Development of Beam Monitor DAQ system for 3NBT at J-PARC

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Abstract

The 3 GeV proton beam transport facility (3NBT) is a high-intensity proton beam line from the 3GeV Rapid Cycling Synchrotron (RCS) to the Material and Life science Facility (MLF) at Japan Proton Accelerator Research Complex (J-PARC). In order to allow hands-on maintenance, a design criterion has been that the average beam loss at 3NBT be less than 1W/m. The systems for beam monitoring and magnet power control play an important role. In J-PARC, the Experimental Physics and Industrial Control System (EPICS) [1] will be used for the main control system. For the proton beam monitor system of 3NBT, EPICS is used and it has to work at 25Hz.

In this study, a data acquisition system for the proton beam monitors is presented that has been developed with EPICS. Its performance has been investigated under 25Hz frequency condition.

1. Introduction

The 3 GeV proton beam transport facility (3NBT) is a high-intensity proton beam line from the 3GeV Rapid Cycling Synchrotron (RCS) to the Material and Life Science Facility (MLF) in Japan Proton Accelerator Research Complex (J-PARC) (Fig. 1). The maximum proton beam power of 3NBT is 1MW (333μA). The length of the beam line is about 310 m and there are about 110 electrical magnets, 89 proton beam monitors, and many vacuum components in the beam line. At 3NBT, the average beam loss must be kept to less than 1W/m to allow hands-on maintenance. Therefore, the beam line design and the control system, which includes the proton beam monitors, are important. In J-PARC, the Experimental Physics and Industrial Control System (EPICS) is used for the main control

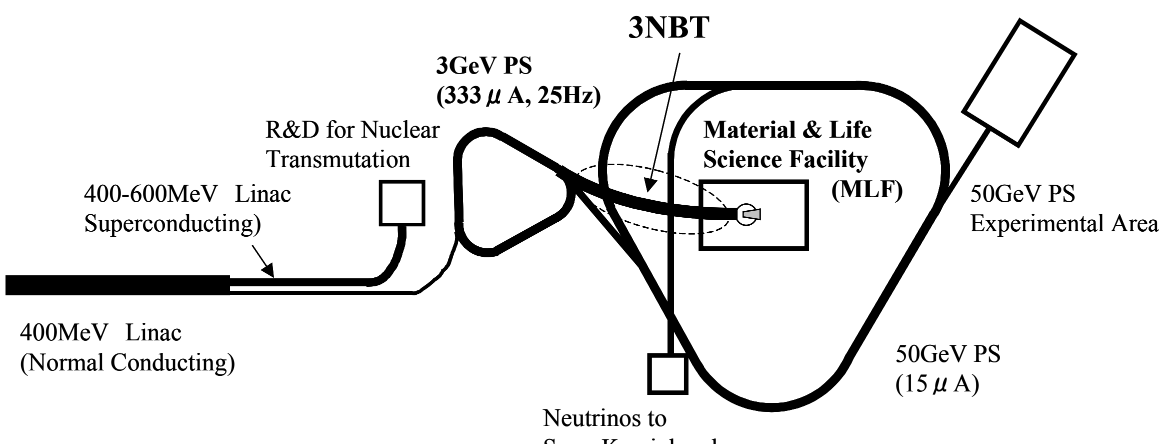

Figure 1. Overview of J-PARC

system. In the proton beam monitor system of 3NBT, EPICS is used with a frequency of 25Hz, which is the same as the proton beam frequency at 3NBT. All data for each proton beam need to be archived without data loss.

In this study, we show the present status of development of the data acquisition (DAQ) system for the proton beam monitors at 3NBT. The DAQ system of 3NBT has been developed with EPICS and CAMAC.

2. 1. Outline of the Beam monitor system

An outline of the beam monitor system is shown in Fig 2. On 3NBT, there are four types of proton beam monitors: profile monitor, halo monitor, loss monitor, and current monitor. The profile monitor consists of 32 wires for horizontal and 32 wires for vertical position monitoring. Wires are made of SiC-clad tungsten. The halo monitors consist of four plates around the beam path. The loss monitor consists of four proportional gas counters that measure secondary particles. The current monitor is a current transformer. All monitor signals are fed into ADC CAMAC modules in crates located in the 3NBT control room. At 3NBT, CAMAC has been selected for the beam monitor DAQ system because of cost and because it has enough performance. In this system, the network CAMAC crate controller CC/NET [2] is used. CC/NET consists of a CAMAC interface module and a PC104 single board computer with Linux OS. CC/NET can connect to the local area network (LAN) and is also able to work as an EPICS IOC.

In the J-PARC proton beam control, every proton beam is assigned a shot tag. The shot tag is a 32-bit number and used for identifying each beam history. The shot tag is generated at Central Control Room (CCR), and from there distributed to each local control system via optical cable. At 3NBT, the shot tag is distributed via VME-based timing modules and forwarded to the CC/NET.

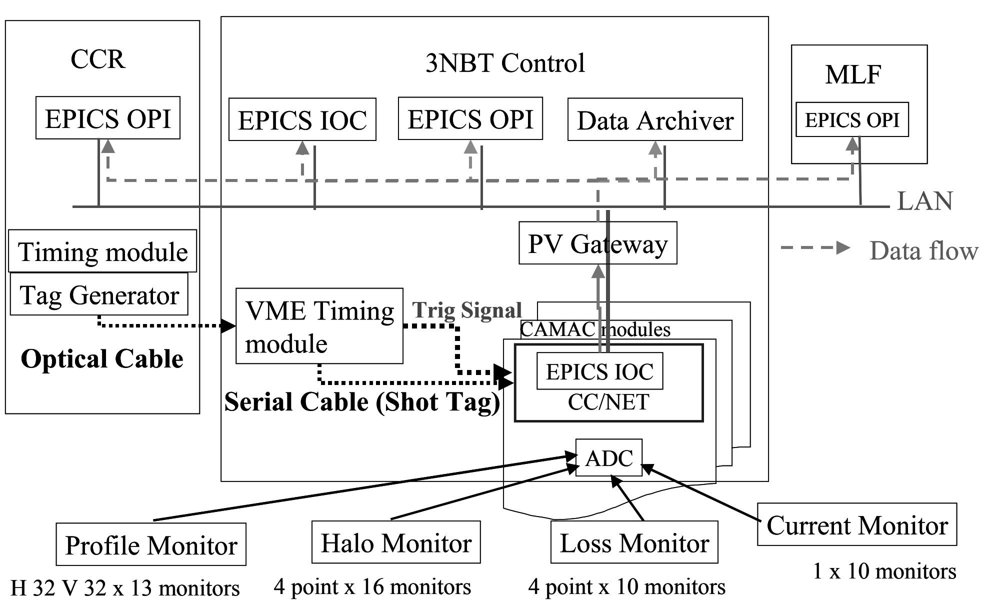

Figure 2. Outline of 3NBT proton beam monitors.

2.2. DAQ system development

The first development for the DAQ system with CC/NET was an EPICS-to-CC/NET device driver. The CC/NET has three CAMAC DAQ modes: single mode, PIO mode, and DMA mode. In general, DMA mode is faster for taking large amounts of data at once. In the 3NBT monitor system, there are many data points (over thousand), but 32 data points per monitor is the maximum (for one axis of profile monitoring). To decide on the best DAQ mode at 3NBT, we made device drivers for each DAQ mode and compared the performance. Results are shown in fig. 3. Each CAMAC crate can house up to 23 ADCs. We use 16ch ADCs, hence 368 data points is the maximum for one CC/NET. In the case of less than 32 data elements with one EPICS record, each DAQ mode shows enough performance, but PIO mode is the best with regards to CPU load and DAQ time. Hence, PIO mode has been selected for the EPICS-to-CC/NET device driver.

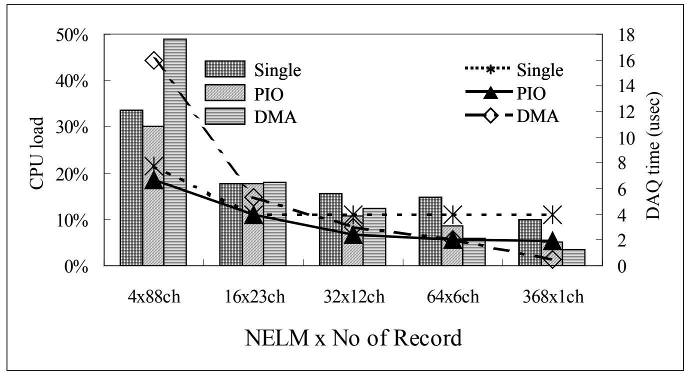

Figure 3. Result of DAQ mode test.

The proton beam monitors at 3NBT are monitored from the CCR, the 3NBT control room, and the MLF control room. In addition, the data storage system accesses these data. This means that if these EPICS client systems were to access the CC/NET directly, the data access capacity to the CC/NET could be exceeded and data could be lost. Figure 4 shows the CPU load of the CC/NET in function of the number of EPICS clients. In the case of direct connections, CPU load is almost proportional to the number of clients. When nine clients access the CC/NET, the CPU load reaches the limit and large amounts of data are lost. But when there is a Process Variable (PV) gateway [3] or external EPICS IOC server, only the PV gateway or the EPICS IOC server access the CC/NET and this limitation problem is solved.

Regarding the shot tag number, it is received from the VME based timing module (see figure 2). In order to synchronize shot tag and beam monitor data, the shot tag is forwarded to the CC/NET. One idea to forward the shot tag from VME to CAMAC could be to use a VME-CAMAC module; but this is relatively expensive. Instead we propose to use a serial connection from the VME controller to CC/NET. The VME controller has a serial port and CC/NET has two RS-232 ports. In real operation, tag timing may not be synchronizing reliably with EPICS sequence timing. Therefore, in the trial version, the VME system sends shot tags with free timing to the CC/NET, where an intermediate transfer program receives the tags and waits for requests from EPICS IOC. As a result, the shot tags are successfully forwarded to the EPICS at 25Hz.

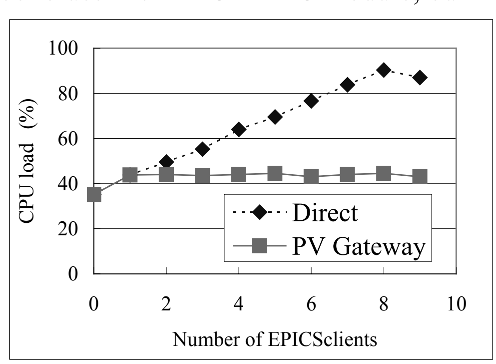

Figure 4. Data access load with and without PV Gateway.

2.3. Data Archiver

The beam monitor data archive is important for off-line beam studies. Loss-less data archiving is required. The standard EPICS Channel Archiver shows almost enough performance. But, as we are planning to use these data for off-line beam transport studies, it may not provide easy data access. Another possibility to archive the data is by using an SQL database. SQL is a free database software and easy to access from other programs. We have written a prototype EPICS-to-SQL device driver and tested its performance. The driver reads all monitor data with Channel Access (CA), and then uses SQL commands to write these data to the SQL server. As long as the frequency is low, it works well but at the frequency of 25Hz there is some data loss. We have to improve its performance.

2.4. Linux Tick Frequency

Another issue is the Linux tick frequency. The default operating system (OS) of the CC/NET is Linux kernel 2.4, and its tick frequency is 100 Hz. The tick frequency is the internal clock of the Linux OS. The DAQ frequency at 3NBT of 25Hz is the same in order of magnitude. So, already a single tick loss has a relatively large effect on the DAQ sequence. We compared the data loss rates at tick frequencies of 100Hz and 1000Hz. When monitor data on the CC/NET are directly archived, there is no data loss. In this performance test, data are generated by on one EPICS IOC then received by another EPICS IOC, and then archived for checking the data.

When the DAQ frequency is low, there is almost no difference between tick frequencies. On the other hand, when the DAQ frequency becomes faster than 25Hz, data loss with tick frequency of 1000Hz is lower than with 100Hz (shown in table 1). We also checked the fluctuation of data access timing from IOC to CC/NET. Timing fluctuation at a tick frequency of 100Hz is ±5msec; at 1000Hz it is ±1msec. Moreover, this fluctuation appears more frequently when the tick frequency is 100 Hz. So, a tick frequency of 1000 Hz is better.

Table 1. Data loss ratio with DAQ frequency and Tick frequency

DAQ Hz	Tick 100Hz Data loss	Tick 1000Hz Data loss
1Hz	0.1%	0.1%
10Hz	0.2%	0.2%
25Hz	0.8%	0.2%
33Hz	0.7%	0.2%
50Hz	0.6%	0.2%

2.5. Other Known Problems

In the above evaluation, we do not take into account any network access to the CC/NET, any input from keyboard, nor the possibility that other processes may be running. It means this is the minimum load on the CC/NET. In the beginning of the performance test, the ‘top’ process is always running on the CC/NET and there is some data loss, but when the ‘top’ process stops, the data loss becomes small or disappears altogether. We then added external load to CC/NET and checked the performance of

EPICS data access.

As a result, it has been realized that other operations affect data loss, e.g.:

- Some programs like 'top',
- Key inputs on the CC/NET,
- Network access to the CC/NET,
- Large data transfers like FTP processes

When these processes are running, there is up to 1% of data loss. So, in real operations, stopping and minimizing such extra processes are important

3. Profile Monitor Test in KEK

3.1. Outline of Profile Monitor Test

Proton beam profile monitors are directly irradiated with the proton beam. Hence they have to have a long lifetime and should produce low beam scattering. The radiation susceptibility of SiC is much smaller than that of tungsten (about one-hundredth). And also due to low atomic number, Rutherford scattering of proton beam becomes small with SiC, resulting in a smaller beam loss. Considering these characteristics, a prototype SiC-clad tungsten wire profile monitor has been produced and tested.

At the existing proton beam line at KEK NML, there is almost the same monitor but using tungsten wire. So, the same amp and ADC module could have been used in the 3NBT profile monitor. However, the main IC of the amp and ADC module used at KEK are no longer commercially available. So we had to develop a new amp and ADC module for our system. To develop the amp and ADC module, we needed to know the signal from the prototype profile monitor and measure the proton beam profile at the KEK proton beam line to check its performance.

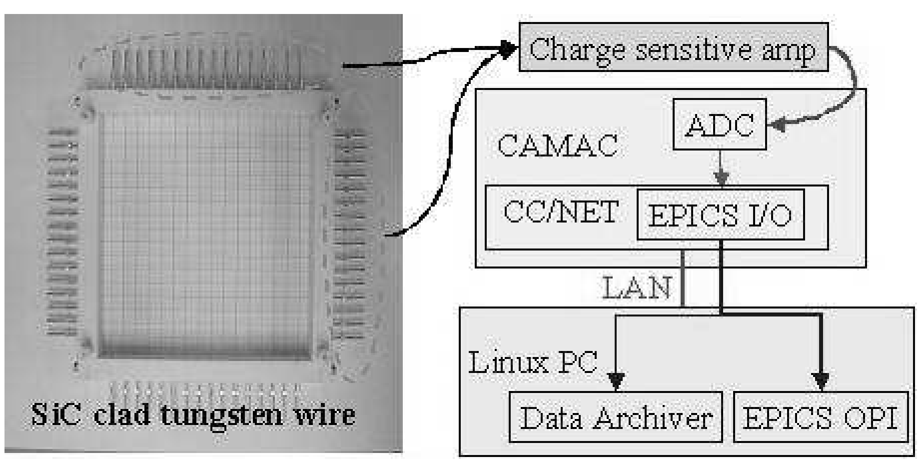

Figure 5. Wire frame profile monitor and data taking.

3.2. Experiment and Results

Figure 5 shows the wire frame of the prototype profile monitor and the outline of the measurement system. The wires are SiC-clad tungsten. The monitor signal is fed to the local control room and monitored by means of CAMAC ADCs with EPICS. The proton energy is 500MeV, the proton current is 1.82×10^{12} protons per bunch, and the repetition rate is 0.45Hz. As a reference, the existing tungsten profile monitor is used which is placed 2m downside of the beam line.

As first step we measured the raw output signal with a digital oscilloscope (Figure 6). The raw signal is rapidly vibrating. So we need to process it with a charge sensitive amp module. Then we measured the proton beam profile with an ADC. The measured data is archived with Channel Archiver on the Linux WS. Figure 7 shows the results of the beam profile measurement. The upper part of Fig 7 shows the measurement from the prototype monitor with the new amp and ADC modules with EPICS; the lower part shows the result from the original KEK monitor system, which is the reference.

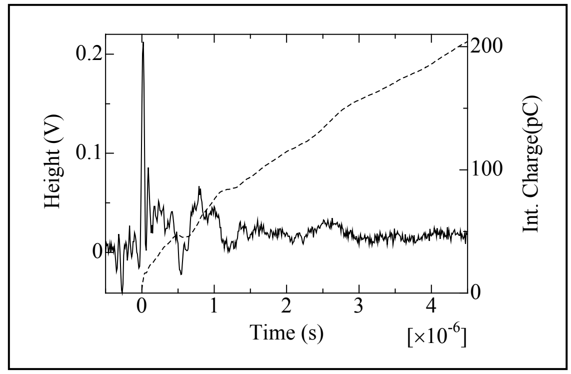

Figure 6. Monitor signal from wire profile monitor

Both results show almost same beam profile in horizontal. Please note that the beam dump line has a vertical inclination. That is the reason for difference in vertical beam positions. As result, we can measure the proton beam profile with EPICS and new amp and ADC CAMAC modules with CC/NET.

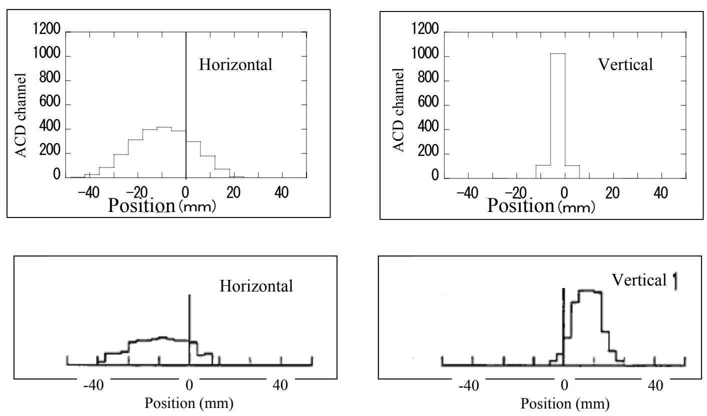

Figure 7. Proton beam profile. Measured with EPICS (up). Reference monitor (down)

4. Summary

We have developed a proton beam monitor DAQ system for 3NBT with CAMAC CC/NET and EPICS. PIO mode has been selected for CC/NET to CAMAC device driver. The data archive system with SQL is under development. The shot tag data is successfully received with CC/NET. These system works well in the profile monitor test in KEK.

References

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[3] http://www.aps.anl.gov/epics/extensions/gateway/index.php