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Digitized signal acquisition of gas-filled, multiwire, neutron detector with delay-line readout

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Abstract. Multiwire counters are likely to remain a reliable and cost-efficient option for a large class of instruments. Delay-line position encoding is widely used in multiwire position sensitive particle detectors. Improvement of several detector parameters is a continuous demand such as count rate or position resolution. Digitization of the analog detector signals retains all information about the detected events at the highest count rate. Neutronic measurement results on our standard detector with 200mm x 200mm active area are presented with different acquisition algorithms. The analog signals were digitized by a high speed, multichannel Acqiris digitizer with 1 ns sampling resolution.

1. Theory of delay-line encoded multiwire proportional chamber

Several spectrometers at BNC are equipped with our standard, multiwire, 2D position sensitive gas-filled neutron detector with delay-line readout. These gas detectors contain a mixture of ^{3}He and CF_4 [1]. In these detectors, the neutron is sensed by the well known reaction:

$$^3\mathrm{He}+\mathrm{n}=\mathrm{p}+\mathrm{T}+764\mathrm{keV}$$

The CF_4 limits the ionization particles by its high stopping power. This effect is the primary limitation of the position resolution of the detector.

Our multiwire detectors contain three parallel wire frames. The central anode and the two surrounding cathodes are mounted in parallel. The wires of one cathode frame are orthogonal to the other cathode frame. An electric field is created between the anode and cathode layers by applying same high voltage on the all anode wires. The small diameter of the anode wires creates large electric field around the anode wires. The high electric field multiplies the ionized electrons. This improves the signal to noise ratio. During this gas gaining effect, signals are induced on the close cathode wires providing the position of the captured neutron [2].

All cathode wires can be lead out from the chamber (individual readout). More cost-efficient solution is the connection of the cathode wires by delay-line elements. This serial connection of the delay-line elements creates a delay-line. In this way the position of the neutron is coded to the time difference between the anode and delayed cathode signals. The connected anode wires and two ends of the two delay-lines give five output signals [3]. Fast current amplifiers are used for these outputs.

The starting-point of these signals correlates with the neutron position. Simple threshold triggering causes a dependence of the trigger time on pulse height. The constant fraction discrimination method can reduce this dependence. Careful fine-tuning is necessary to minimize this dependence as any kind of signal dispersion in time degrades the position resolution of the detector.
Finally, the delays between the CFD output signals are measured by a time to digital converter (TDC). Many readout system follow this solution [4,5]. The usual time resolution of a TDC is around few hundred of picoseconds. The total length of a delay line is between 100-200 ns.

2. Digitized signal acquisition results

The conventional delay-line readout electronic converts the delay-line analog outputs to digital signals causing loss of information like pulse height, rise time or fall time. Sufficiently fine digitizations of the analog signals preserve all the possibly useful information about the detected neutron event. We investigated different data acquisition procedures that can improve several detector parameters but further offline improvements on the stored data are also possible. Fast, multichannel digitizer was used for storing the data. The data were processed in Matlab.

2.1. CFD software replacement

The operation of the conventional analog CFD is well known and published in many articles [6]. Our first improvement is the numerical realization of the constant fraction discrimination. This means a Matlab-simulated CFD. This algorithm performs the same operation as a real analog CFD. Two further numerical discriminator algorithms have been also tested. Either of them calculates the starting point from the falling edge of the signal because this seems the simplest way to calculate the starting

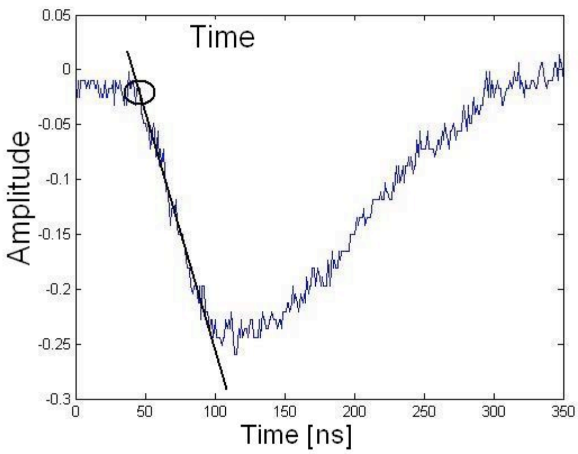

Figure 1. Linear fitting on the analog output signal of a delay-line detector

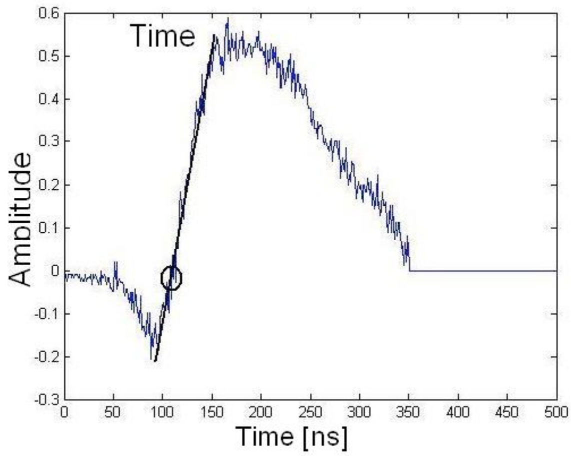

Figure 2. Linear fitting on the CFD signal of a delay-line detector

point. This method is illustrated in Figure 1. The other algorithm follows the original CFD method simulation but the zero cross finding on the rising edge is improved by linear fitting on 10 digitized points. This method decreases the effect of the noise on the rising part of the signal. This is illustrated in Figure 2.

The three numerical algorithms have been compared with the real, analog PS715 constant fraction discriminator. The comparators are compared by the time dependence mentioned before. The sum of the travelling times of the cathode signals on the delay line should be equal to the length of the delay line. This sum is dispersed in time by the CFD. The discriminators are characterized by the FWHM of the curves represent this dispersion. The results are displayed in Figure 3. The values are summarized in Table 1. The result of the simulated CFD algorithm is very close to the real, analog CFD. The simple linear fitting on the falling edge of the signal provides bad result. This indicates the necessity of constant fraction discrimination. The improved method provides the best results.

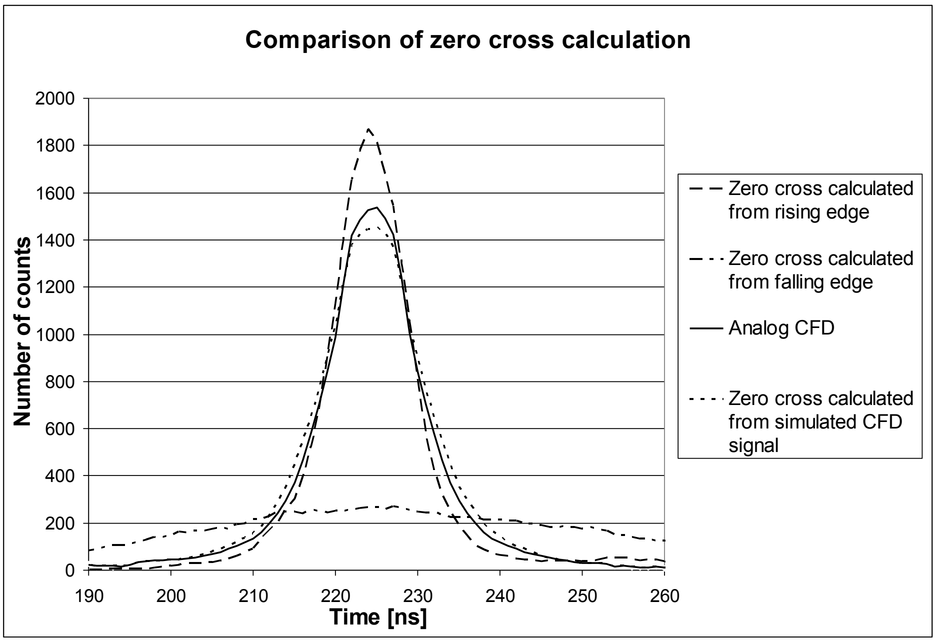

Figure 3. Comparing the different methods

Table 1: Quantitative comparison of the CFD methods

Type	Time dispersion FWHM [ns]
Analog CFD	12,2
Simulated analog CFD	13
Improved simulated CFD	10,5
Linear fitting on falling edge	63

2.2. Variable threshold

Further improvement is the position dependent discriminator threshold that can improve the homogeneity and also the gamma sensitivity. The solution is similar to the individual readout where every wire has an individual threshold but in this solution an optimal threshold is assignable for every pixel that can separate the neutron signals from the noise and gamma signals. The method is demonstrated on Figure 4 where effect of higher gain due to a low-tensioned wire is compensated between the 120th and 127th channels. The tuning of the individual virtual thresholds set takes a long time but the numerical way can be automated by a complex algorithm. We should mention that the conventional threshold tuning by potentiometers in individual readout detectors takes also a long time.

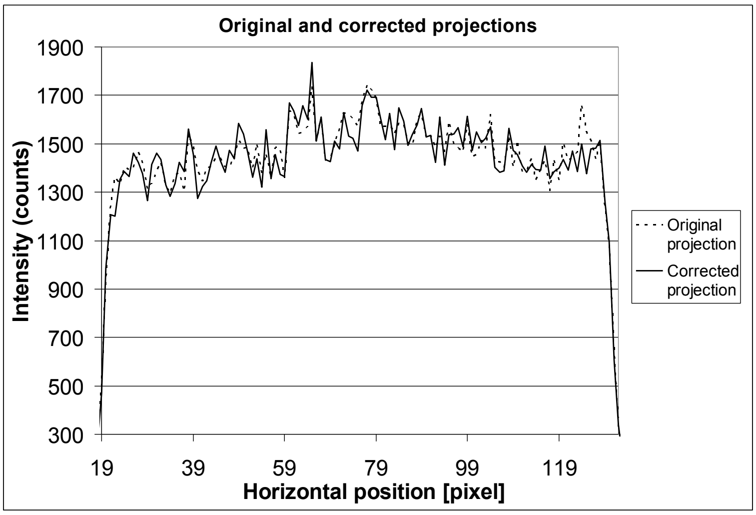

Figure 4. Demonstration of inhomogeneity compensation

2.3. Signal integration

Another practical application is the real-time numerical integration of the digitized signals that improves the energy resolution and gamma sensitivity of the detector keeping the high count rate capability of the detector. Delay-line detectors generally use fast current amplifiers because the fast falling time gives lower jitter and better time and position resolution. The analog integration of the detector current signals gives better energy resolution because the linearity between the pulse height and total charge is better but the count rate capability of the detector is degraded due to the slower integrated signals. Numerical integration keeps the high count rate capability of the detector meanwhile the charge is integrated.

The better separation of neutron and gamma events is illustrated on Figure 5. The first peaks belong to the noise and gamma events, the seconds to the neutron events. The curves show the pulse height spectra of the original and the numerically integrated anode signals. After calibration the neutron peaks are at the same position for the better comparability of the curves. The methods are characterized by FWHM of the peaks belongs to the neutron events. The FWHM of the curve belongs to the original current signals is 243mV, the FWHM of the curve belongs to the integrated signals is 198mV.

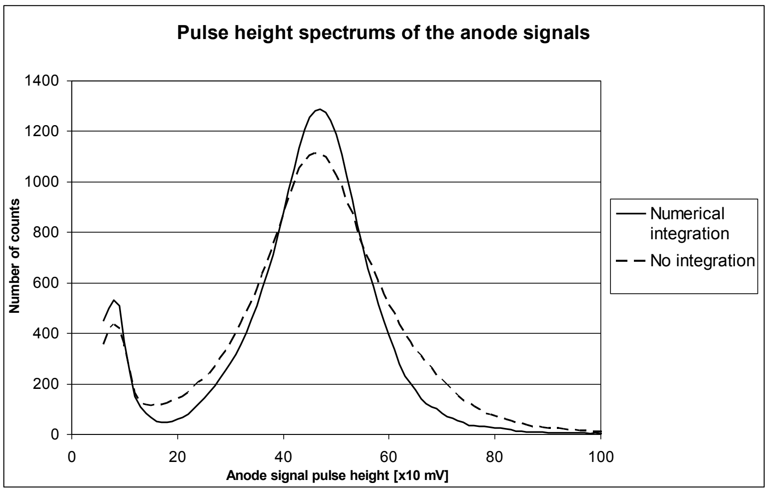

Figure 5. linear fit on the analog output signal of a delay-line detector

3. Conclusion

Effect of an acquisition method on digitized detector signals of a delay-line detector is presented. The data were recorded on-line by an Acqiris digitizer and processed off-line by Matlab for demonstration. Precise acquisition of the delay-line analog signals improves several detector parameters. New acquisition algorithm on numerically realized CFD signals improves the time dispersion comparing with a real, analog CFD. This leads to better position resolution. The homogeneity is also improvable by set an individual discrimination threshold for every pixel. The numerical signal integration improves the energy resolution by the better signal to noise ratio without degradation of the count rate capability. This signal digitization method provides a flexible system because the recorded signals retain all information and can be processed off-line with different algorithms.

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