EPICS-BASED CONTROL SYSTEM FOR BEAM DIAGNOSTICS OF J-PARC LINAC

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Abstract

Various beam monitor has been used to satisfy different purposes in the J-PARC LINAC. A control system for the monitor devices has been developed and implemented utlizing EPICS software. Two kinds of hardware are used to acquire waveform data from monitor devices, and results are transmitted to upper EPICS Input/Output controllers through the control network. This paper describes the detailed realization, the system performance, and the current status.

INTRODUCTION

The proton beam has been accelerated to 181-MeV in the J-PARC (Japan Proton Accelerator Research Complex) LINAC during the beam commissioning. To diagnose the beam status, different types of monitor devices are installed along the sequence of J-PARC LINAC. The layout of monitor devices is illustrated in Fig. 1 [1 ~ 3].

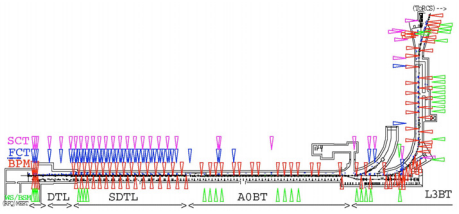

Figure 1: Monitor Device Layout in J-PARC LINAC.

Fig. 1 shows 4 types of beam monitors described as followings:

- BPM: beam position monitor to measure the beam orbit showed as a red triangle marker;
- FCT: fast current transformer to measure the beam phase and beam energy showed as a blue triangle marker;
- SCT: slow current transformer to measure the beam current showed as a pink triangle marker;
- WSM: wire scanner monitor to measure the beam profile showed as a green triangle marker.

The control for all above devices is implemented using a popular software toolkit, EPICS (Experimental Physics and Industrial Control System) [4].

For a high intensity proton machine, it is also very important to monitor the beam loss. The beam loss is measured using a BLM (Beam Loss Monitor) device in the J-PARC LINAC. Parts of the BLM devices are controlled under EPICS framework, which utilizes a same architecture with other monitor devices, and others are controlled using a special hardware. The control of BLM under the EPICS is also presented in this paper.

SYSTEM ARCHITECTURE

The raw data from monitor device is digitized by 2 types of hardware: (1) WE7000, a commercial digitizer from the Yokogawa Company; (2) WER (Wave Endless Recorder) [5], a home-made digitizer. Two control architectures are realized corresponding to 2 different hardware digitizers.

WE7000

The WE7000 is a module-type measurement station, and supports network-based data transmission and communication. Two types of WE7000 modules are used for the digitization: (1) WE7111, which is a 100MS/s digitizer with 1 channel, and supports 8-bit resolution; (2) WE7118, which is a 100-MS/s digitizer with 2 channels, and supports 14-bit resolution.

Fig.2 demonstrates a schematic for the monitor control in the MEBT1 section. The waveform signal from BPM FCT, or WSM, is acquired using the WE7118 module, and signal from SCT is acquired using the WE7111 module. In the other section such as SDTL, a SCT waveform signal is also digitized by the WE7118.

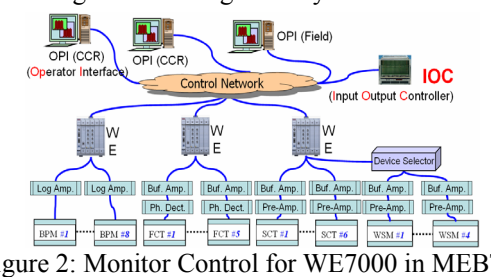

Figure 2: Monitor Control for WE7000 in MEBT1.

The beam phase is detected using a phase detector. It compares the measured signals from a FCT and from the reference RF signal. The output signal from a phase detector is digitized using a WE7118 module. The control of attenuation and dynamic range of phase detector is controlled by WE7262, which is a digital input/output module from Yokogawa.

The digitized waveform signals by a WE7000 station are sent to an EPICS IOC through the control network.

WER

The WER is used to control the BPMs around the last section of LINAC and the BLM. The BPM is digitized using a 200MS/s module, which supports 4 input channels with 12-bits resolution. The BLM is digitized using a 200MS/s or a 10MS/s module. The system configuration is demonstrated as Fig. 3.

The WER is controlled using a METIS software, which is a Java-based application running on a standalone Linux server. One METIS application supports 8 input channels, and can control 2 WER modules.

The raw waveform data from monitor device is digitized by the WER, and transferred to the METIS server. The METIS computes the signal voltage according the requirement and writes the results to an EPICS IOC. All data are transferred through the control network.

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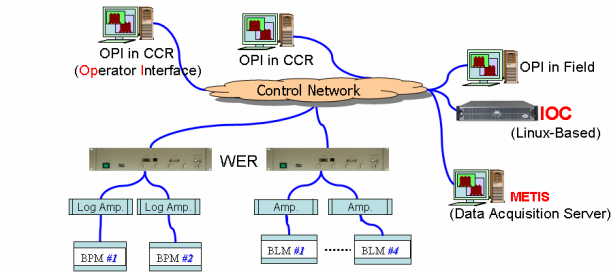

Figure 3: Configuration of Monitor Control using WER.

IOC DEVELOPMENT

Two kinds of IOC are used corresponded to the different control schematic of monitor device.

The IOC for WE7000 adopts a VME-bus based SBC (Single Board Computer), and uses the vxWorks real-time operating system. It performs hardware control, data acquisition, and data processing. A raw waveform acquired by a WE7000 module is sent to the IOC, and converted to the voltage from the raw digital count. An average is performed according the beam condition to calculate the signal voltage. With this voltage, some physical variables are calculated including beam current, position, phase, and beam energy.

The IOC for WER is a soft-IOC, and runs on a standalone Linux server. The signal voltage for BLM or BPM is saved in the IOC. The beam position is calculated each time when the voltage is updated.

Device Driver of WE7000

An EPICS driver for the WE7000 station has been developed in J-PARC project [6]. It supports various WE7000 modules including WE7111, WE7118, and WE7262.

A problem was found for the WE7118 driver during converting a digital count to a voltage. It showed that the converted voltage was about 10% lower than a real signal voltage. The reason was found finally that the manufacturer narrowed the dynamic range to improve the hardware capacity to avoid the noise and increase the accuracy of measurement. Some necessary parameters are saved in the hardware, which are necessary to convert the digital count to voltage. Those parameters are updated each time when the hardware is turned on. The driver was updated to support that functionality. After improving the device driver, a correct voltage is obtained.

Beam Position

The beam position is calculated inside an IOC using a difference signal. The difference signal is outputted from a logarithmic amplifier for BPM. The equation [3] used for the calculation is listed as following:

$$\begin{cases} S = \dfrac{160}{\ln 10} \cdot \dfrac{\sin(\phi/2)}{\phi} \cdot \dfrac{1}{r} \\ x = V_{x.diff} / S, y = V_{y.diff} / S \\ X = \Sigma_{i=0}^{4} \Sigma_{j=0}^{(4-i)} a_{ij} \cdot x^i \cdot y^j, Y = \Sigma_{i=0}^{4} \Sigma_{j=0}^{(4-i)} b_{ij} \cdot x^i \cdot y^j \end{cases}$$

Here, S is a geometrical parameter determined from BPM radius (r), and the opening angle width (ϕ) of pickup electrode. The a_{ij} and b_{ij} are parameters obtained from the offline calibration.

All parameters are saved in the EPICS records. Because the value of S parameter is a constant for a particular BPM, the calculated value is saved in a record.

The final position value, X and Y, is calculated using a "hugesub" record, which was developed against R3.13 by KEK, and is updated in J-PARC for R3.14. It is based on the standard subroutine record, and supports about 32 input links.

Beam Phase and Energy

The beam phase and energy is measured with the aid of FCT pair based on a TOF (Time-Of-Flight) method. The signal detected by a FCT is compared with the reference signal using a phase detector. The output voltage from the phase detector is linear proportional to the beam phase.

The time of flight of beam is measured by calculating the phase difference at 2 FCTs. The beam energy is calculated after obtaining the beam flight time, and getting the distance between 2 FCTs. To improve the system accuracy, the distance between 2 FCT's is measured using a laser-tracker with an accuracy of ~0.2mm.

IOC Performance

As original plan, the beam was delivered to 30º beam dump before the 2007 summer shutdown. The control system for the beam diagnostic system was finished to 30º beam dump using 8 VME-Bus based IOCs. In each IOC, there were about 32 waveform channels controlled with a waveform length of 2KB.

The usage about CPU and memory for each IOC is showed as Fig. 4 under the beam condition with 2.5-Hz repetition. The upper part is the CPU usage, which is less than 40% for all IOCs. The lower part is the memory usage, which is about 25% for all IOCs.

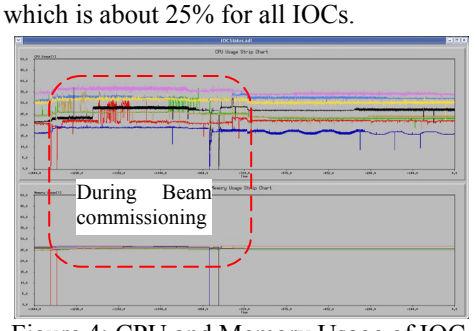

Figure 4: CPU and Memory Usage of IOC.

The IOC can provide a system repetition up to 6-Hz, which reaches the bottleneck of WE7000 hardware. It has enough capacity and satisfied the current beam commissioning requirement, which is 2.5-Hz.

During the summer shutdown, the installation for the left part of beam monitor system has been finished. Corresponding to the construction progress, the control system is implemented for the whole LINAC by adding 3 vxWorks based IOCs and a Linux-based soft-IOC.

OPI APPLICATION

The OPI application for monitor device is designed using various tools such as MEDM (Motif Editor and Display Manager), EDM (Extensible Display Manager), and JCE (J-PARC Commissioning Environment) [7].

The waveform monitor is developed using the MEDM showed as Fig. 5. It displayed a waveform acquired from the SCT in MEBT1 section, which was a result at the first day of first beam study at J-PARC LINAC.

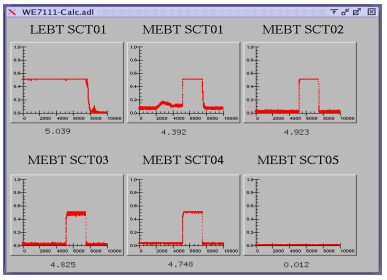

Figure 5: Beam Current Waveform Monitor from SCT.

The beam current is monitored using an EDM application as Fig. 6 demonstrated. It demonstrated the beam current detected by the SCT in the straight section of J-PARC LINAC. The first SCT locates before a RFQ, and the current shows about 30-mA. The others are locate behind the RFQ, the currents show about 26-mA. It also shows the pass rate of the RFQ is high than 85% roughly.

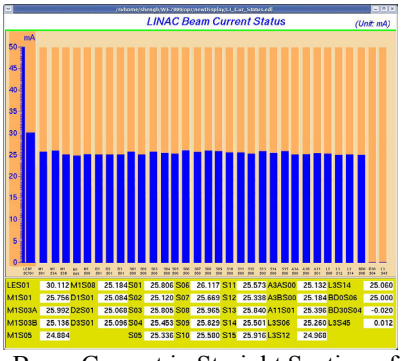

Figure 6: Beam Current in Straight Section of LINAC.

The real-time beam energy calculated inside IOC is also monitored using an EDM based application showed as Fig. 7. The beam energy is measured using those FCT pair without RF cavity in-between, which is available at MEBT1, SDTL, and ACS section as Fig. 7 demonstrated. It shows dynamic beam energy at each measure point.

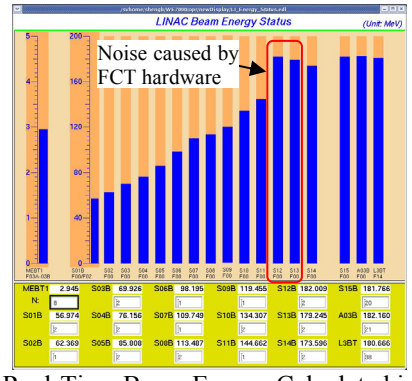

Figure 7: Real-Time Beam Energy Calculated inside IOC.

The energy measured at SDTL13 and SDTL14 did not show correct beam energy. It is caused by the FCT hardware problem. The noise of FCT pick-up electrode is too large, and can not be calibrated. The hardware will be changed in the near future.

Some JCE-based applications are developed to monitor the status of monitor system. Fig. 8 demonstrated the beam orbit measured by the BPM in the J-PARC LINAC.

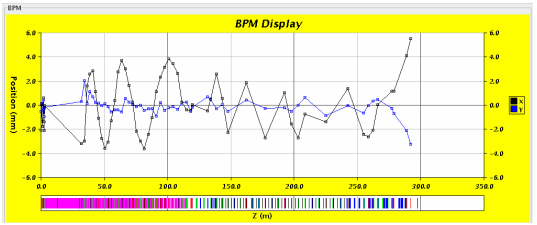

Figure 8: Beam Orbit Display Developed with JCE.

SUMMARY

A control system for the beam diagnostics system has been realized using the EPICS software. The waveform signal from a monitor device is digitized using a commercial WE7000 or a home-made WER. All the devices of beam diagnostics system are controlled using 11 vxWorks based IOCs and one Linux based soft-IOC. A real-time calculation for beam physical variable is perform inside the IOC including beam current, position, phase, and energy. The system repetition is up to 6-Hz, which shows enough capacity and satisfied current beam commissioning requirement.

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