Jefferson Lab's Distributed Data Acquisition

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Abstract. Jefferson Lab's Continuous Electron Beam Accelerator Facility (CEBAF) occasionally experiences fast intermittent beam instabilities that are difficult to isolate and result in downtime. The Distributed Data Acquisition (Dist DAQ) system is being developed to detect and quickly locate such instabilities. It will consist of multiple Ethernet based data acquisition chassis distributed throughout the seven-eighths of a mile CEBAF site. Each chassis will monitor various control system signals that are only available locally and/or monitored by systems with small bandwidths that cannot identify fast transients. The chassis will collect data at rates up to 40 Msps in circular buffers that can be frozen and unrolled after an event trigger. These triggers will be derived from signals such as periodic timers or accelerator faults and be distributed via a custom fiber optic event trigger network. This triggering scheme will allow all the data acquisition chassis to be triggered simultaneously and provide a snapshot of relevant CEBAF control signals. The data will then be automatically analyzed for frequency content and transients to determine if and where instabilities exist.

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BACKGROUND

CEBAF is seven-eighths of a mile long and consists of an injector where the electron beam is generated, two linear accelerators (Linac), two arcs to re-circulate the beam, and three experimental halls. The need for the Dist DAQ system stems from a reoccurring beam loss signature captured by the Beam Loss Accounting (BLA) system. This system measures the beam current out of the injector, compares it to the currents in the three experimental halls, and uses these measurements to calculate the beam loss. The BLA system shuts down the accelerator if the loss becomes too great. The beam current and loss data for approximately 40 milliseconds before the trip is archived and plotted. Figure 1 is an example plot from the BLA and shows the beam current from the Injector, the current in one of the experimental halls, the instantaneous loss, and the Fast Fourier Transform (FFT) of the instantaneous loss. In this case the Injector current is constant while the current in Hall A has an oscillatory structure. The loss signature also shows this structure, as it is the difference of the Injector and Hall A currents, and the FFT of the loss has a frequency spike at approximately 820 Hz which is typical of these faults and generally vary from 800 to 900 Hz.

FIGURE 1. BLA plots after a beam loss trip.

The 820 Hz signature detected by the BLA system was also observed by Beam Position Monitors (BPM) in high dispersion areas. Figure 2 shows an example of this where the beam takes a turn in the horizontal plain. The oscillation is mainly detected in the horizontal axis which indicates an energy fluctuation. The beam energy is determined by the accelerating cavities so the next step in the investigation was to look for this signature in a RFCM.

FIGURE 2. BPM detects horizontal motion in high dispersion area.

Figure 3 is data taken from a Dist DAQ prototype connected to a RFCM. A test was executed that caused the cavity and RFCM to go into oscillations. The result was a fluctuation in cavity gradient that produced the same structure observed by the BLA and BPM systems. This verified that the accelerating cavities were the root cause of the beam loss faults.

FIGURE 3. Dist DAQ prototype plot verifies gradient oscillations in RFCM and cavity.

Accelerating Cavity Instabilities

The RF accelerating cavities, and the klystrons that drive them, are often run near their maximum RF power. Effects on the cavity from electron beam loading can make it difficult for the RFCM to maintain the cavity's gradient and phase. This could be due to microphonics, the cavity being out of tune, or a miscalculation of the maximum power. As a result, the RFCM requests more power from the klystron and pushes the klystron beyond its nominal range. Occasionally, this causes oscillations in the RFCM control loop, and thus electron beam energy fluctuations, which result in beam motion and loss since the beam can no longer traverse the accelerator. Beam loss detection systems then shut down the accelerator to protect against a burn through. Once the accelerator is shut down, the effects of beam loading diminishes and the struggling cavity and RFCM returns to a stable state. This entire process typically happens within 10 milliseconds. Although these instabilities can be indirectly detected using the BPM and BLA systems, the responsible cavity cannot be easily identified. Diagnostics on the RFCM cards do not have the bandwidth necessary to identify the problematic cavity and report it back through EPICS. Presently, the only option is to hand check each of the 338 cavities (160 in each Linac and 18 in the Injector). Even then the probability of isolating the unstable cavity is low due to the sporadic nature of the faults.

SYSTEM OVERVIEW

Each of the 338 RFCMs output 6 analog control signals for a total of 2,028. The Dist DAQ system will monitor all the available RFCM signals in the accelerator to offer insight into the behavior of the RFCM control loop and help quickly identify misbehaving cavities. It will operate similarly to a triggered oscilloscope with a large number of inputs and have a sample rate high enough to identify fast transients that are

currently undetectable. Each channel will be sampled simultaneously and stored in circular buffers. Event triggers will be used to freeze the buffers and provide a snapshot of all the signals. Once the buffers have been read, the system will reset and continue sampling until the next event trigger. These triggers may be based on fast shutdown (FSD) events, beam sync, software timers, or any other relevant signals. The data will be stored in files and provide the foundation for automated troubleshooting and testing tools for RFCM cards and other systems that are integrated in the future. These tools will include performing an autopsy after a FSD event trigger to quickly determine the root cause of the fault. Software initiated event triggers will also be used to collect data and preemptively evaluate the performance of accelerator systems. The Dist DAQ system is currently being designed and will be tested in the CEBAF Injector before being expanded to the entire accelerator.

Specifications

The completed Dist DAQ system will consist of 44 Data Acquisition Chassis (DAQ Chassis) and 4 Event Trigger Chassis (ET Chassis). These standalone chassis will run EPICS locally and communicate via the CEBAF Ethernet. A DAQ Chassis will be installed in each zone that has a RFCM rack. This includes 4 zones in the injector service building and 20 zones in each Linac service building. Each DAQ Chassis will receive global event triggers from a dedicated fiber optic network. They will monitor the 48 signals produced by the 8 RFCM cards in a rack and also have 12 spare channels for incorporating future systems such as magnet controls, BPM, BCM, etc.

The Central Event Trigger Chassis (CET Chassis) will reside in the Machine Control Center. A star topology will be used to distribute the event triggers from the CET Chassis to 3 Repeater Event Trigger Chassis (RET Chassis) located in the 2 Linacs and the injector. The RET Chassis will then relay the event triggers to all of the DAQ Chassis in their respective service buildings. This results in approximately equal propagation delays to all the DAQ Chassis to allow for synchronous triggering of all signals. Local triggers can be feed into the system from any ET or DAQ chassis. The trigger is routed up to the CET Chassis which then distributes it back though the trigger network to ensure synchronous triggering. These trigger packets will contain information such as the trigger type and number. This tag will be appended to all the data collected as a result of the trigger so that the data can be categorized and time stamped.

Data Acquisition Chassis

The DAQ Chassis will have 5 ADC PCB modules (shown in Figure 4) that monitor 12 inputs each. The ADC boards accept +/- 15 V inputs and are divided into two 6-input sections that each monitor a RFCM. Each of the input channels has a dedicated 1.25 MHz ADC with a resolution of 16 bits. An additional 40 MHz, 14-bit ADC is multiplexed across 6 RFCM inputs and used to detect higher frequency signals components. A 16-bit digital-to-analog converter (DAC) is multiplexed to the 7 ADC channels in each section. The DAC is used as a self check for the ADC channels and available as an output if need in the future. All of these components are controlled by

a Field Programmable Gate Array (FPGA) that also processes and stores the ADC data in Static Random Access Memory (SRAM). The data is organized in circular buffers and collection ceases when an event trigger is received. The FPGA will then transfer the data to a motherboard PCB that it is plugged into. After the transfer, the FPGA will resume data collection.

The motherboard will have 5 ADC PCB cards plugged into it as well as a PC/104-Plus single board computer (shown in Figure 4). A FPGA on the motherboard will be responsible for receiving fiber optic event triggers and freezing the corresponding ADC channels on the ADC boards. It also collects the appropriate ADC data in Synchronous Dynamic Random Access Memory (SDRAM) and provides this data to the PC/104-Plus module through a Peripheral Component Interconnect (PCI) bus. The PC/104-Plus single board computer is based on a 586 processor with Ethernet capabilities. The module will run RTEMS (Real-Time Operating System for Multiprocessor Systems) and be the gateway into the EPICS (Experimental Physics and Industrial Control System) control system used for the accelerator.

FIGURE 4. Above are pictures of the ADC PCB (left) and PC/104-Plus module (right).

Event Trigger Chassis

Each ET Chassis will contain the same PC/104-Plus board used in the DAQ Chassis. They will be responsible for creating the event triggers based on trigger inputs such as FSD and beam sync signals as well as distributing the event triggers to all of the DAQ Chassis. To accomplish this, the chassis will also include a Trigger PCB that accepts fiber optic, TTL, and analog trigger inputs. The board will also have fiber optic inputs and outputs used to distribute event triggers to other ET and DAQ Chassis. A FPGA will again be used to handle the triggers and communicate with the PC/104-Plus module.

Software Tools

All data and controls will be available through EPICS. The user controls will include selecting sample rates and configuring global triggers. Global event triggers will be created based on different trigger input signals and each trigger can include just one channel, all channels, or any combination of channels. This yields global trigger tables that will reside in the CET Chassis and used to generate the event triggers. The DAQ Chassis will also use these tables to collect data for each event and stamp the data with the event type and event number. The data is then stored in file-based ring buffers according to trigger type. The length of the ring buffers will be

selectable and users will be able to find any event in the buffers based on the stamped information. These files will be used as a platform to build automated software for detecting RF cavity abnormalities. High level software applications will display the information in these files as well as analyze them to find signals with large standard deviations and frequency information that indicate instabilities. A set of standard operating modes are defined below.

Oscilloscope Mode

This mode allows RF maintenance staff to observe the RFCM signals for individual cavities remotely. They will be able to trigger the signals with beam sync or take data in a free-running mode. Data will be presenting in an oscilloscope-like format for interpretation by the RF maintenance staff. The multiplexed 40 MHz channels will only be configurable using this mode. This and other modes will use the dedicated RFCM and spare 1.25 MHz channels in tandem.

RFCM Health Check Mode

The automated RFCM Health Check routine will periodically trigger the Dist DAQ to collect tens of milliseconds of data from the relevant RFCM signals. The software will then calculate the standard deviation, peak-to-peak values, and FFT for the acquired signals. Abnormal cavities will be flagged for intervention by operators and RF maintenance staff. The program could also automatically adjust cavity parameters to try to correct certain identifiable problems.

Autopsy Mode

A Dist DAQ trigger will be generated by FSD events (such as beam loss) and include relevant RFCM signals. Data will be recorded for tens of milliseconds before the FSD fault. The standard deviation, peak-to-peak value, and FFT will be calculated for each signal and any cavity exhibiting abnormalities just prior to the fault will be flagged for the operations staff.

CONCLUSIONS

The Dist DAQ system will provide the foundation for many automated tools that will help maximize accelerator cavity performance. It will also allow users to remotely capture and view various signals from throughout CEBAF in an easy-to-use oscilloscope format. The high sample rate and circular buffers will allow previously undetectable issues to be uncovered and addressed and the ability to synchronously trigger the system to provide a snapshot of the entire accelerator allows instabilities to be isolated quickly. The system can be expandable to incorporate other accelerator signals by adding DAQ Chassis as needed or using spare channels. The standalone chassis design frees the system from the traditional card cage topology, thus reducing costs and increasing flexibility. All of these features will result in the Dist DAQ system being a valuable asset to the operation CEBAF.