THE SOFTWARE AND SOLUTIONS FOR EXPRESS PROCESSING OF THE RAW LIST MODE DATA MEASURED ON THE NEUTRON SPECTROMETERS OF THE IBR-2 REACTOR USING A DELAY LINE POSITION-SENSITIVE DETECTOR AS DESIGNED TO BE INTEGRATED INTO THE EXPERIMENT CONTROL SYSTEM

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Recently we have performed a comparative study of the characteristics of the data acquisition systems for the position-sensitive detectors with a delay line operating on the neutron instruments of the IBR-2 reactor. As a result, to have an optimal version of electronics we have chosen two directions of further development: the DeLiDAQ-2 system for high-flux measurements and the CAEN N6730 digitizer-based system for high-precision experiments. The study has also revealed an urgent need to integrate list mode measurements into the experiment control system on some of the neutron spectrometers. So far, the experiment control system SONIX operating on most of the IBR-2 spectrometers has received and displayed the data measured in the histogram mode. The report, besides the results of the comparative study, describes the software that is developed to solve the task of formation of events from raw data, their sorting, selecting by appropriate criteria, and histogramming as well as to be appropriate for integration into the SONIX. The proposed solutions are not limited to any specific types of electronics for PSD.

Keywords: time-of-flight, position-sensitive delay line detector, FPGA

1. Introduction

Significant non-uniformity in time of the neutron flux of the pulsed reactor IBR-2 toughens seriously the requirements for the bandwidth of the data acquisition systems operating on its neutron instruments. Since, in recent years, a number of the time-of-flight (TOF) spectrometers at the reactor have received new two-coordinate position-sensitive detectors (PSD) of local production [1-2], the task of choosing optimal electronics for such detectors has become critically important. An overview of the long-term work on creation of data acquisition systems for PSD carried out in our department is presented in [3]. In this article, we highlight some difficulties in doing the task and ways to overcome them. When measuring a direct beam on our spectrometers, the peak load at the detector is 30–50 times higher than the load averaged over time. Under such conditions, our full-time electronics for the two-coordinate PSD with delay line DeLiDAQ-1 [4-5], which has also been successfully operating for many years in other neutron centers, though in the mode without TOF, has revealed the problem of reducing the count in the tail part of the time-of-flight window at high loading. Our electronics of the next generation DeLiDAQ-2 [6] showed excellent performance at high loads from the very first application. Later, however, this system has encountered the problem of positional spectra smearing at low loads.

2. Comparative study overview

To find out the limits of applicability of our systems in the time-of-flight mode and compare them with the alternative ones, we have carried out parallel measurements with the three systems: DeLiDAQ-1, DeLiDAQ-2, and the system based on the CAEN N6730 digitizer with the DPP-PSD firmware [7], and have performed a comparative study of their characteristics. For independent control of the input load, the anode signal was registered by a fourth data acquisition system MPD16 [8]. We used homemade two-coordinate 200x200 mm2 He3 position-sensitive detectors at the REFLEX (Beam 9) and the GRAINS (Beam 10) neutron instruments of IBR-2. A more detailed description of the parallel measurements will be presented in another publication; due to volume limitations, we only list the main points here.

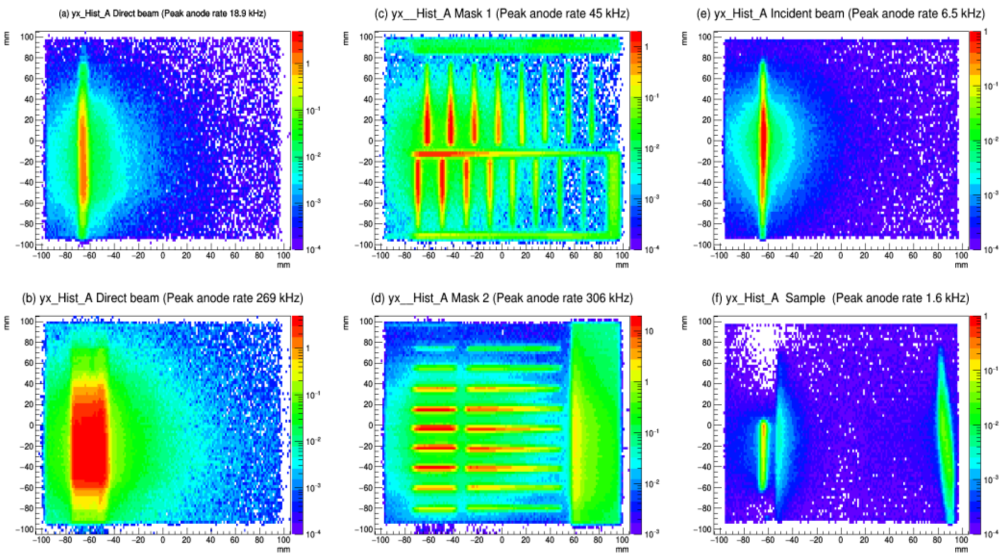

Figure 1. Raw positional spectra from measurements on Beam 9: (a,b) – the first and last steps when scanning the direct beam with a gradually increasing input load; (c,d) – slotted cadmium masks vertically and horizontally; (e,f) – reflectivity measurements

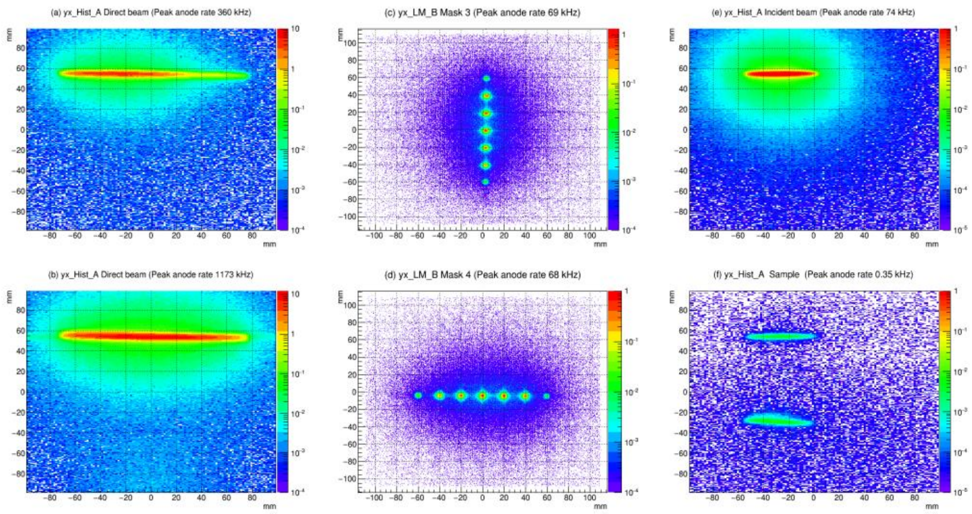

Figure 2. Raw positional spectra from measurements on Beam 10: (a,b) – the first and last steps when scanning the direct beam with a gradually increasing input load; (c,d) – hole cadmium mask vertically and horizontally; (e,f) – reflectivity measurements

All the three systems for PSD can deliver the raw data measured in the list mode (i.e., raw hits or events from the detector). Besides, DeLiDAQ-1 and DeLiDAQ-2 have modes for delivering filtered list mode data and the histograms calculated at the board firmware level. For implementation of long-time measurements in the list mode, it was necessary to upgrade the firmware of the DeLiDAQ-2 system, which was carried out in 2018 (this change is indicated below as "modernization"). We performed three types of parallel measurements: 1) scans of the direct beam with a gradually increasing input load regulated by collimators or a deflecting mirror (on Beam 10) (Fig. 1 a, b and Fig. 2 a, b); 2) calibration measurements with slotted or perforated cadmium masks (Fig. 1 c, d and Fig. 2 c, d); and 3) measurements of reflection from samples (Fig. 1 e, f and Fig. 2 e, f).

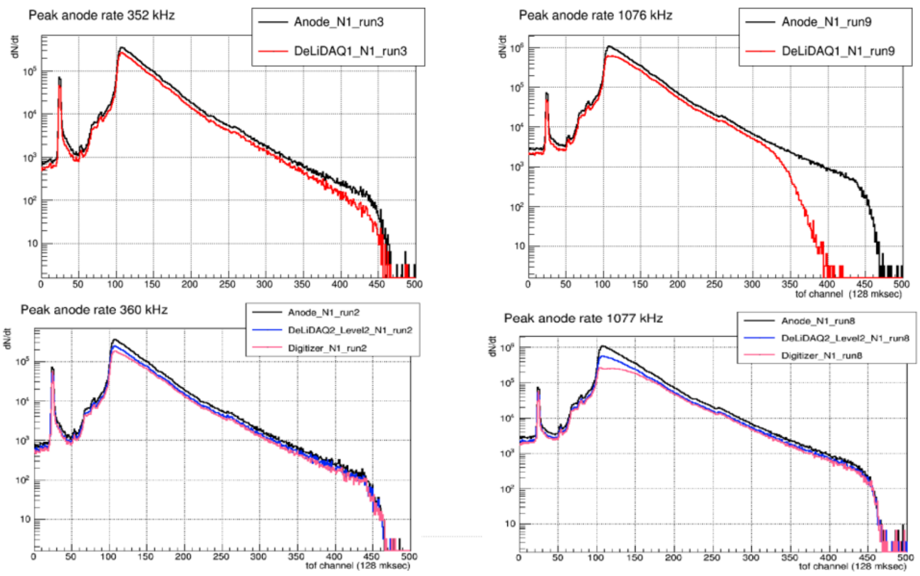

Figure 3. Typical distortions on the measured TOF spectra of the direct beam for high input loads (Beam 10)

As samples, we used standard film samples for our spectrometers. The measurements show good agreement between the results yielded by all the three systems for typical workloads.The high load level at which distortions of the shape of time-of-flight spectra begins (see Fig. 3) was found and is indicated for all systems in the conclusions. It is especially important that recent modernization of the DeLiDAQ-2 firmware made it possible to actually use a mode in which this system does not smear positional spectra at low load levels (progress in results is illustrated in Fig. 4).

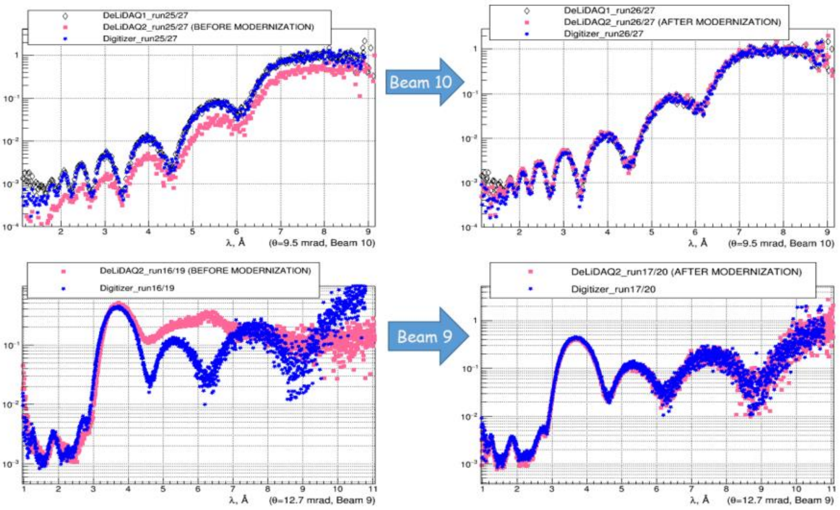

Figure 4. The reflectivity plots with distortions from DeLiDAQ-2 when using filtering at the FPGA level (before modernization, left), and without such distortions when using filtering at the software level (after modernization, right)

3. Software

The comparative study could not have been performed without at least minimal integration of all the three electronic systems into the existing experiment control software. The unified software for experiment control at IBR-2 spectrometers is the SONIX+ software package [9] which operates under the Windows family of OS. For all the three systems, middleware driver modules have been implemented for execution under the SONIX+. For the study, we created a set of express-analysis tools, namely the ROOT- [10] based stand-alone programs and macros specially developed for processing list mode data and visualization of the results. Next, the primary part of the express-analysis tools must be embedded into SONIX+ to enable basic work with list mode data. The newly embedded tools must follow the already implemented logics of the SONIX+ for dealing with data from neutron detectors. The implemented logics consider the neutron spectra as 1D, 2D or 3D numerical arrays (which can be visualized or saved to some other formats for further analysis). The requirement for the integrated software is to calculate 3D numerical arrays from the list mode data on the fly in respond to the user request to plot the data.

At first the idea was to use only ROOT in the design to create trees and histograms. For the digitizer data, using the ROOT tree conception seems to be the only possible solution. The corresponding DLL was implemented, though two problems arose immediately: a slow data sorting procedure (necessary step to build raw events) and serious limitations on the size of the resulting three-dimensional histogram. For our users the size restriction of 3D spectra is a very undesirable feature. We hoped that transfer from ROOT 5.34.36 to ROOT 6.18.04 would solve the memory problems, but this did not work with 3D histograms. At the same time, with ROOT 6 a more effective and fast procedure for sorting raw data from a digitizer can be developed. Since the DeLiDAQ-2 data is sorted at the FPGA level, for such data in the list mode an additional module which calculates spectra on the fly without using ROOT was implemented at the middleware level, and this solution was tested in a real experiment.

4. Conclusions

The presented study defines the regions of applicability of electronic systems and helps to make an adequate choice of electronics for time-of-flight measurements with position-sensitive detectors of thermal neutrons with a delay line. The study confirmed that the quality of spectra does not depend on the average load in the input stream but depends on the peak input load. DeLiDAQ-1 has an overload at 250 KHz peak input load. Therefore, it will soon be replaced by more advanced electronics. DeLiDAQ-2 has no overloads up to 1200 KHz in the TOF mode, but it can only measure reliably the data in the list mode with unfiltered sorted events (while without TOF it successfully filters events and calculates histograms at the FPGA level). A digitizer-based system has an overload at 360 KHz peak input load. It also can only deliver the list mode (with raw unsorted events). At the same time, it needs longer processing of raw unsorted hits to build events. It has, however, an excellent spatial resolution. For the nearest future we have selected the DeLiDAQ-2 system for high-flux measurements and the CAEN N6730 digitizer-based system for high-precision experiments. The list mode measurements have become a daily routine for many neutron instruments that previously received data only in the form of ready-made spectra. Thus, integration of list mode measurements into the experiment control system has become an actual task today. For the DeLiDAQ-2 system, such integration is already implemented. As for the digitizer-based system, the integrated software has not had online visualization so far. So, the work continues.

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