STATUS OF THE RIKEN RI BEAM FACTORY CONTROL SYSTEM

M. Komiyama*, A. Uchiyama, N. Fukunishi, M. Wakasugi,
RIKEN Nishina Center, Wako, Saitama, Japan
M. Hamanaka, M. Nishimura, SHI Accelerator Service, Ltd., Shinagawa, Tokyo, Japan

Abstract

RIKEN Radioactive Isotope Beam Factory (RIBF) is a cyclotron-based heavy-ion accelerator facility for producing unstable nuclei and studying their properties. The Superconducting Ring Cyclotron is the final stage accelerator of RIBF and its first beam extraction was achieved in 2006. Afterward, several updates have been performed. We will here present recent upgrades to the RIBF control system. These are related to two large-scale experimental instruments, now under construction, that will enable new types of experiments. One of these projects is an isochronous storage ring. It aims at precise mass measurements of short-lived nuclei. The other project is construction of a new beam transport line dedicated to more effective generation of seaweed mutation induced by energetic heavy ions. To control these instruments, the experimental physics and industrial control system-based RIBF control system is now being upgraded. Each device used in the new experimental instrumentation is controlled by the same kind of controllers as those already in use, such as programmable logic controllers. Additionally, we have introduced the new Control System Studio (CSS) as the operator interface. We plan to use the CSS not only for the new projects but also for stepwise usability improvements to the existing RIBF control system.

INTRODUCTION

Figure 1 shows a bird's eye view of RIKEN Radioactive Isotope Beam Factory (RIBF), which is a cyclotron-based in-flight facility. RIBF consists of two heavy-ion linacs (RILAC [1], RILAC2 [2]) and five heavy-ion cyclotrons, including the world's first superconducting ring cyclotron (SRC). RIBF accelerators can supply radioactive isotope (RI) beams at energies hundreds of MeV/nucleon over the entire range of atomic masses [3]. Since the last Icalepcs in 2011, we have continued upgrading the control system of the RIBF accelerators. We have developed an in-house data archiving system and started using it. We have also replaced some outdated controllers and dozens of servers with a new server system that uses virtualization technology [4]. Here, we will concentrate on recent development of the RIBF control system to manage two large-scale experimental instruments.

RARE-RI RING PROJECT AND ITS CONTROL SYSTEM

Overview of the Rare-RI Ring

A major research activity at RIBF is exploring unknown fields of short-lived nuclei by using intense RI beams. Nuclear mass is one of the most important quantities, and for extremely neutron-rich nuclei far from the β-stability line it is important to determine the pathway of r-process nucleosynthesis. We have succeeded in producing some r-process nuclei at RIBF [5]; however, due to low production rates of such nuclei (~1 event/day) and their short lifetimes (less than 50 ms), low yields prevent us from precisely determining the mass of nuclei by conventional techniques. To overcome this problem, isochronous mass spectroscopy using a conceptually new storage ring, the "rare-RI ring", has been proposed. The construction of the rare-RI ring as a large-scale experimental instrument of RIBF [6] was started in the middle of fiscal year 2012.

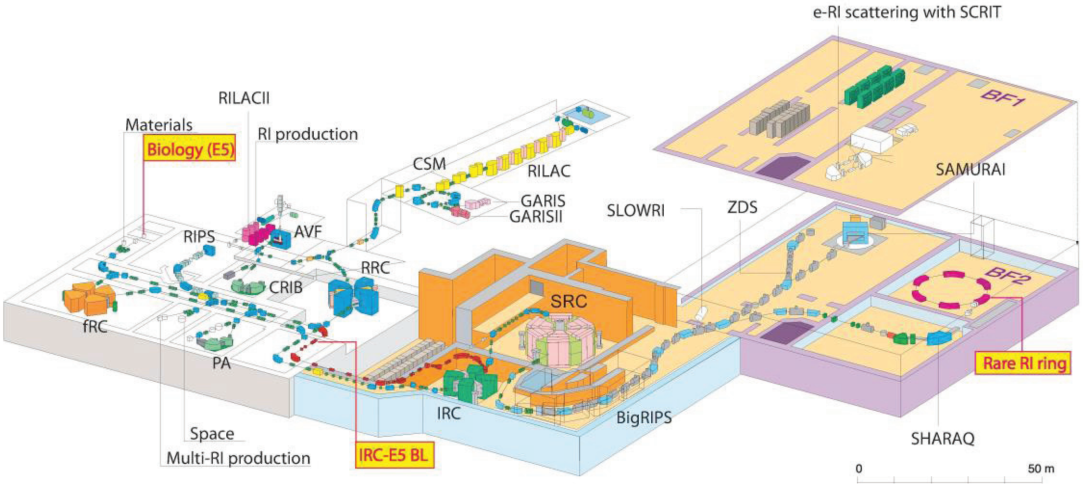

Figure 1: Bird's eye view of RIBF.

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* misaki@riken.jp

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The rare-RI ring can determine masses of short-lived rare nuclei with an order of 10^{-6} s precision, even for only one particle. Mass is determined by measuring the revolution time of each ion by isochronous optics. The storage ring consists of 24 dipole magnets: 4 bending magnets form each sector and 6 sectors make up the ring. To optimize the isochronism of circulating particles occupying a large acceptance, 10 trim coils are installed to each of half of the bending magnets. The circumference of the ring is 60.35 m, which corresponds to a revolution time of 355 ns for rare-RI beams with 200 MeV/nucleon. A newly developed fast-response and fast-charging kicker system enables selective and efficient injection of the produced rare nuclei into the ring one at a time and an extraction of the circulating particle for time-of-flight measurement. A schematic view of the rare-RI ring is shown in Fig. 2.

In fiscal year 2013, we are preparing for the commissioning of the rare-RI ring, scheduled for fiscal year 2014. The first mass measurement is scheduled for fiscal year 2015.

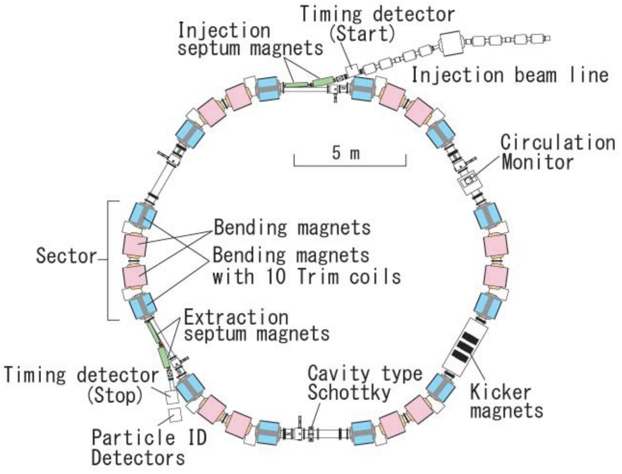

Figure 2: Schematic view of the rare-RI ring.

Control System

Components to be controlled in the rare-RI ring are magnets, beam diagnostic systems, vacuum systems, detectors for mass measurements, and so on. They are classified into two groups: components for operating the rare-RI ring as a storage ring and other components used solely for precise mass measurements. The components belonging to the former group, such as magnets and vacuum systems, are similar to those used in existing RIBF accelerators and will be controlled by an Experimental Physics and Industrial Control System (EPICS)-based control system independent from the existing RIBF accelerator control system. As a first step in implementing the new control system, we have started developing the control system for the magnet power supplies that will be used during magnetic-field measurements of the rare-RI ring. Control systems for vacuum components and beam diagnostic components are also scheduled for integration into the control system.

To save on construction cost and time, the new control system is designed to use the software resources of the extant accelerator control system, which was developed over the last 10 years. The design baseline of the control system of the rare-RI ring is to be developed based on EPICS [7], and the types of controllers used in the ring will be simplified as much as possible.

The major part of the RIBF accelerator complex has been controlled by EPICS [8] and operated without any serious trouble. However, the maintainability of the control system could become a serious problem because controllers used for controlled objects of the same kind—for example, magnet power supplies—are not unified due to the long history of the RIBF accelerator complex. This heterogeneity makes maintenance complex and inefficient. Having learned from the experience, we are trying to reduce the number of types of controllers used in the rare-RI ring as much as possible.

The control system of the rare-RI ring has introduced the programmable logic controllers (PLCs) manufactured by Yokogawa Electric Corporation (hereafter, FA-M3), following recent trends in the control systems of RIBF accelerators. One of the advantages of adopting the FA-M3 is that we can set up a simple control system because a Linux-based PLC-CPU (F3RP61 [9]), on which EPICS programs can be executed, can be chosen and F3RP61 can work not as only 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 FA-M3 system has another PLC-CPU whose logic is developed by using a ladder program.

The present status of the controllers used for the magnet power supplies is summarized in Table 1.

Table 1: Controllers Used in the Rare-RI Ring

Type of Magnet (Number)	Number of magnet power supplies	Type of controller (Number)
Main coil of dipole magnets (24)	1	F3SP66 (1)
Trim coil of dipole magnets (10)	10	Serial-Ethernet Converter (1)
Septum magnet (4)	2	F3SP66 (2)
Kicker magnet (5)	10	Under discussion
Correction coil magnet (24)	6	Under discussion
Quadrupole magnet (10)	10	F3SP66 (5)

Magnet power supplies, except for those exciting the trim coils, are newly developed for the rare-RI ring. As mentioned previously, usage of F3RP61s for these new power supplies would be preferable for system simplicity, but we actually decided to use conventional ladder PLC-CPUs (F3SP66) after taking into account the tight construction schedule and the insufficient experience of company engineers with Linux-based PLC-CPU and EPICS programing. These ladder CPUs are controlled by using netDev, an EPICS device and driver support for general network devices developed by KEK and RIBF control groups [11]. For the power supply of the dipole magnets, we use a 32-bit digital output module instead of using an analog output module; this is done to enable current-setting precision of 10^{-6}.

Old power supplies are being reused for the trim coils; these are controlled by serial communication, RS422. High-level systems control the power supplies by sending commands via serial communication. We have connected a serial-Ethernet converter to the magnet power supply and control it via Ethernet by using StreamDevice, an EPICS device support for devices controlled by sending and receiving strings [12]. In August 2013, the excitation test of magnets is in progress and a remote control test of the magnets is just beginning.

For the operator interface (OPI), we have selected Control System Studio (CSS) [13]. In the control system of RIBF accelerators, Motif Editor and Display Manager (MEDM) [14] and Extensible Display Manager (EDM) [15] have been used to create and execute graphical user interfaces (GUIs) for beam tuning, Alarm Handler [16] has been used for an alarm system, and operating data have been stored in a relational database (RDB) using an in-house data archiving system which has been developed to adapt to a facility having multiple control systems [17]. CSS, MEDM, EDM, and Alarm Handler are applications supported by the EPICS collaboration. Because CSS is at the forefront of recent OPIs, we have given development priority to usability.

Figure 3 shows an outline of the network configuration of the rare-RI ring. Servers and controllers for each component in the rare-RI ring are connected to the local area network (LAN) dedicated to the rare-RI ring (hereafter, rare-RI ring LAN), and client PCs are connected to the LAN of the RIKEN Wako campus (hereafter, Wako LAN). The two networks are connected to each other across a firewall. We can get information about the rare-RI ring from every PC on the Wako LAN; however, we can affect controlled components only by using dedicated client PCs.

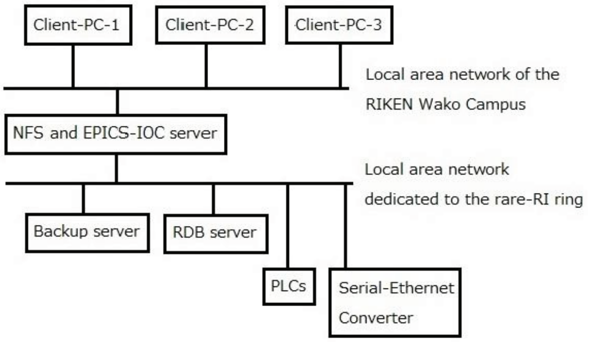

Figure 3: Network configuration of the rare-RI ring.

Three kinds of servers will be used in the rare-RI ring LAN. The first is an NFS and EPICS-IOC server. Its functions are the following.

- Working as a soft IOC to control ladder CPUs.
- Working as a firewall and router in the connection of the rare-RI ring LAN and the Wako LAN by using iptables. It is configured to deny all access to ports not allowed by iptables. In addition, access to a specific port from a client PC is set to forward to the RDB server.
- Working as an NFS server. It has all the EPICS program files to control the components in the rare-RI ring and discloses them to other machines in the control system of the rare-RI ring.
- Working as a Process Variable Gateway [18] server. Process Variable Gateway mediates a request from a client PC to IOCs, and it provides additional access security.
- Working as an NTP server.

The second server acts as a backup server. The files on the NFS and EPICS-IOC servers' local hard disks are copied to this backup server. Rsync commands running on the backup server surveys all the files on the NFS and EPICS-IOC servers and on the backup server; updated files are saved once a day, at midnight, to avoid missing files and data.

The third server acts as an RDB server. PostgreSQL is required for operation of the data archiving system and the alarm system of CSS on client-PCs. This server also simultaneously executes a data acquisition program, Archive Engine [19], to save operations data and a program for operating a GUI of the CSS alarm system.

NEW BEAM TRANSPORT LINE FOR BIOLOGICAL EXPERIMENTS

Outline

The E5 experimental vault of the old RIKEN Ring Cyclotron (RRC) facility is dedicated to material and biological irradiation. Various kinds of biological samples such as plants, animals, and cells are irradiated in the atmosphere by heavy ion beams extracted from the RRC. Beams widely used for biological irradiation are 135 MeV/nucleon ^{12}C beam and 95 MeV/nucleon ^{40}Ar beams. Many results have been obtained from this facility [20]. Some recent experiments require a beam having a higher energy in order to induce mutations in samples more efficiently. For example, there is a request for an ^{40}Ar beam having an energy higher than 95 MeV/nucleon to efficiently produce a high yield of seaweed mutant by increasing the ion range. Because of this, the construction of a new beam line that transports a beam extracted from the intermediate stage ring cyclotron (IRC) to the E5 experimental vault (hereafter, IRC-E5 BL) has been started because the IRC can accelerate higher energy beams than the RRC (Fig. 1). Construction is progressing steadily, and an early start for beam commissioning is scheduled for fiscal year 2014.

Control System

The control system for the IRC-E5 BL will be constructed as a natural extension of the existing control system of the RIBF accelerator complex by adding the new components used in the IRC-E5 BL to the existing control system. This is possible because the IRC-E5 BL is a part of the beam transport lines of RIBF. In the IRC-E5 BL, there are no new types of components. Magnet power supplies are controlled by using a commercially available Network-IO control board from Hitachi Zosen Corporation and F3RP61. Vacuum systems and beam diagnostic devices such as beam profile monitors are controlled by using an in-house controller as a network device interface module [21]. A summary of new components introduced to the IRC-E5 BL is shown in Table 2.

Table 2: Components to be Installed in the IRC-E5 BL

Component	Number to be installed
Magnet power supply	57
Beam profile monitor	17
Faraday cup	5
Vacuum pump	10
Gate valve	18

FUTURE UPGRADES

The RIBF control system is an extension of the control system of our old facility that started its operation in the 1980s. The accelerator complex has been greatly expanded since then and there has been a continuous process of introducing many new apparatuses to RIBF to upgrade performance. The RIBF control system has also been extended and modified to meet the accelerators' requirements. As a result, the control system is very complicated and difficult to perform maintenance on it. In particular, programs for OPI, such as GUIs, have become too complex to be feasible. Therefore, we plan to replace the existing OPI with CSS at the same time as completion of the IRC-E5 BL. Installing CSS to the RIBF control system will be performed in steps that depend on the experience gained constructing the control system of the rare-RI ring. For the first step, we replaced Alarm Handler with the CSS alarm system in fiscal year 2012. Alarm signals from vacuum systems and magnet power supplies of the RIBF accelerators and their beam transport lines are monitored by the CSS alarm system, which has operated steadily. In addition to the upgrade of the alarm system, the update of GUIs from MEDM/EDM to CSS-Best OPI Yet has been started to unify the operator interface; this is expected to improve the efficiency of beam tuning. We expect that installation will be finished in time for the commissioning of the IRC-E5 BL.

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