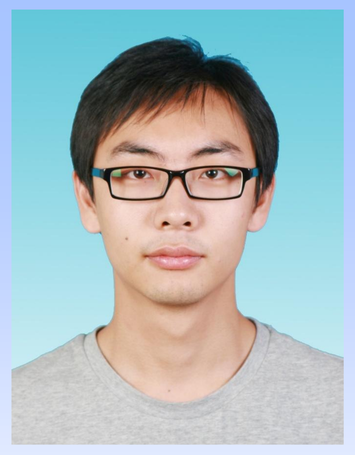
High Counting-rate Data Acquisition System for the Applications of PGNAA



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1.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.

2.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 , according to the Poisson distribution, the probability of the appearance of n gamma rays in the time of is:

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

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

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

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.

3.System Design

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.

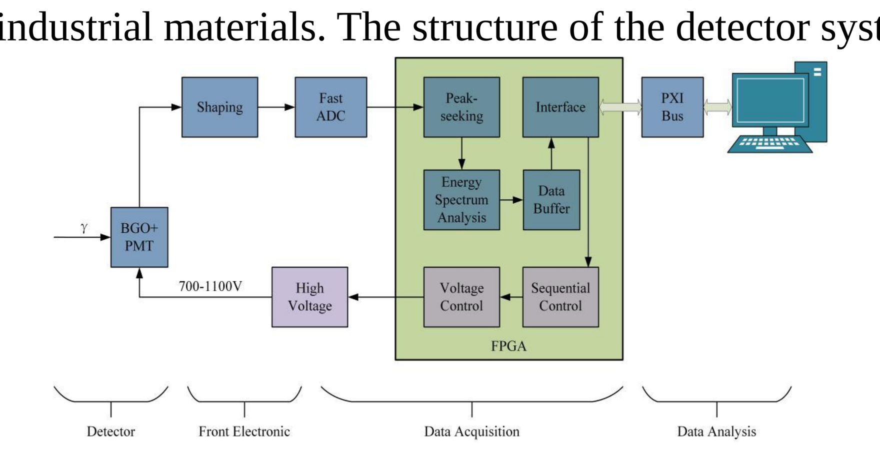


Fig.1 Block Diagram of PGNAA Readout System.

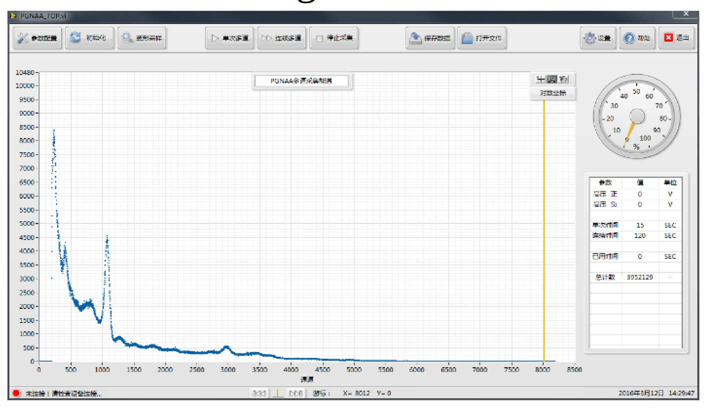


Fig. 2 The photo of the GUI pane.

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 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. 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. 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.

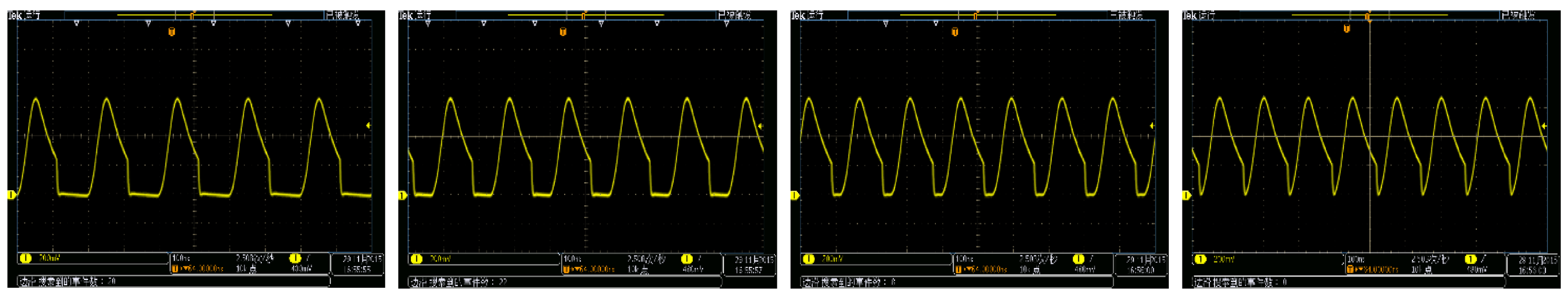
C. Run Control Interface

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, 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.

4. 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.



a b c d

Fig.3 The signal outputted by the shaping circuit, a 5MHz, b 6MHz, c 7MHz, d 8MHz.

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

B. Nonlinear & Relative Error

An Agilent 33250A signal generator is also used as signal source. By adjusting the output amplitude 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.

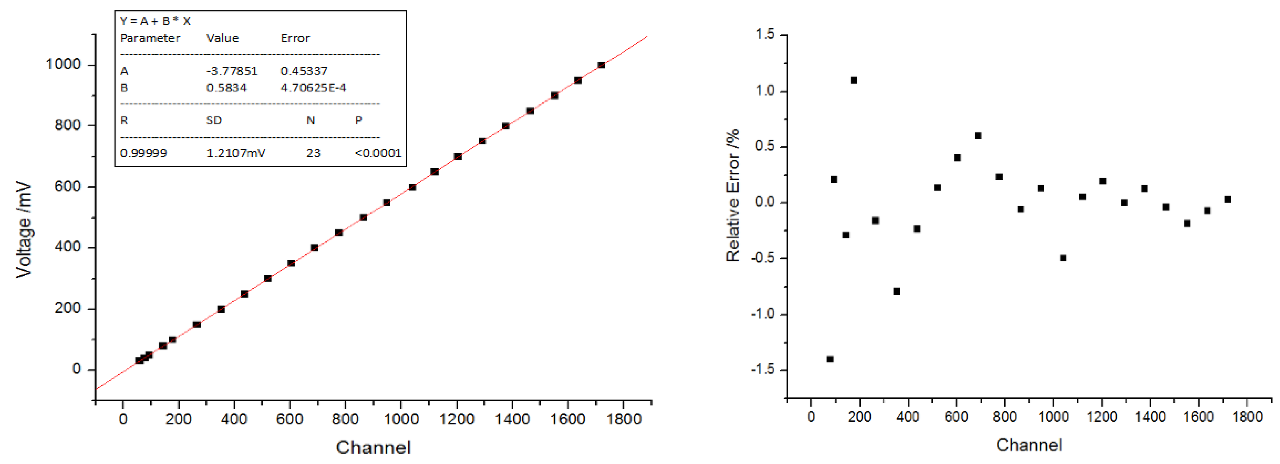


Fig.4 The linearity (left) and the relative error (right) test of the readout system.

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].

5.Experimental Results

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.

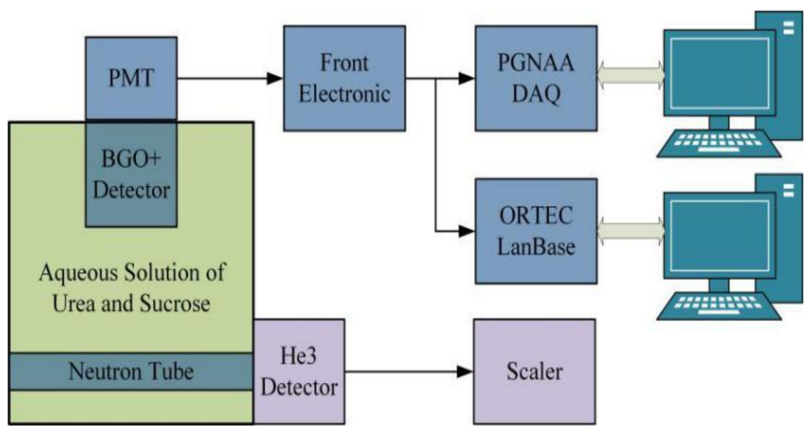


Fig.5 The sketch map of the energy spectrum acquiring experiment

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

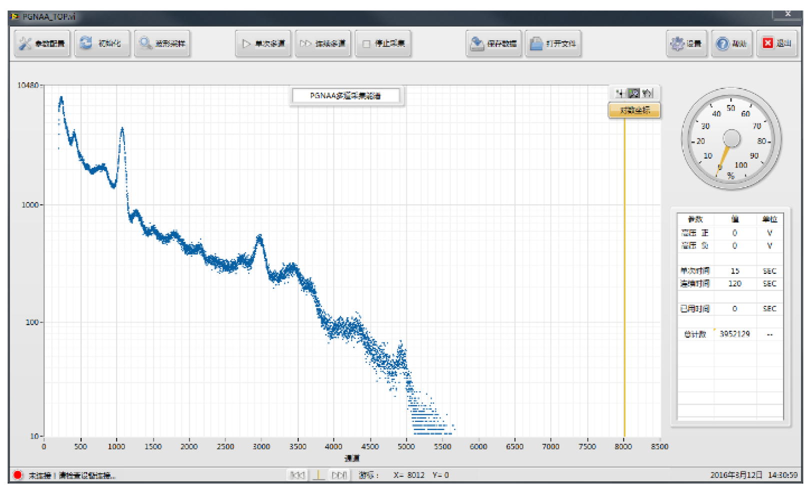


Fig.6 The energy spectrum acquired by PGNAA DAQ.

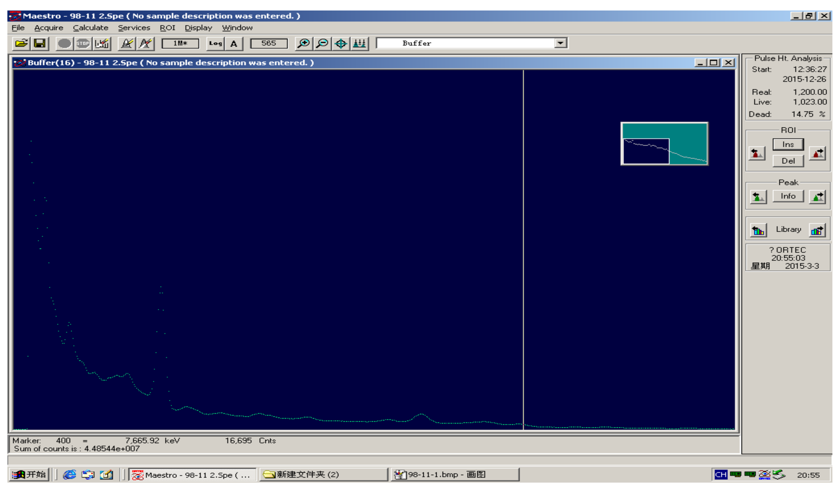


Fig.7 The energy spectrum acquired by ORTEC LanBase.

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.

6.Conclusions

In this paper, we presented a data readout system for the applications of PGNAA. 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.

References

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