RECENT UPDATES ON THE RIKEN RI BEAM FACTORY CONTROL SYSTEM

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Abstract

RIKEN Radioactive Isotope Beam Factory (RIBF) is a cyclotron-based heavy-ion accelerator facility for producing unstable nuclei and studying their properties. Following the first beam extraction from a superconducting ring cyclotron, the final-stage accelerator of RIBF, in 2006, several types of extensions and updates have been performed in the RIBF control system as well as the accelerators and their components. In this paper, we will present two latest updates of the RIBF control system. One is the upgrade of the existing beam interlock system in order to adapt to the increase in the types of experiments performed in RIBF recently. The other is the development of two types of successors that are designed to be compatible with the existing controllers for magnet power supplies.

INTRODUCTION

Overview of RIBF Accelerator Complex

RIKEN Radioactive Isotope Beam Factory (RIBF) is a multistage accelerator complex, which consists of two heavy-ion linacs and five heavy-ion cyclotrons including the world's first superconducting ring cyclotron (SRC); several acceleration modes can be made available by selecting a combination of the accelerators depending on the purpose of the experiment [1]. The RIBF accelerator research facility consists of the old facility, which was commissioned in 1986, and the newly constructed one (new facility), which was commissioned in 2006. At the old facility, various types of experiments such as biological irradiation are performed using the RIKEN ring cyclotron (RRC) [2]. The new facility was constructed in the downstream of the old facility and has added new dimensions to the facility's capability. Three new cyclotrons were constructed in the downstream of the RRC to accelerate beams with energies of several hundreds of MeV/nucleon over the entire range of atomic masses. In May 2015, a 345-MeV/nucleon ^{238}U beam of 39.5 pnA was successfully extracted from the SRC. A high-power heavy-ion beam extracted from the SRC is transported to the superconducting radioactive isotope beam separator, BigRIPS [3]. At the BigRIPS, various types of RI beams are produced, separated, and identified in an event-by-event mode. The tagged RI beams are delivered to experimental setups placed downstream of the BigRIPS.

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Overview of the RIBF Control System

Figure1 shows the overview of the RIBF control system. The components of the RIBF accelerator complex, such as magnet power supplies, beam diagnostic devices, and vacuum systems, are controlled using the experimental physics and industrial control system (EPICS) [4]. In addition, there are several control systems, such as a system for radio frequency (RF) and ion source, that are not integrated into the EPICS-based system. The RIBF accelerator complex is operated under the control of the EPICS-based and the non-EPICS-based control systems [5].

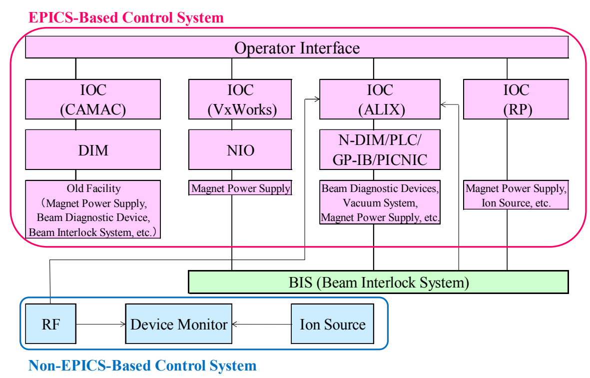

Figure 1: Overview of RIBF Control System.

There are two kinds of interlock systems in the RIBF facility, which are independent of the above-mentioned control systems. One is a radiation safety interlock system for human protection, HIS [6], and the other is a beam interlock system (BIS) to protect the hardware of the RIBF accelerator complex from significant beam losses for high-power heavy-ion beams [7]. The BIS stops a beam within 10-15 ms after detection of any interlock signal. For realizing the specification, after the BIS detects an interlock signal, it sends the signal to a beam chopper placed at the exit of the ion source. In addition, the BIS sends a signal to the closest Faraday cup located upstream of the trouble point to be set into a beam transport line. Although in the latter process, approximately 1 s is required to complete the movement of the Faraday cup, which is determined by mechanical limitations, this function is effective to ensure redundancy of the safety mechanism. At present, the BIS stops a beam within 10-15 ms in average. Many interlock signals such as failure signals are transported to the BIS sent from RF systems used in cyclotrons, magnet power supplies, vacuum gate valves in the beam transport lines, and beam

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spill monitors installed in the cyclotrons. Since there are several acceleration modes in the RIBF, parameter files defining the interlock signals relevant to each acceleration mode are prepared and one of them is registered to the BIS before performing an experiment.

Two sets of BIS are in operation: one at the old facility (RRC-BIS) and the other at the new facility (RIBF-BIS). Both the BIS have the same components and the systems are exactly the same. The hardware constitution of the BIS is shown in Fig. 2. Each BIS has approximately 320 digital input signals, 80 analog input signals, and 30 digital output signals. All of the interlock signals are connected to the I/O modules of the programmable logic controllers (PLCs) manufactured by Mitsubishi Electric Corporation (hereafter, Melsec PLCs). Since the components issuing the interlock signals are distributed over a wide area in the facility and fulfill the requirement of the response time, the BIS is constructed using five Melsec PLCs and a dedicated PC for setting and monitoring the interlock signals. The Melsec PLCs are connected to each other through the MELSECNET/H network system, an optical loop system. All signal information is summarized in one of the five PLCs, which has an Ethernet module, and we monitor and control the signal at the dedicated PC using SoftGOT [8] through the Ethernet. We have started their operation since 2006.

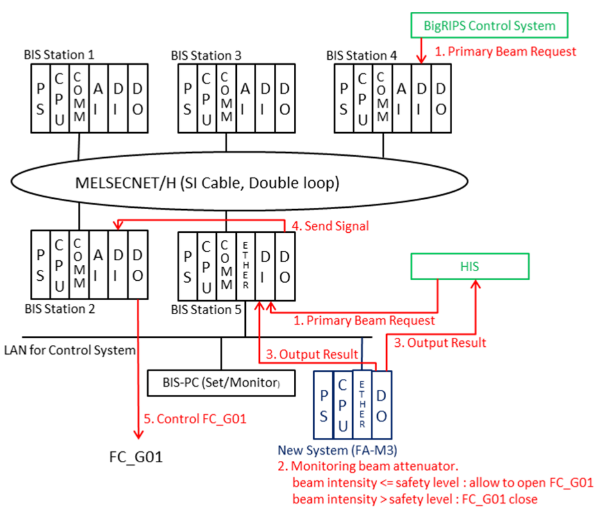

Figure 2: Hardware constitution of the Beam Interlock System. Blue module and colored logic have been added in 2014.

UPGRADE OF BEAM INTERLOCK SYSTEM

During the past 10 years, the intensity of a 345-MeV/nucleon ^{238}U beam extracted from the SRC has increased ~100 times by implementing various improvements. As the performance of the accelerators has improved, the variation in the experiments performed at RIBF has also increased. Especially, an experiment has been performed using a primary beam extracted from the SRC with the experimental instruments placed at the downstream of the BigRIPS, which are designed to perform experiments using faint RI beams produced by the BigRIPS (hereafter, a secondary beam), and the maximum beam intensity there is limited to 10^7 pps. While transporting the primary beam directly to the downstream of the BigRIPS, the beam intensity may exceed the safety limits set by the radiation safety regulation. Although the HIS secures radiation safety of the whole facility, the BIS is required to protect the experimental setups more reliably from accidental irradiation with high-intensity primary beams. Therefore, we upgraded the BIS in 2014 to have a function that allows transportation of the primary beam to the downstream of the BigRIPS only when the intensity of the primary beam is lower than the safety limit. In other words, when the intensity of the primary beam exceeds the safety limit, the BIS has to stop the beam immediately.

In order to achieve the above-mentioned functions, the BIS has to constantly monitor the beam intensity of the primary beam extracted from the SRC. However, the existing BIS has no information about the beam current, and there is no non-destructive beam current monitor for this purpose in the RIBF beam transport line because we usually obtain the data of beam intensity at the beam transport line by stopping a beam by Faraday cups. Therefore, we decided to monitor the insertion status of the beam attenuators in the beam transport line. Since the beam intensity at the ion source is frequently checked, it is possible to evaluate the maximum beam intensity by knowing the attenuation of the beam. There are many beam attenuators in the low-energy region of the RIBF accelerator complex controlled by EPICS. Therefore, we additionally installed a dedicated small PLC system manufactured by Yokogawa Electric Corporation (hereafter, FA-M3) in the EPICS-based control system to achieve the following three tasks.

- To evaluate the attenuation of the beam continuously.
- To send the signal to the RIBF-BIS so as to prohibit the injection of the primary beam to the BigRIPS when the attenuation of the beam does not satisfy the safety level.
- To send the signal to the HIS so as to update the result.

Usually, the beam is stopped by the Faraday cup at the exit of the SRC, denoted as FC_G01, during accelerator tuning before it is injected into BigRIPS. Before the experimental instruments start using the primary beam, the BigRIPS control system, which is independent from the RIBF control system, sends a start signal to the RIBF-BIS. Therefore, when the attenuation of the beam satisfies the safety level, we can set out the FC_G01 from the beam transport line and can transport the beam to the BigRIPS. After that, when the insertion status of the attenuators is changed and it does not satisfy the safety level, the RIBF-BIS stops the beam immediately by the beam chopper and FC_G01. After this improvement of the BIS, we can perform the experiments of BigRIPS more safely and efficiently because the high-intensity

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primary beam is no longer transported to the downstream of the BigRIPS in the event of misoperation.

DEVELOPMENT OF SUCCESSORS FOR MAGNET CONTROL

The second topic is the update of the Network I/O (NIO) system, which is used to control many magnet power supplies in the new facility and a part of the old facility. The NIO is a commercially available control system manufactured by Hitachi Zosen Corporation, and 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 and controls it according to a signal sent from an upper-level control system through the NIO-C board. The NIO-C board works as a master board of the NIO-S boards and is designed to operate in the Versa Module European (VME) computing machines. The NIO-C and NIO-S boards are connected using an optical fiber cable through a branch board. Since one NIO-S board can control only one magnet power supply, there are about 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. The major part of the remaining power supplies are used in the old facility. We are gradually updating the old power supplies to a new power supply controlled by the NIO system. The existing NIO system has been working stably, but production of the present NIO-S board was terminated because some parts used for communication are currently not available. Therefore, in 2014, we developed a successor of the existing NIO-S board. This successor was designed to be compatible with the existing NIO-S board. Communication is the most significant feature of the successor; the high level data link control procedure (HDLC) transmission method, which is performed using an adaptor chip used for serial communication in the existing NIO-S, is replaced by using the IP in the field-programmable gate array (FPGA) in the successor. As another improvement in the successor, we increased the number of digital inputs from 32 to 48 in consideration of future expandability. We tested the successor by attaching it to one of the existing power supply and confirmed that the successor successfully controlled the power supply as the existing NIO-S.

Production of the NIO-C has also been terminated for the same reason as the NIO-S. Hence, we should also develop a successor of the present NIO-C, and its research and development began in 2014. The specifications required for the new board are essentially the same as for the existing one, but we decided to design the new board to run in a control system constructed by PLC modules instead of the VME computing environment currently used, in order to achieve cost reduction and functional scalability. The NIO-C successor is based on FA-M3, according to 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 because a Linux-based PLC-CPU (F3RP61 [9]), on which EPICS programs are executed, is chosen and F3RP61 works not only as a device controller but also as an input/output controller (IOC). This means that additional hardware to serve as an EPCIS IOC is not required for F3RP61 [10]. The major features of the NIO-C successor are summarized in Table 1. Software development is in progress in 2015, where some new features will be added while maintaining full compatibility with the existing NIO-C.

Table 1: Specifications of the NIO-C Successor

CPU	NIOS2 Processor 32 MHz
ROM	EPCS16 16 Mbit
DRAM	16 M*16
DPRAM	16 Kbyte (in FPGA)
SCA	TD-HDLCip
FPGA	Cyclone4 EP4CE22
Bus Controller	A6374LG (Yokogawa)
Serial interface	RS-485 *1 (2 Mbps(max), HDLC)
Debug Port	RS-232C *1
External Dimensions	1 slot
Supply Voltage	5 V DC. 2 A (max)

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