High Counting-rate Data Acquisition System for the Applications of PGNAA

Yuzhe Liu, Lian Chen, Futian Liang, Feng Li, and Ge Jin

***Abstract*–The prompt γ-ray neutron activation analysis (referred PGNAA) technology is a use of the strong penetrating power of neutron and γ-ray, which can get the whole information of the elements inside a thick material. Therefore, the PGNAA technology has become the best choice to meet the needs of detecting the composition of industrial materials. This paper presents a data acquisition scheme for the physical targets of PGNAA, which has a high pass rate, high SNR and can analyze and process a large number of pulses which the detector outputs. This system is designed to rapidly analyze the composition and content of the industrial materials in real-time. Since we have to dynamically analyze the moving materials, the expected time for a measurement can not exceed 120s, The average counting rate is expected to reach more than 500kc/s.**

I. Introduction

PROMPT Gamma-ray Neutron Activation Analysis (PGNAA) technique is a non-destructive nuclear analysis technique for the determination of elements. It can detect the composition and the content of the materials by analyzing the prompt gamma spectrum, which is emitted from thermal neutron capture or neutron in-elastic scattering reactions. This detection technique can obtain the internal element composition of the large thickness material, because of the neutron and gamma ray's penetration ability. Therefore, the PGNAA technique is becoming the best choice of element detection of industrial materials [1]–[3].

As an on-line and in situ inspection method, the PGNAA technique need to acquire an accurate spectral information in a relatively short measurement time. That demands a high counting rate and little counting loss of the data acquisition system.

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II. Shaping Principle

Nevertheless, when the counting rate is at a higher level, the pile-up effect of the signal pulse becomes much more critical.

The probability of the gamma ray signal pulse induced by neutron appears to obey the Poisson distribution in time [4]. So, if the average counting rate of gamma ray is defined as $\overline{n}$, according to the Poisson distribution, the probability of the appearance of n gamma rays in the time of ΔT is:

$$P(n,\Delta T) = \frac{(\bar{n}\Delta T)^n}{n!} e^{-\bar{n}\Delta T} \tag{1}$$

So the probability of the peak pile-up is not generated in time is:

$$P(0,\Delta T) = e^{-\bar{n}\Delta T} \tag{2}$$

According to this formulation, to achieve an average counting rate of 500kc/s, with the counting loss less than 10%, the highest counting rate of the data acquisition system is as much as 5Mc/s. That demands the time width of processing one signal pulse must be less than 200ns to avoid a worse counting loss caused by the pile-up effect. That is not easy for the electrical system which has to insure the accurate of the spectrum analysis. To obtain a better SNR, the signal pulse has to be wider, however that will lead to an increasing of the counting loss caused by the pile-up effect. Therefore, a new method of data acquisition to ensure an accurate energy spectrum analysis and high counting rate acquisition is shown in this paper.

III. System Design

The detector system is formed with a bismuth germinate (BGO) gamma ray detector and a matched high count rate readout electronics system. The gamma ray detector detects the prompt characteristic gamma rays produced by neutron source, and converts the fluorescence into electric pulse, then the pulses are transfer to the data acquisition system to analyze.

The detector system detects and processes the event information to the analysis system so as to carry out real-time, accurate monitoring and analysis of the composition and the content of the industrial materials. The structure of the detector system is shown as Fig.1.

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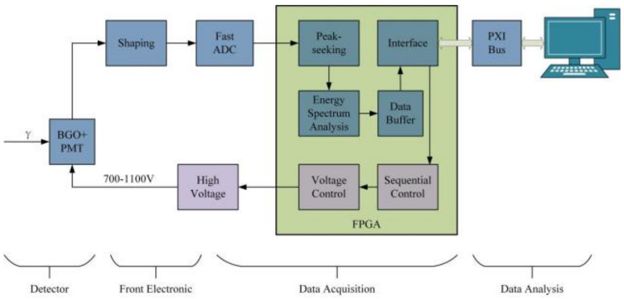

Fig.1 Block Diagram of PGNAA Readout System

A. *Front End Electronics*

The shaping circuit transforms the impulse signal outputted by the PMT into a quasi Gauss pulse, in order to improve the SNR and reduce the effect on energy resolution of the electric noise. The traditional shaping circuit usually transfers the signal into a sharp pulse to improve the SNR, however the sharp pulse generates a large track loss and the tail edge of exponential decay will produce a large dead time which reduces the counting rate and is unsuited for high counting rate analysis. Therefore, the front end electronics use a multistage CR-RC$^{(m)}$ shaping circuit, which transfers the signal pulse into a much more flat top waveform which has a shorter tailing edge. That provides a high accuracy of peek seeking and does not bring out much counting loss.

B. *Data Acquisition*

In order to achieve a higher accuracy of peek seeking in the condition of a 200ns pulse width only, we need to obtain enough sampling points around the peek range. That demands a high accuracy and high sample rate ADC. The traditional multi-channel uses a Willkinson ADC in a converting circuit, which has a good nonlinear performance but a much lower sampling rate, which will increase the dead time to a magnitude of microsecond. Therefore the traditional converting circuit is not suitable for the high speed data acquisition system of PGNAA. So this system uses a 14 bits high speed FADC circuit, which has a sample rates of up to 250 MSPS.

Furthermore, the analog-to-digital converting, peek seeking and multi-channel analysis are operated as a pipeline, which can finish a data acquiring circle in the time of 4 system clocks. When passed through the CR-RC$^{(m)}$ shaping circuit, the tailing edge of the signal pulse reduces to about 140ns, and the whole time from the ADC output delay to finish the multi-channel analysis is up to 60-70ns(depends on the peek-seek method). Nonetheless, the whole time of adding one signal count to the energy spectrum is far less than the time width of the tailing edge of the signal pulse. There is no additional dead time leaded in by the data acquisition system.

The data buffer provides a double buffering method to prevent the counting loss during the reading out of the energy spectrum for display.

C. *Run Control Interface*

In order to operate the DAQ module and configure the hardware parameters, a Graphical User Interface (GUI) has been built. The software sets acquisition parameters and readouts energy spectrum and waveform stored in the FPGA through PXI bus interface. As is shown in Fig. 2, the software panel is majorly divided into five parts.

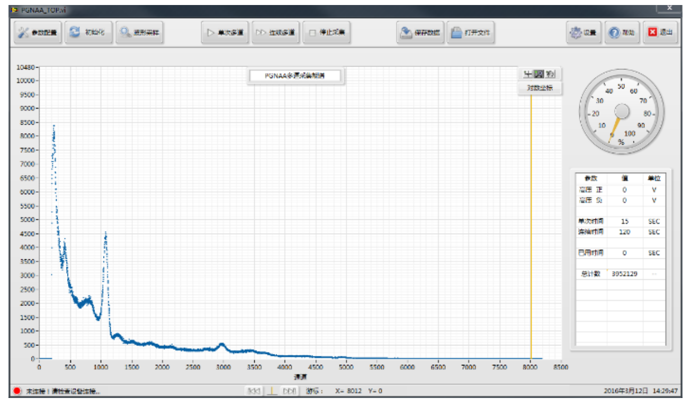

Fig.2 The photo of the GUI pane. This panel can help setting the threshold of the peek-seeking module, the control voltage of the high voltage control module, and the parameters of sequential control. And it also provides a function of energy spectrum display and analysis

IV. Electronic Tests

A. *Counting Rate*

In order to conform that the DAQ system can achieve a highest counting rate of 5Mc/s, an electronic test of counting rate is implemented with an Agilent 33250A signal generator as signal source and Tektronix MDO3032 Oscilloscope to observe the output pulses. By observing the signal outputted by the shaping circuit while adjusting the frequency of the signal generator, the highest counting rate is consistent with the frequency of the signal generator when the pulses becoming connected together. As is shown in Fig. 3, the highest counting rate reaches 8Mc/s (Fig.3 lower-right) much higher than 5Mc/s (Fig.3 upper-left) which is required.

Fig.3 The signal outputted by the shaping circuit, upper-left 5MHz, upper-right 6MHz, lower-left 7MHz, lower-right 8MHz.

B. *Nonlinear & Relative Error*

There are other electronic tests of nonlinear and relative error of the system, to confirm that the system can meats the accuracy requirements. An Agilent 33250A signal generator is also used as signal source. By adjusting the output amplitude

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and recording the peak channel and FWHM of the energy spectrum of each amplitude, the curves of relative error and input amplitude voltage in different channel can be obtained with simple calculation. As is shown in Fig.4.

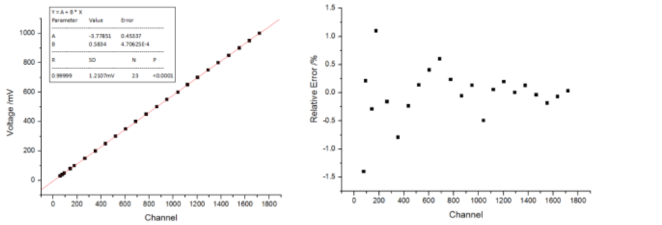

Fig.4 The linearity (left) and the relative error (right) test of the readout system.

The result of liner fitting of the curve of the input amplitude voltage in different channel shows that the standard deviation is 1.23mV (Fig.4 left), while the relative error is lower than ±1.5%, which is lower than ±0.5% in the middle and high channel range (Fig.4 right). The test result shows the system is well to meet the accuracy requirements. And the non-linearity can be improved roughly an order of magnitude using a sliding pulse generator [5].

V. Experimental Result

An energy spectrum of aqueous solution is record in another experiment in low fidelity environment. The structure of the experimental system is shown in Fig.5.

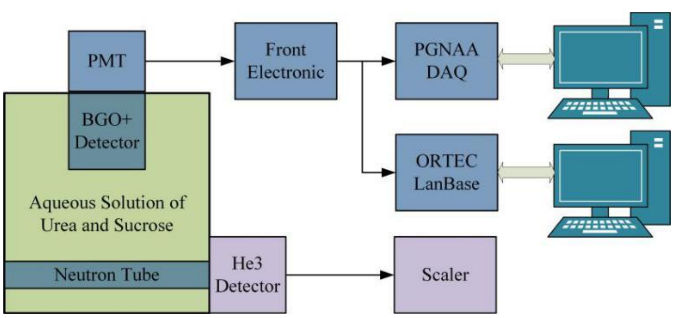

Fig.5 The sketch map of the energy spectrum acquiring experiment.

The aqueous solution of urea and sucrose is filled in the barrel tank which has a neutron tube through the bottom horizontal. There are a He3 detector and a scaler monitoring the neutron flux of the tube. The BGO detector and PMT transfer the gamma ray into electric pulse, which is shaped by the front electronic circuit. The output pulses of front electronic circuit are transmitted to both the DAQ system and the ORTEC LanBase commercial multi-channel analyzer. The energy spectrum of both analyzer are shown in Fig.6 and Fig.7.

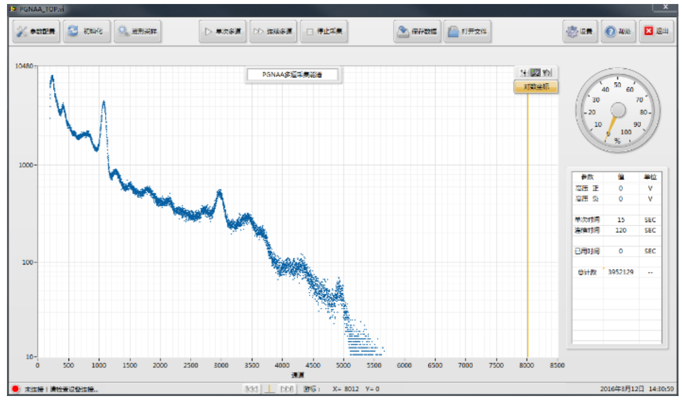

Fig.6 The energy spectrum acquired by PGNAA DAQ

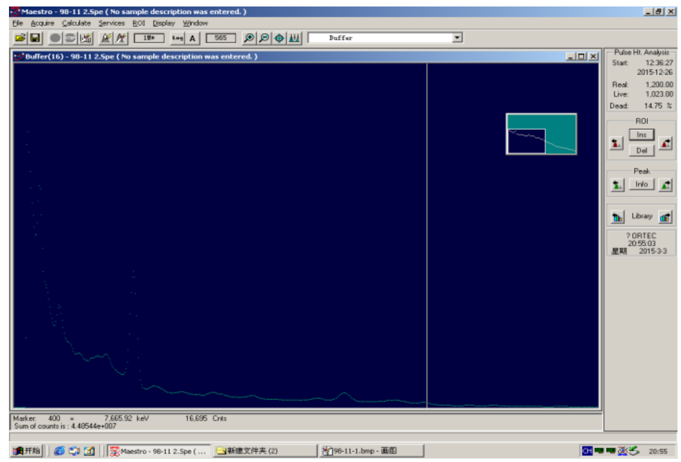

Fig.7 The energy spectrum acquired by ORTEC LanBase

The photo in Fig.6 up shows the result of PGNAA DAQ system, the photo shown in Fig.7 shows the result of ORTEC LanBase. As is shown, the energy resolution of hydrogen peak measured by ORTEC LanBase is 9.3%, the average counting rate is 37.4K/s, the dead time is 14.75%. however, the energy resolution of hydrogen peak (around 1100 channel in Fig.6) measured by PGNAA DAQ system is 8.9%, the average counting rate is 40.5K/s, the dead time is less than 1%. The result of this experiment indicates that the PGNAA DAQ system can achieve a higher counting rate than the ORTEC LanBase commercial multi-channel analyzer with much less dead time and guarantees a good accuracy in the same condition. The test result confirms that this PGNAA DAQ system can well meet the actual needs.

VI. Conclusion

In this paper, we presented a data readout system for the applications of PGNAA. It uses advanced electronic technologies to study a new spectrum measurement method through continuous testing and improvement to meet the needs of a high counting rate. This system uses a number of special processing methods to solve the key problems of high counting rate, such as signal accumulation, reducing the dead time, data reading and saving, fast online analysis, etc.. This system improved the counting rate, reduced the counting loss and ensured a high accuracy at the same time. All the performance parameters had satisfied the requirements of the online measurement for the applications of PGNAA.

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