination of the relative weight of the amounts of light emitted respectively in the fast and slow component of the light pulse. The implementation of the charge-comparison method generally relies upon the integration of the pulse over two different intervals, whose choice depends on the actual experimental set-up adopted. The statistics of this method is much simpler than that of the rise-time technique, being essentially driven by the binomial law. In general, the charge-comparison approach performs better than the rise-time method [6].

More recently, there has been a turning point in n/γ discrimination in accordance with the advent of related fast and high resolution digital devices such as A/D converters, digital signal processors (DSPs), and field programmable gate arrays (FPGAs). These digital processors can sample and store the complete waveform of the liquid scintillator signals for post-processing, thus have offered the feasibility to transport the traditional PSD algorithms into the digital framework and also opened a new window for the digital n/γ discrimination techniques that afford additional benefits in terms of speed and discrimination performance. For example, Moszynski et al. [7] carried out the study of the n/γ discrimination for a large volume BC501A liquid scintillator coupled to a 130 mm diameter XP4512B photomultiplier (PMT) by the digital charge-comparison method and achieved a very good n/γ discrimination down to 100 keV of recoil electron energy. Ambers et al. [8] presented a hybrid PSD method which combines a charge-comparison PSD method with a reference-pulses PSD method, and the results demonstrated that the method gave considerable improvement over the charge-comparison method for light output bins below 70 keVee. S. Marrone et al. [9] described an algorithm based on the fit of an analytical shape (three exponential functions) to the recorded signals, and the performance of this method, both in terms of energy resolution and particle identification, is comparable to that of the charge-comparison method. In addition, several original digital methods have recently been developed such as the correlation method [10], the method of pulse gradient analysis (PGA) [11–13], the method of artificial neural networks [14], the fuzzy *c*-means algorithm

---

* Corresponding author. Tel.: +86 731 84573353; fax: +86 731 84574962.
E-mail address: delongtmac@163.com (X.L. Luo).

0168-9002/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.nima.2013.04.004

[15], the wavelet algorithm [16,17], and the method of frequency gradient analysis (FGA) [18,19].

In summary, all of the above mentioned methods have been implemented successfully for n/γ discrimination in terms of some specific aspect of discrimination performance. However, most of them exploit directly the pulse response arising from the PMT, often by averaging a large number of neutron and γ-ray pulses to obtain the reference-pulse as the criterion for n/γ discrimination, i.e. *the reference-pulses method*. Since the signal response of the scintillant cell and the PMT is statistical and very noisy, the natural variance in the pulse shape may deteriorate the n/γ discrimination performance of these PSD methods. In this paper, we propose a new n/γ discrimination method which is based on analyzing the power spectrum of the detector signal. The primary consideration of this research is to decrease the sensitivity to pulse variation and improve the n/γ discrimination performance of the PSD method by transforming the signal into the frequency-domain. The method has been tested using the Time-of-Flight (TOF) measurement system described in Section 2. In Section 3, the principle of the method is given and its n/γ discrimination performance is investigated by comparing with that of *the reference-pulses PSD method*. Finally, the conclusions arising from this research are stated in Section 4.

2. The experiment

The experimental data analyzed in this work were acquired using the TOF measurement system at the Institute of Nuclear Physics and Chemistry, the Chinese Academy of Engineering Physics, Mianyang, China. As shown in Fig. 1, through deuterium–tritium fusion reaction, an associated particle neutron generator (APNG) produces neutrons and alpha particles that are correlated in time and travel in opposite directions to conserve momentum. The energies of neutrons and alpha particles are 14.1 MeV and 3.5 MeV, respectively.

For TOF research, one plastic scintillation detector detects the arrival of the alpha particle beam pulse and provides a timing reference point for the arrival of each pulse and is referred to as the beam-pickup signal, and the other liquid scintillation detector placed at an adjustable distance from the tritiated target detects the corresponding neutrons or γ rays. The plastic scintillation detector consisted of a Φ25.4 mm × 0.1 mm cylindrical cell scintillation detector, optically-coupled to an EMI 9807B PMT, which was operated with a negative supply voltage of −1600 V DC. The output signal from the plastic scintillator was connected to Channel 1 of a Tektronic digital phosphor oscilloscope (DPO) 4104, via approximately 25 m of high bandwidth cable. The liquid scintillation detector consisted of a Φ50.8 mm × 50.8 mm cylindrical cell scintillation detector filled with BC501A organic liquid, optically-coupled to another EMI 9807B PMT, which was operated with a negative supply voltage of −1400 V DC. The output signal from the liquid scintillator was connected to another input of the digital oscilloscope and used to trigger acquisition.

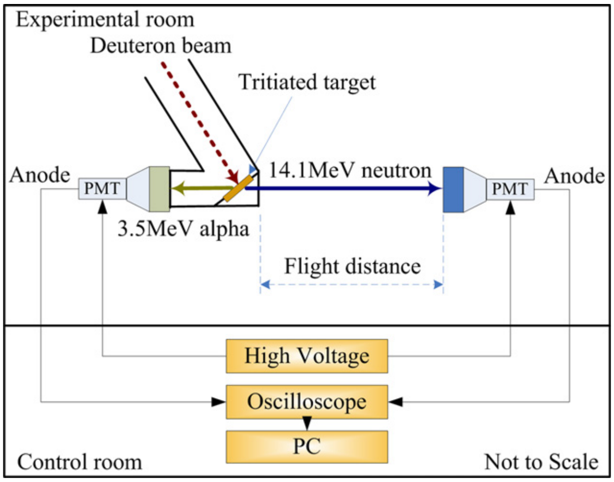

Fig. 1. A schematic of the experimental set-up used for the associated particle neutron generator at the Institute of Nuclear Physics and Chemistry, the Chinese Academy of Engineering Physics, Mianyang, China.

The liquid scintillator pulse and the corresponding beam-pickup pulse data were captured digitally with the Tektronix DPO4104 with 8-bit resolution working at 5GSample/s. This enabled all detected events, both γ rays and neutrons, to be sorted in terms of their time-of-arrival relative to the initial beam-pick up. Based on the difference in flight time for neutrons and γ rays across the known flight path length, we extracted 2304 neutron and 1103 γ-ray pulses for the research on n/γ discrimination in this paper. The misidentification rate of the TOF method in this experiment for neutron and γ-ray pulses are approximately 0.012 and 0.008 respectively because of the scattered events and other accidental particles. Since TOF is in general a high-accuracy method of n/γ discrimination, the results of TOF can be used for the research of n/γ discrimination with the PSD methods in Section 3.

3. n/γ discrimination with PSD methods

The pulse processing began with the removal of the baseline shift where a constant baseline shift was calculated in the pre-trigger range of the captured signal and then subtracted from the digitized waveform to retrieve its original pulse with zero-baseline drift. The starting time of each signal was defined as the time when it reaches 10% of its maximum amplitude and the duration of the pulse was set to 110 ns. These pulses were subsequently sorted out into three pulse height bins ranging from 0.25 to 8.30 MeVee, i.e. bin 1 (1714 pulses, 0.25–2.25 MeVee), bin 2 (820 pulses, 2.25–5.60 MeVee) and bin 3 (873 pulses, 5.60–8.30 MeVee).

3.1. *The power spectrum PSD method*

The concept of the power spectrum of a signal is fundamental in electrical engineering, especially in electronic communication systems, often being used to identify the frequency components of the signal. However, no research has been devoted to the application of the power spectrum in n/γ discrimination. Since the pulse shape of the neutron-induced signal is different from that of the γ-induced signal, in this section we will attempt to investigate the n/γ discrimination by observing and measuring the power spectrum of the output signals in the experiment.

For continuous signals that describe for example stochastic physical processes, the power spectrum gives a plot of the portion of a signal's power falling within given frequency bins. Here, power can be the actual physical power, or more often, for convenience with abstract signals, can be defined as the squared value of the signal. The power spectrum of a given signal $x(t)$ is defined as

$$P(\omega) = \lim_{T \to \infty} \frac{1}{T} \left| X_T(\omega) \right|^2 \tag{1}$$

where ω is the normalized discrete-time frequency and $X_T(\omega)$ is the Fourier transform of the signal $x(t)$ in period T, i.e.

$$X_T(\omega) = \int_0^T x(t) \exp(-\mathrm{j}\omega t) \mathrm{d}t \tag{2}$$