EPICS-BASED CONTROL SYSTEM FOR NEW SKEW QUADRUPOLE MAGNETS IN J-PARC MR

K.C. Sato *, S. Yamada, J. Takano, N. Kamikubota, S. Igarashi, N. Yamamoto
J-PARC, KEK & JAEA, Ibaraki, Japan
S. Yoshida, Kanto Information Service (KIS), Accelerator Group, Ibaraki, Japan

Abstract

In J-PARC Main Ring (MR), a control system for new skew quadrupole magnets has been constructed. This system is based on EPICS (Experimental Physics and Industrial Control System). The system comprises a PLC controller running Linux, a function generator, and a commercial DC amplifier. The function generator is controlled using VXI-11 protocol over Ethernet, and the amplifier is connected to PLC I/O modules with hardwire. Both devices are controlled by the PLC controller. The function generator produces a ramp-up waveform at each MR machine cycle of 2.48 seconds. The DC amplifier drives the skew quadrupole magnet. The control system for skew quadrupole magnets was developed in 2012, and has been in operation since January 2013.

INTRODUCTION

J-PARC (Japan Proton Accelerator Research Complex) is a high-intensity proton accelerator facility. It has been operated collaboratively by Japan Atomic Energy Agency (JAEA) and High Energy Accelerator Research Organization (KEK). It consists of three accelerators: a linear accelerator (LINAC), a Rapid Cycling Synchrotron (RCS), and a Main Ring (MR).

MR started beam operation in 2008. MR has a three-fold symmetry. Three straight sections are dedicated to "injection and beam collimators", "slow extraction", and "rf cavities and fast extraction" [1]. Four skew quadrupole (SKQ) magnets were installed into the two of three straight sections in November 2011. Two magnets are located in each insertion section. Figure 1 shows locations of the SKQ magnets. The purpose of these magnets is to reduce the sum resonance effect, which comes from the rotational alignment errors of the 216 quadrupole magnets and the vertical closed orbit distortion at the 72 sextupole magnets [2].

The effectiveness of quadrupole magnets was demonstrated in the MR beam study of April, 2012. However at that time, they were stand-alone devices: not remote controllable, and not synchronized to the MR machine cycle.

In J-PARC, we have been using a control system to control the accelerator equipment [3]. It was developed by EPICS (Experimental Physics and Industrial Control System) toolkit [4]. A new EPICS-based sub-system has been constructed to control the SKQ magnets. Using a standard

* kenichi.sato@j-parc.jp

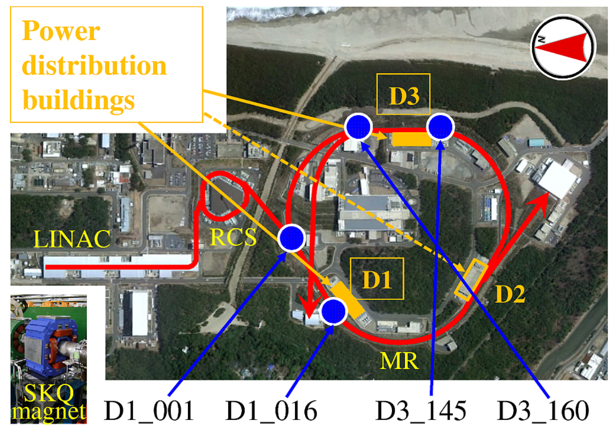

Figure 1: Four SKQ magnets in J-PARC MR.

controller (i.e. PLC) and a commercial amplifier as a power supply, we succeeded to develop the sub-system at lower cost, in shorter-time, than usual.

OVERVIEW OF SKQ CONTROL SYSTEM

Control overview for two of four SKQ magnets is shown in Figure 2. The SKQ control system is composed of four different devices.

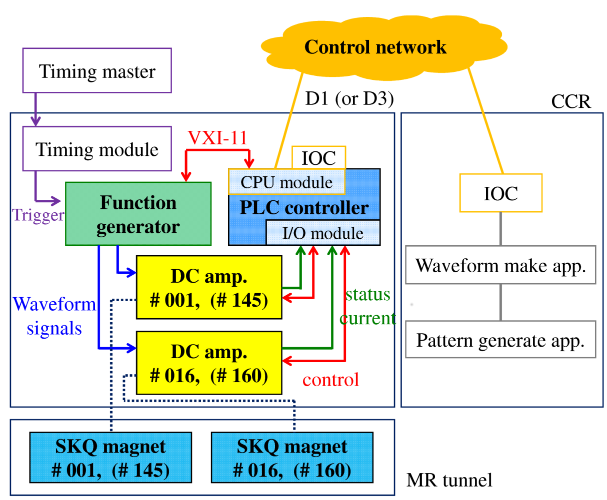

Figure 2: Devices of the SKQ control system.

(a) A PLC controller (YOKOGAWA F3RP61-2L [5]), which has a CPU loading Linux and I/O modules.

ISBN 978-3-95450-139-7

On this controller, an EPICS IOC (Input Output Controller) is embedded [6].

(b) A function generator (Tektronix AFG3022B) to generate ramp-up pattern signals. It is controlled using VXI-11 protocol via Ethernet.

(c) Two DC amplifiers (NF Corporation BP4620), which signal cables are connected to the PLC I/O modules.

(d) A timing module (REPIC RPN-1110) , which provide a trigger signal to the function generator.

For all the MR magnets, ramp-up patterns and corresponding waveform data are calculated by dedicated applications. An IOC in CCR (Central Control Room) manages all the waveform data. As in Figure 2, patterns and waveform data for the SKQ magnets also follow this scheme. Signals are generated by the function generator, by referring the waveform data on the IOC, and are delivered to DC amplifiers.

The devices shown in Figure 2 are installed in a control rack. One rack is located in the 1st power distribution building (D1), and another is in the 3rd power distribution building (D3). Figure 3 is a photograph of one of two control racks.

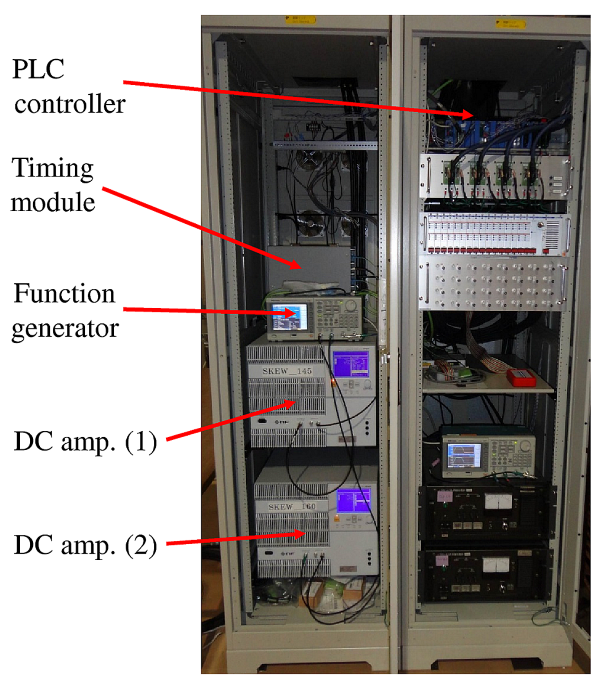

Figure 3: Control rack of skew quadrupole magnets.

CONTROL OF EACH DEVICE

PLC Controller

The PLC controller consists of a CPU module (F3RP61-2L) and I/O modules. On the CPU module, Linux runs instead of a ladder sequence. During the CPU boot-up sequences, it refers a startup file in a remote file server. An EPICS IOC runs automatically.

Table 1 shows the types of PLC modules used in this PLC controller. The Din and Dout modules control the DC amplifiers mainly. The ADC module monitors output currents of DC amplifiers.

Table 1: Selection of PLC Modules

Slot	Category	Model	Connected to
1	CPU	F3RP61-2L	Control Network
2	Din	F3XD32-3F	DC amp. (Status)
3	Dout	F3YC08-0C	DC amp. (Control)
4	ADC	F3AD08-5R	DC amp. (Output currents)

Control of Function Generator

The function generator, AFG3022B provided by Tektronix, is used to produce waveform signals. It is controllable remotely by the VXI-11 protocol over network connection. An EPICS device support has been developed for this function generator. The device support is loaded on the CPU module of the PLC controller. Thus, the PLC controller works as a protocol converter between the VXI-11 protocol and the EPICS protocol.

Control of DC Amplifier

BP4620 is a commercial DC amplifier provided by NF Corporation. A DC amplifier is used to excite a SKQ magnet in the current range between -20A and +20A. BP4620 can be operated remotely using external input/output signal cables. An analog input, which is connected to the function generator, is used as an output current control.

On and off controls and status surveillances are controlled by PLC I/O modules. Connected signals to them are summarizes in Table 2.

Table 2: Connected Signals of DC Amplifier

In/Out	Purpose	Connected to
AnalogIn	Control (output current)	Function Generator
Out	Status (amplifier power)	PLC Din
Out	Status (current output)	PLC Din
In	Control (set output on)	PLC Dout
In	Control (set output off)	PLC Dout
Out	Status (over-current)	PLC Din
Out	Status (soft-busy)	PLC Din

Timing Trigger

A trigger signal is needed to start the signal generation of the function generator. As in Figure 2, a timing module, RPN-1110 provided by REPIC, receives a reference signal from the timing master, and generates a trigger signal.

ISBN 978-3-95450-139-7

The generated signal is synchronized to the MR machine cycle. Description of the MR timing system are given elsewhere [7].

CONTROL BY EPICS

EPICS Naming Convention

In an EPICS system, all the signals have unique names. In the SKQ control system, we applied our naming convention to four SKQ magnet names: MRMAG:SKQPS_D1_001, MRMAG:SKQPS_D1_016, MRMAG:SKQPS_D3_145, and MRMAG:SKQPS_D3_160. Here D1 (or D3) indicates a power-distribution building where the DC amplifier is located, and a number shows the address of the MR ring where the SKQ magnet is located.

Each SKQ magnet has several signals, which correspond to EPICS PVs (process variables). A PV name is a combination of a SKQ magnet name and a functional name. For example, in a case of the MRMAG:SKQPS_D1_001, (a) status of DC amplifier output (on or off) is the PV "MRMAG:SKQPS_D1_001:STAT:OUT", (b) ramp-up pattern to be generated by a function generator is the PV "MRMAG:SKQPS_D1_001:SET:CURRENT", (c) on-and-off control of the function generator is the PV "MRMAG:SKQPS_D1_001:SET:PTNOUT", and so on. List of important functional names are given in Table 3.

Table 3: Important Functional Names for a SKQ Magnet

Func. Name	Type	Description
:STAT:PWR	bi	Status of amp. power
:STAT:OUT	bi	Status of amp. output
:OPE:OUT_ON	bo	Amp. output on
:OPE:OUT_OFF	bo	Amp. output off
:STAT:OC	bi	Amp. fault (over-current) Normally 0
:STAT:BUSY	bi	Amp. fault (soft-busy) Normally 0
:VAL:CUR	ai (calc)	Magnet current
:SET:PTNOUT	longout	Set func.gen. output ON=1, OFF=0
:SET:CURRENT	waveform	Ramp-up pattern data

EDM Screen for Operation

Operation screens for the SKQ magnets have been developed using EDM (Extensible Display Manager), which is a standard screen editor of EPICS. An example screen (Figure 4) shows status of both the function generator and the DC amplifier, together with the pattern shape and the calculated output current. In the bottom of Figure 4, on and off control buttons are also shown.

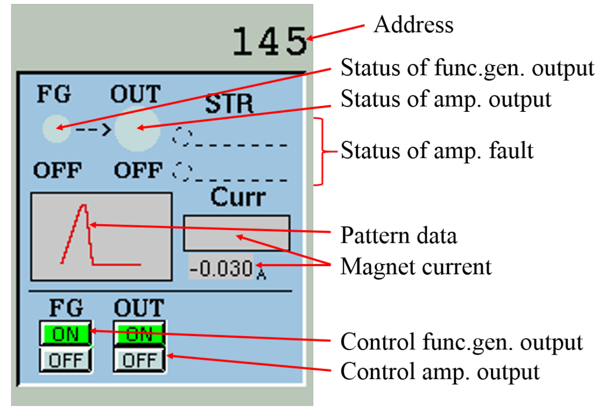

Figure 4: Control screen for SKQ magnet setup.

OPERATIONAL EXPERIENCE

The first prototype of this control system, with which only on and off were possible remotely, was used in October, 2012. After that, we improved remote control functionalities. Development of production version was completed in January, 2013. Data archiving of the SKQ control system started in April, 2013.

We started to use the system in the MR beam operation since January, 2013. It had been used successfully until the machine stop in May, 2013.

REFERENCES

[1] T. Koseki, et al., "Beam Commisioning and Operation of the J-PARC Main Ring Synchrotron", Progress of Theoretical and Experimental Physics (PTEP) 2012, 02B004, 10.1093/ptep/pts071.

[2] J. Takano, et al., "Beam Study with Skew Quadrupole Magnets for the J-PARC Main Ring", (in Japanese), PASJ Annual Meeting in Osaka, Japan, Aug. 2012, pp. 391-393.

[3] N. Kamikubota, et al., "J-PARC Control toward Future Reliable Operation", ICALEPCS 2011, Grenoble, France, Oct. 2011, MOPMS026, pp. 378-381; http://www.JACoW.org

[4] http://www.aps.anl.gov/epics/

[5] http://www.yokogawa.co.jp/rtos/rtos-index-ja.htm

[6] J.-I. Odagiri, et al., "Application of EPICS on F3RP61 to Accelerator Control", ICALEPCS 2009, Kobe, Japan Oct. 2009, THD005, pp. 916-918; http://www.JACoW.org

[7] N. Kamikubota, et al., "Overview of Timing System for J-PARC MR", (in Japanese), PASJ Annual Meeting in Hiroshima, Japan, Aug. 2008, pp. 286-288.

ISBN 978-3-95450-139-7