RECENT DEVELOPMENT OF THE RIKEN RI BEAM FACTORY CONTROL SYSTEM

M. Komiyama, M. Fujimaki, N. Fukunishi, K. Kumagai, A. Uchiyama
RIKEN Nishina Center, Wako, Saitama, Japan

Abstract

We report on the development of the successor to the existing controller devices used for the magnet power supplies in the RIKEN Radioactive Isotope Beam Factory (RIBF). The existing system controlling the magnet power supplies is operated on the Versa Module Europa (VME) computing machines, under the Experimental Physics and Industrial Control System (EPICS) framework. The present controller system has been operated stably for over 10 years. However, it is now commercially unavailable, because the supply of some parts has already ceased. From 2011 to 2016, we have been developing a successor system to achieve essentially the same function as the existing one, but the successor system is designed to run in control systems constructed by programmable logic controller (PLC) modules instead of the VME computing environment, in order to achieve a cost reduction and easily cooperate with other systems.

We set up a test system using this successor and confirmed that a magnet power supply could be controlled in the same manner as the existing system. Now, we plan to begin controlling magnets of beam transport lines using this successor system in the current year.

INTRODUCTION

The RIKEN Radioactive Isotope Beam Factory (RIBF) is a cyclotron-based accelerator facility aiming at the development of nuclear physics, materials, and life science studies. RIBF consists of two heavy-ion linear accelerator injectors and five heavy-ion cyclotrons, including the world's first superconducting ring cyclotron (SRC). Cascades of the cyclotrons can provide the world's most intense RI beams over the whole atomic mass range, using fragmentation or fission of high-energy heavy-ion beams [1]. For example, a 345-MeV/nucleon ^{238}U beam of 70 pnA was successfully extracted from the SRC in 2017. RIBF was constructed as an extension of the old facility commissioned in 1986, by adding three new cyclotrons, and began operation in 2006.

The components of the RIBF accelerator complex, such as the magnet power supplies, beam diagnostic devices, and vacuum systems, are controlled by the Experimental Physics and Industrial Control System (EPICS) [2], with a few exceptions such as the control system dedicated to the radio frequency system of RIBF [3]. However, all the essential operation datasets of EPICS and other control systems are integrated into the EPICS-based control system. In addition, two types of interlock systems that are independent of the accelerator control systems are also operated in the RIBF facility: a radiation safety interlock system for human protection [4] and a beam interlock system (BIS) that protects the hardware of the RIBF accelerator complex from potential damage caused by high-power heavy-ion beams [5].

UPDATE OF CONTROLLER DEVICE FOR MAGNET POWER SUPPLY

Controller Device for Magnet Power Supplies in RIBF

The magnet power supplies are operated both in the old facility section and in the newly added facility section commissioned since 2006 (hereafter, the new facility section). However, there are differences in these controllers according to their introduction times. The magnet power supplies in the old facility section are controlled by our in-house controller device based on Computer-Aided Measurement And Control (CAMAC), a device interface module (DIM) [6]. On the other hand, the magnet power supplies in the new facility section are designed to be controlled by the Network I/O (NIO) system, which is a commercially available control system manufactured by the Hitachi Zosen Corporation. A block diagram of the NIO system is presented in Fig. 1.

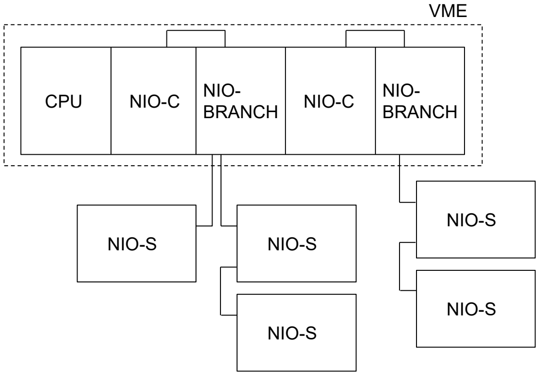

Figure 1: Block diagram of the NIO system under operation.

The NIO system consists of three types of controllers: the NIO-S board, NIO-C board, and branch board. The NIO-S board is a slave board attached directly to the magnet power supply, which controls it according to a signal sent from an upper-level control system through the NIO-C board. The NIO-C board acts as a master board of the NIO-S boards and is designed to operate in the Versa Module Europa (VME) computing machines. The NIO-C board not only has an NIO board, but also an additional board dedicated to High level Data Link

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* misaki@riken.jp

Control procedure (HDLC) communication. The NIO-C and NIO-S boards are connected using an optical fiber cable through a branch board. One NIO-C board can control 43 NIO-S boards via branch boards, and there are 15 NIO-C boards in operation connected to seven VME chassis distributed in RIBF. Because one NIO-S board can only control one magnet power supply, there are approximately 500 NIO-S boards in the RIBF accelerator complex, and this corresponds to 60% of the total magnet power supplies used in the RIBF accelerator complex.

Development and Update to the Successor

DIM has been working stably for over 30 years, with improvements being added as required. However, in addition to its serious aging, it has become difficult to maintain DIM because there are no engineers who can produce or repair it. Considering this situation, we are systematically replacing the old magnet power supplies controlled by DIM to new ones controlled by the NIO. As a result, the number of magnet power supplies controlled by DIM was reduced from over 680 to 375 in 2017. In this situation, the production of NIO was terminated, and we can no longer purchase NIO boards. Therefore, we needed to develop a successor, and we planned to develop this in the order of an NIO-S board, NIO-C board, and branch board. We developed an NIO-S successor between 2011 and 2014. Table 1 lists the hardware specifications of the NIO-S under operation and its newly developed successor.

Table 1: Specifications of NIO-S Under Operation and its Successor

NIO-S	Under operation	Successor
CPU	SH-2 28.33 MHz	SH-2 SH7084 32 MHz
EPROM	128 Kbyte	-
Flash ROM	256 Kbyte	32 Mbyte
SRAM	512 Kbyte	512 Kbyte
SCA	HD64570	TD-HDLCip
Digital input (points)	32 (8 points/ 1 common)	48 (8 points/ 1 common)
Digital output (points)	32 (8 points/ 1 common)	32 (8 points/ 1 common)
Serial interface	RS-485 Optical link	RS-485 Optical link
Debug port	RS-232C	RS-232C

This successor was designed to be compatible with the NIO-S board currently under operation. Communication is the most significant feature of the successor. The HDLC transmission method, which is performed using an adaptor chip used for serial communication in the NIO-S under operation, is replaced in the successor by using the IP in the field-programmable gate array (FPGA). We also increased the number of digital inputs from 32 to 48, in consideration of future expandability.

After the development, we updated the existing NIO-S installed in the three independent magnet power supplies to the successor and began testing its operation from 2014. We can control these as smoothly as other magnet power supplies without modifying anything in the existing control programs.

In the development of a successor for the NIO-C board, the required specifications are essentially the same as for the existing board. However, we decided to design a successor to run on a control system constructed by programmable logic controller (PLC) modules instead of the VME computing environment used currently, in order to achieve a cost reduction and easily cooperate with other systems. The hardware specifications of the NIO-C under operation and its newly developed successor are listed in Table 2.

Table 2: Specifications of the NIO-C Under Operation and its Successor

NIO-C	Under operation		Successor
	NIO-board	Communication-board (HDLC)	
CPU	TMPZ84C013A-10 6.4 MHz	TMPZ84C013A-10 8 MHz	NIOS2 Processor 32 MHz
ROM	28 Kbyte	28 Kbyte	EPCS16 2 Mbyte
RAM	32 Kbyte	28 Kbyte	
DRAM	-	-	32 Mbyte
DPRAM	2 Kbyte	2 Kbyte	16 Kbyte (in FPGA)
SCA	HD64570		TD-HDLCip
FPGA	-		Cyclone4 EP4CE22
Bus controller	- (VME)		A6374LG (Yokogawa)
Serial interface	RS-485		RS-485
Debug port	RS-232C		RS-232C

The NIO-C successor was developed based on the PLC system manufactured by the Yokogawa Electric Corporation (hereafter, FA-M3), following recent trends in the control systems of RIBF accelerators. One of the advantages of adopting FA-M3 is that we can set up a simple control system by choosing a Linux-based PLC-CPU (F3RP61 [7]) on which EPICS programs are executed. In that case, F3RP61 works not only as a device controller, but also as an EPICS Input Output controller (IOC) [8]. Figure 2 presents a block diagram of the successor system of the NIO system. We designed the NIO-C successor to communicate data and commands with a PLC-CPU via a shared RAM contained on it.

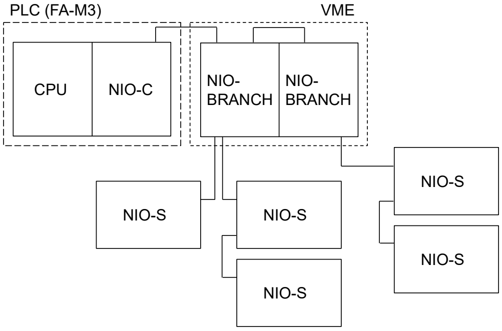

Figure 2: Block diagram of the successor system of the NIO system.

The software of the successor was developed maintaining full compatibility with the NIO-C under operation. The NIO-C successor has 13 kinds of command codes, such as magnet power supply on/off, polarity switching, and pulse output. Most of these command codes inherit those of the NIO-C under operation: there is one updated command code for setting current value to the magnet power supply. In the existing system, there are two ways of setting a current target value for a magnet power supply: one is to give only the target current value to the magnet power supply, in which a default current excitation rate is used; the other is to provide a target current value and specify its current excitation rate (hereafter ramp control). The ramp control command code in the existing system requires setting parameters such as the current target value, step time, and total setting time to reach the target current value. It is assumed that the current value is 0 A, and ramp control is performed from 0 A towards the target current value. In other words, this cannot be used when starting from other current values. Therefore, we now only use former command code in the current control of the magnet power supply. When we need to significantly change the current value, we employ a program developed by implementing ramp control starting from an arbitrary current value, in order to ensure safety and not damage the magnet power supply. Therefore, in developing the software for the NIO-C successor an upgraded command code for ramp control was developed by adding a current starting value to the parameter set with the existing ramp command. We assume that this command code is utilized in the control of a large current magnet power supply, such as for a dipole magnet.

We completed the development of the software of the NIO-C successor in 2016. Subsequently, we have started to develop the control program of the magnet power supply, using F3RP61 as an EPICS IOC. As a first step, we have developed a program that implements equivalent usability to existing control programs by using a test unit containing only F3RP61 and the NIO-C successor, as shown in Fig. 2. The test unit has been attached to one of the NIO stations in operation, which controls the magnets of beam transport lines including dipole magnets, quadrupole magnets, and steering magnets. There is one VME-CPU, five NIO-Cs, and two or three branch boards connected to each NIO-C, and approximately 150 of the magnet power supplies are controlled by this NIO station. For testing the NIO-C successor, we replaced one of the NIO-Cs in operation with the successor and connected this to an existing branch board. This NIO-C is controlling 34 magnet power supplies. As a first step, we tested all 13 command codes by developing test programs, and we confirmed that all commands successfully performed according to their specifications. Based on this result, we have developed an EPICS run-time database and graphical user interface (GUI) for the magnet control based on the existing one. As a result, we successfully controlled all 34 magnet power supplies in the same manner as the existing system. The response to the command input was the same as for the current system. Furthermore, we can control these by using an updated command for the ramp control by setting the parameters of some patterns.

As a next step, we will start the development of a successor to the branch board. The branch board is a non-intelligent board for a star connection between an NIO-C and NIO-S with an optical cable. Although the existing branch board runs in the VME chassis, a necessary input power of 5 V should be fed independently from VME. Therefore, we plan to develop a successor to the branch board with specifications of not using VME, in order to lower the costs and simplify the board.

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