

THE DEVELOPMENT OF LINUX-BASED PULSED MAGNET CONTROL SYSTEM USING PXIe DEVICES AT KEK LINAC

D. Wang^{1*}, M. Satoh¹, S. Ushimoto²,

¹KEK, Ibaraki 305-0801, Japan

²Mitsubishi Electric System & Service Co., Ltd

Abstract

The pulsed magnet control system (PMCS) at KEK electron positron injector LINAC operates at every 20 ms to achieve simultaneous injection for four rings, a 2.5 GeV Photon Factory (PF), a 6.5 GeV PF-AR, a 4 GeV SuperKEKB lower energy ring (LER) and a 7 GeV SuperKEKB high energy ring (HER). The system consists of a control server that operates on the Windows 8.1 platform, in conjunction with a PXIe chassis equipped with a DAC, an ADC, and an event timing module. The PXIe DAC board responds to the trigger signal which is generated from the event receiver and sets the current of the pulsed magnet. The current readback value of the magnet is retrieved from the ADC module. Despite its long success, the PMCS has several problems in use. One is the discontinued support of Windows 8.1. Another key concern is the unsatisfactory long-term stability. To solve the problems, an upgraded system using real-time Linux to communicate with PXIe modules is adopted. The EPICS driver for PXIe devices is developed to integrate with the LINAC control system. The development of the new Linux-based PMCS is introduced in this work.

INTRODUCTION

The injector LINAC at KEK is responsible for the injection of 4 target rings which consist of a 7 GeV electron high energy ring (HER), a 4 GeV positron low energy ring (LER), a 2.5 GeV Photon Factory (PF) and a 6.5 GeV PF-AR ring, as shown in Fig. 1. It should perform simultaneous top-up injections into four storage rings and a DR by pulse-to-pulse modulation (PPM) [1].

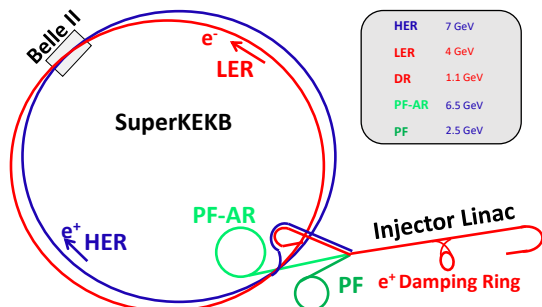


Figure 1: A schematic view of LINAC, SuperKEKB, and PF/PF-AR.

To satisfy such PPM requirements, 16 pulsed magnet control units have been installed along the 600-m LINAC since 2017. When the magnet control units receive an event code

that represents a kind of beam mode, it starts responding and sets the magnet current. By using these magnets, the magnetic field can be changed pulse-to-pulse in 20 ms, and the beam profile is optimized for each destination ring.

PULSED MAGNET CONTROL SYSTEM

Hardware

Figure 2 shows the rack of one pulsed magnet control unit. Each unit consists of a homemade server and a National Instruments (NI) PXIe-1082 chassis fitted with four modules, a controller control module (NI PXIe-8381), an event receiver (EVR) board (MRF PXI-EVR-230), a DAC board (NI PXI-6733), and an ADC board (NI PXIe-6356).

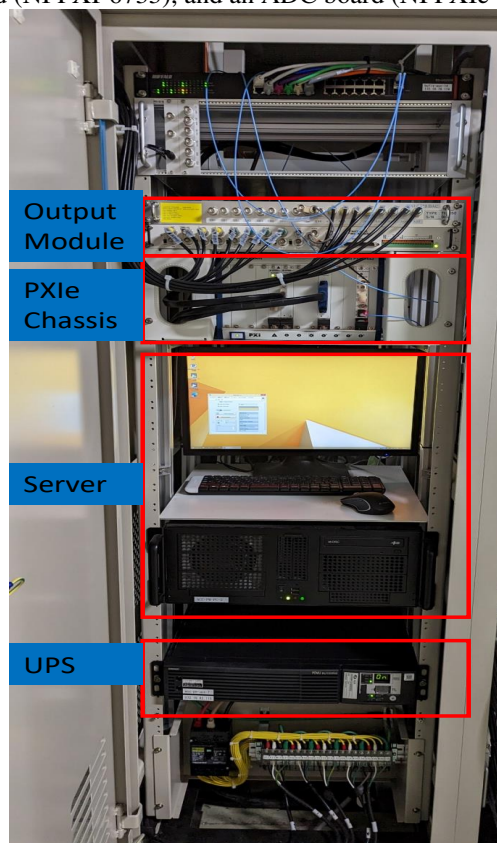


Figure 2: Rack of a pulsed magnet control unit.

This setup controls and monitors the output current of up to 8 power supplies independently, offering a resolution of 16 bits and operating at a sampling rate of 1 MSa/s. To avoid instability stemming from power outages or signal interference, an uninterruptible power supply (UPS) system has been deployed to furnish seamless auxiliary electrical

* di.wang@kek.jp

power. The comprehensive system is securely housed within a unified rack infrastructure.

Every individual unit can manage up to 8 pulsed magnets. Each of these pulsed magnets is responsive to 12 distinct beam modes. The output magnet current value is determined by the specific injection beam mode in operation.

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Software

On the software front, a LabVIEW application governs the process of data acquisition and provides connectivity through EPICS Channel Access (CA) [2].

Due to a variety of reasons, a resolution has been reached to enhance the current system through an upgrading process. Various justifications for this decision are enumerated as follows.

- Windows 8.1 is discontinued.
- The trigger dropping rate is high [2].
- System restart is required occasionally [2].
- The compatibility and performance issue of NI network shared variable.

NEW SYSTEM

PXIe modules under Linux

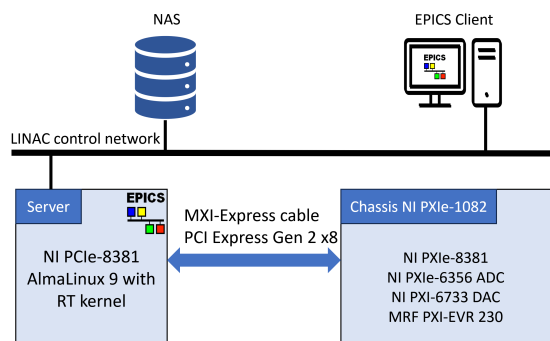


Figure 3: Diagram of the PMCS.

Figure 3 shows the structure of the new PMCS. The initial step of the upgrade process involves the preparation of the AlmaLinux distribution, after which an evaluation of the viability of the operation is conducted through the testing of drivers and access libraries.

In the case of NI modules, the server establishes a connection with the chassis using an NI PCIe-8381 module via an MXI-Express cable, which can transmit at a rate of 40 Gbps in each direction simultaneously. The Linux kernel driver is provided within the NI-DAQmx package. This package offers comprehensive assistance for devices oriented towards data acquisition and signal conditioning. The data acquired

via the ADC can be effectively stored within an EPICS waveform record, accomplished through the utilization of the callback function afforded by NI-DAQmx.

The mrfioc2 module from the EPICS community is used as a low-level driver of the PXI EVR module. Additionally, it is noteworthy that a minor modification of the mrfioc2 module is necessary to facilitate the reception of the data buffer from the EVR, owing to a compatibility issue related to CPU endianness.

Trigger System

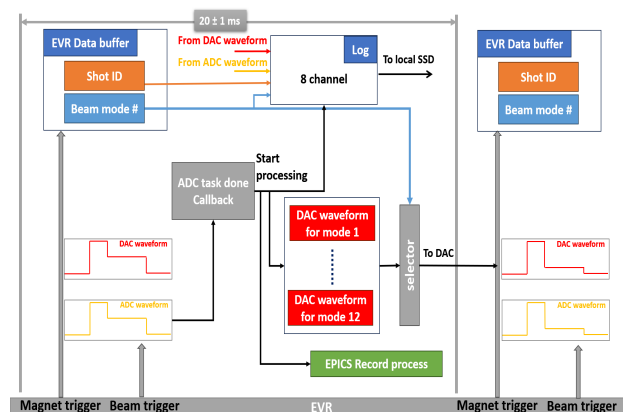


Figure 4: The data flow and trigger system.

As shown in Fig. 4, every 20 ms, the PMCS is triggered by a magnet trigger event. The current beam mode and shot ID are extracted from the data buffer of EVR. Meanwhile, the DAC outputs a waveform spanning a duration of 4 ms, directed towards the pulse driver. Upon completion of waveform acquisition by the ADC, an interrupt is generated, subsequently prompting the initiation of the logging system to store data originating from 8 distinct channels. Concurrently, the output waveform of the subsequent pulse is determined by the specific shot ID. The callback function also triggers the initiation of the record processing procedure. Finally, after writing a new waveform of the next pulse to the memory, the DAC enters a standby state and prepares for the forthcoming trigger event.

The synchronization mechanism between the DAC and ADC is established by configuring the trigger mode to operate in an external trigger. In this setup, the DAC is triggered through an external signal. The ADC performs a continuous process of data sampling, although the generation of the sample clock is synchronized to the arrival of the external trigger signal.

Real Time Configuration

The implementation of a real-time operating system plays a significant role in mitigating the concern of trigger drop occurrences. This brings the installation of a real-time kernel and the optimization of its policy settings to ensure a high-performance mode. With the help of the MCoreUtils module, the configuration of real-time parameters for EPICS Input/Output Controller (IOC) threads is also accomplished.

PASJ2023 THP09

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[Wed Jul 12 11:25:59 2023] epics> mcoreThreadShowAll
[Wed Jul 12 11:26:10 2023]
[Wed Jul 12 11:26:10 2023]
NAME          EPICS ID   LWP ID   OSIPRI   OSSPRI   STATE   POLICY   CPUSET
m_main_       0x1d32960  7470     0         0        OK      ?        ?
mrtLog        0x1d45a00  7472     10        10       OK      FIFO  1-7
EVRFIFO       0x1ded6b0  7473     90        89       OK      FIFO  1-7
PCISR0800:0f:0c 0x1e1f300  7474     98        97       OK      FIFO  1-7
[Wed Jul 12 11:26:10 2023]
pmlLog        0x2b5ac00  7479     10        10       OK      FIFO  1-7
tunerQueue   0x292f640  7480     19        19       OK      FIFO  1-7
[Wed Jul 12 11:26:10 2023]
cbLow         0x260cde0  7481     70        69       OK      FIFO  1-7
cbMedium     0x26066f0  7482     59        58       OK      FIFO  1-7
cbHigh       0x2615410  7483     64        63       OK      FIFO  1-7
[Wed Jul 12 11:26:10 2023]
dbCalLink    0x2615410  7485     50        50       OK      FIFO  1-7
tunerQueue   0x2611c10  7486     58        57       OK      FIFO  1-7
[Wed Jul 12 11:26:10 2023]
scanMedium   0x2953090  7491     67        66       OK      FIFO  1-7
scan-10      0x2952ab0  7492     65        64       OK      FIFO  1-7
[Wed Jul 12 11:26:10 2023]
scan-5       0x2952d00  7493     66        65       OK      FIFO  1-7
scan-2       0x2952f50  7494     67        66       OK      FIFO  1-7
[Wed Jul 12 11:26:10 2023]
scan-1       0x29531a0  7495     68        67       OK      FIFO  1-7
[Wed Jul 12 11:26:10 2023]
scan-0.5     0x29533f0  7496     69        68       OK      FIFO  1-7
scan-0.2     0x2953640  7497     70        69       OK      FIFO  1-7
[Wed Jul 12 11:26:10 2023]
scan0c-1     0x2953890  7498     71        70       OK      FIFO  1-7
[Wed Jul 12 11:26:10 2023]
CAS-TCP      0x295e3f0  7499     16        16       OK      FIFO  1-7
[Wed Jul 12 11:26:10 2023]
CAS-IDP     0x295e640  7500     12        12       OK      FIFO  1-7
[Wed Jul 12 11:26:10 2023]
CAS-busacm  0x295e990  7501     14        14       OK      FIFO  1-7
[Wed Jul 12 11:26:10 2023]
tpIOAscIProxy 0x7f88bc0f:50 7502    10        10       OK      FIFO  1-7
[Wed Jul 12 11:26:10 2023]
tunerQueue   0x7f88bc0103:f0 7503    52        51       OK      FIFO  1-7
[Wed Jul 12 11:26:10 2023]
CAC-IDP     0x7f88bc0118:50 7504    54        53       OK      FIFO  1-7
[Wed Jul 12 11:26:10 2023]
CAC-event   0x7f88bc0699:0e 7505    52        51       OK      FIFO  1-7
    
```

Figure 5: A real-time IOC configuration with different priorities, FIFO scheduling policy, and defined CPU affinity.

Adapting the MCoreUtils module allows for the adjustment of thread priorities, and scheduling policies (FIFO or Round-Robin). Additionally, optimizing the CPU affinity of IOC threads can enhance system performance, achieved through the segregation of CPU cores utilized by the house-keeping threads and the EPICS IOC threads. Figure 5 shows the result of our real-time IOC configuration.

Monitoring and Log System

Instead of employing EPICS channel access for logging purposes, an independent log thread is created. This approach serves to avoid potential performance complications caused by an excessive number of EPICS channel access clients. A ring buffer is established to accept log data from the ADC waveform every 20 ms and write them to a local SSD storage.

The log entries consist of three process variables associated with magnet currents, along with pulse information. The process variables include the magnet current’s designated set value, its actual output value, and the value retrieved from ADC readback. All data from 8 channels is recorded within a log waveform, tagged with a timestamp sourced from the EVR, the shot ID of current pulse, and injection beam mode of current pulse. These appended attributes facilitate the subsequent diagnostic analysis in case of system failures.

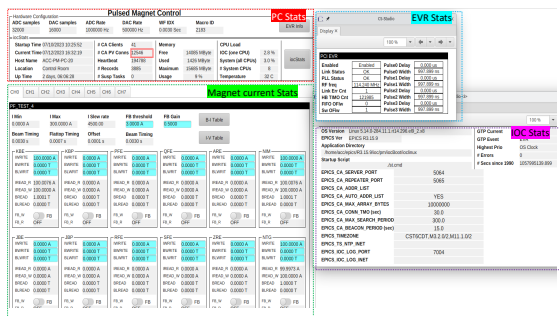


Figure 6: A monitoring OPI for PMCS.

An operator interface (OPI) panel is also provided to help operators monitor the IOC status and quickly find any anomalies. Figure 6 shows the interface.

Performance and Stability

The stability result measured in 2018 is reported in the paper [3]. Similarly, we undertook measurements of a test magnet and subsequently computed the relative stability utilizing statistical metrics including the mean value and standard deviation. The result is shown in Fig. 7. During the 8-hour experiment, the relative stability was 88 ppm, corresponding to the level with the precedent measurement.

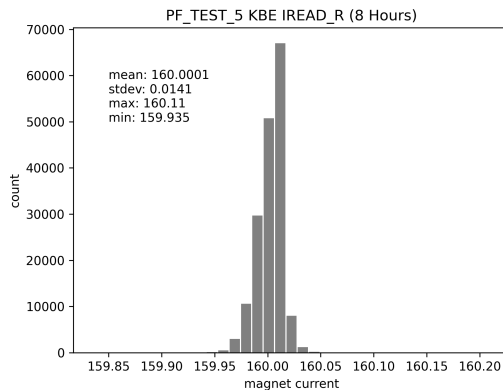


Figure 7: The measured magnet current result of a test magnet for 8 hours operation. The mean value and standard deviation of the current were 160 A and 0.0141 A, respectively.

For the long-term stability, after establishing 10 thousand channel access connections to the EPICS IOC, the new system demonstrated sustained and consistent performance during the operation of one month. Notably, no failures were observed during this period.

CONCLUSION

The pulsed magnet control system is upgraded from a Windows 8.1-based LabVIEW program to a non-proprietary operating system and software. We implement, test, validate, and modify the control software under the PXIe platform while keeping the available hardware. The experiment shows both the performance and stability are satisfactory.

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[3] Y. Enomoto et al., “Pulse-to-pulse Beam Modulation for 4 Storage Rings with 64 Pulsed Magnets,” in *Proceedings of the 29th Linear Accelerator Conf.*, vol. LINAC2018, 2018, pp. 609–614. doi:10.18429/JACOW-LINAC2018-WE1A06/