DETAILS OF BEAM DIAGNOSTIC SYSTEM FOR RIKEN SUPERCONDUCTING RING CYCLOTRON

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Abstract

Superconducting ring cyclotron (SRC) is the main accelerator for the RI Beam Factory project at RIKEN Nishina center, and that enables us to realize the uranium beam with energy of 345 MeV/nucleon. The SRC was successfully commissioned and the first uranium beam was extracted in March 2007. Beam diagnostic system for the SRC consists of seven wire monitors, four faraday cups, three radial probes, 20 pairs of phase probes, and 60 elements of baffle slits. Their signals were amplified and led to another room, and converted to digital signals. The digital data were read out through the Ethernet by the control system using EPICS, and displayed on PC monitors. In this report, details of the beam diagnostic system, their availability, and what to be improved are presented.

INTRODUCTION

RIKEN superconducting ring cyclotron (SRC) [1] is the world's first and largest ring cyclotron using superconducting sector magnet, that is the final booster for the accelerator complex of Radioactive Isotope Beam Factory (RIBF) at RIKEN Nishina Center [2]. The maximum sector field of 3.8T achieves the K=2600 MeV, it can accelerate any kind of heavy ions up to $\beta = v/c = 0.7$. As shown in Fig. 1, beam diagnostic system for the SRC consists of the following elements: three radial probes for measuring the beam current and turn pattern at the circumference orbital region, seven wire monitors for observing the beam profile, four faraday cups for determining the total beam current, 20 channels of phase probes to search the isochronism condition, and total 60 channels of baffle slits for the adjustment of injector and extractor elements.

DETAILS OF EACH ELEMENT

Wire Monitor

For transporting the incident beam to the center of the SRC, beam trajectory have to be adjusted to negate the deviation caused by stray field at the valley region. Four horizontal-steering magnet and three vertical-steering magnet are provided for the adjustment. To measure the beam profile, five wire monitors are mounted on the transport line for incident beam: one monitor at the upstream of the SRC, two monitors at the valley region, and two monitors at the central region of the SRC. Other two wire monitors are located at the beam line just after the extraction of the SRC
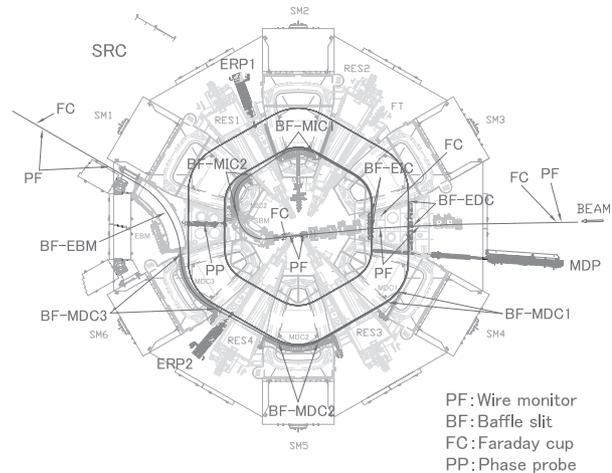
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Figure 1: Entire map of beam diagnostic probes on SRC.

to confirm the beam profile providing to the experiment facility. Each monitor has three wires that are made of tungsten with 0.3 mm $\times$ 3 mm section. As shown in Fig. 2, signals are amplified by a linear pre-amplifier located in the vicinity of each monitor, and connected to Network Device Interface Module (N-DIM) [3] using a low-noise multi-wire cable. Signal of potentiometer is also read out by the N-DIM. The N-DIM includes analog to digital converters, and digital data are collected through the Ethernet by a controller system [4] using EPICS. Figure 3 describes beam profile of $^{84}\text{Kr}^{31+}$ plotted on a PC monitor.
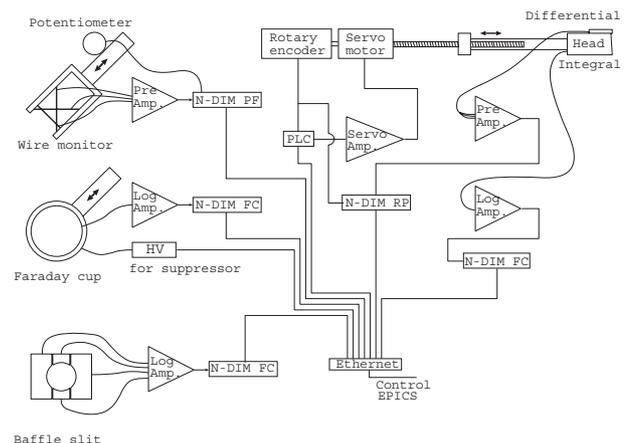

Figure 2: Schematic diagram of measuring system for wire monitor, faraday cup, baffle slit, and radial probe.
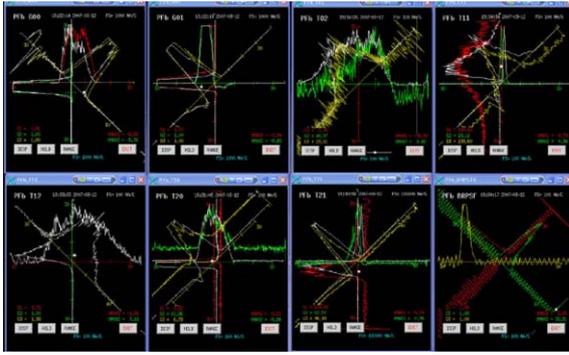
Figure 3: Example for data plots of wire monitors.

Faraday Cup

Total beam intensity are measured by faraday cups installed at the entrance, central region, orbital region, and exit of the SRC. The cup is made of oxygen-free copper with water cooling, and two types of secondary-electron suppressor are used, one is a suppressor by electrostatic field up to 1 kV, the other is a suppressor by magnetic field using a neodymium magnet. The cups of magnetic-suppressor type, which endure heat load up to 10 kW, are mounted except for the one on the orbital region. Signal is fed to logarithmic amplifiers using low-noise coaxial cable and read out by the N-DIM as described in Fig 2.

Figure 4: Monitor view of beam current (faraday cup and baffle slits).

Baffle Slit

Baffle slits are mounted on the inlet and outlet of magnetic deflecting channels (MIC, MDC) as listed in Table 1. Each slit is divided into four pieces, left, right, up, and down. Some slits have the piece for orbital side. Electrostatic deflectors (EIC, EDC) have a slit for protection of electrode and slits at side hole where incident beam is passing through. The slit piece is made of tantalum plate with 5 mm thickness. Signals are connected to vacuum-feedthrough by either tantalum wires with alumina bead or fiberglass cables, and fed to relay panel by coaxial cables.

As shown in Fig. 2, the procedure of signal readout is similar to the faraday cup. Four trendlines are plotted on a display with the one of faraday cup simultaneously.

Table 1: Location of baffle slits

Element	Position	Type
Side of EDC	L, R, U, D	Fixed
Side of EIC	L, R, U, D	Movable
Inlet of MIC2	L, R, U, D	Fixed
Outlet of MIC2	L, R, U, D	Fixed
Inlet of MIC1	L, R, U, D, Orbit	Fixed
Outlet of MIC1	L, R, U, D, Orbit	Fixed
Inlet of EIC	R	Fixed
Inlet of EDC	L	Fixed
Inlet of MDC1	L, R, U, D, Orbit	Fixed
Outlet of MDC1	L, R, U, D, Orbit	Fixed
Inlet of MDC2	L, R, U, D, Orbit	Fixed
Outlet of MDC2	L, R, U, D, Orbit	Fixed
Inlet of MDC3	L, R, U, D	Fixed
Outlet of MDC3	L, R, U, D	Fixed
Center of EBM[1]	L, R, U, D	Movable

[1]bending magnet for extraction

Radial Probe

Three radial probes (MDP, ERP1, ERP2) are mounted on the SRC. The MDP can sweep entire region from injection to extraction, whereas the ERP1 and ERP2 can measure in the outside region. Each probe has a block for measuring total beam current (INTEGRAL) and three electrodes for observing turn pattern (DIFFERENTIAL). The block is made of oxygen-free copper with 50 mm thickness, which is water cooled. The electrode is made of tantalum with 5 mm thickness, and mounted on the back of the copper block with 0.5 mm overhang. As shown in Fig. 5, the turn
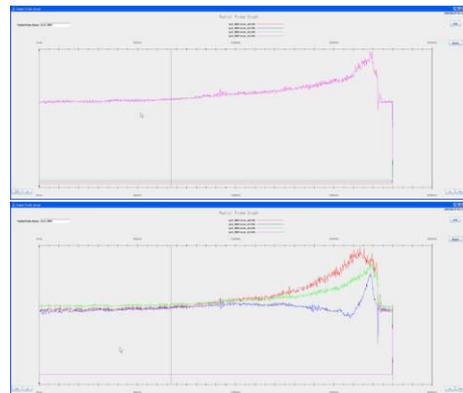

Figure 5: MDP turn pattern. Performance is insufficient now (see text).

pattern can be plotted on the PC monitor by three components (up, mid, down) or sum spectrum. The tips of copper block is cut with the angle of beam trajectory evaluated

Table 2: Radial probe specifications

	MDP	ERP1	ERP2
Head INTEG. (Tips) (Tilt) DIFF.	OFC 50mm 3.3 deg 4.5 deg Ta 5 mm	OFC 50mm 10 deg fixed Ta 5mm	OFC 50mm 9.9 deg fixed Ta 5mm
Stroke	3050 mm	900 mm	900 mm
Speed	$\leq$ 33 mm/s	$\leq$ 33 mm/s	$\leq$ 33 mm/s
Accuracy	0.5 mm	0.1 mm	0.1 mm

by calculations. The head of MDP is automatically tilted when it arrives in the inside region. Specifications of radial probes are summarized in Table 2. Moving directive and sense of position are controlled by a programmable logic controller as shown in Fig. 2. When the execution of turn pattern measurement, signal of electrodes and encoder output are read out by N-DIM.

Phase Probe

Phase probe unit consists of 20 pairs of electrodes which are made of copper plate with 73 mm $\times$ 123 mm. The unit is located at the valley region where bending magnets are placed. As shown in Fig. 6, signals for upper and lower pair are combined and selected by the cascade of RF coaxial switches. The selected signal is fed to a linear pre-amplifier and the lock-in amplifier (SR844) by a coaxial cable. For $^{238}U^{86+}$ beam, the frequency of reference signal is decided the second harmonic of acceleration RF voltage, 73 MHz. Data are captured on a PC via the GP-IB interface, and plotted on the monitor by the system [5] using LabVIEW to obtain the isochronism condition of the magnetic field index.
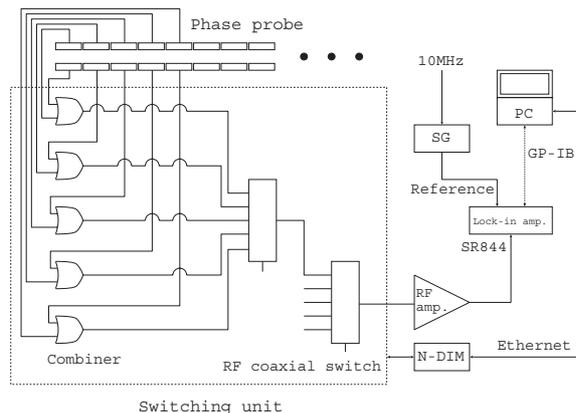

Figure 6: Schematic diagram of measuring system for phase probe.

AVAILABIRITY AND OUTLOOK FOR IMPROVEMENT

The beam diagnostic system was launched at December 2006 for beam commissioning. The first beam was $^{27}Al^{10+}$, that was passing through the baffle slit mounted on the extraction region. The adjustment of extraction channels was performed as the current indicator with 1 nA loading shifted to minus. All wire monitors were available, however, the ERP1, ERP2, and switching unit for phase probe were inoperative because of the stray field. In the beginning of 2007, the movable baffle slit at the center of EBM and wire monitor just after the EBM were newly mounted. The ERP1, ERP2, and EIC cylinder were shielded by iron plate. The switching unit was mounted on a stainless-steel rack and shielded by iron plate. These improvement made all probes be in working order.

During the beam commissioning of $^{238}U^{86+}$, several problems of performance were found. One considerable matter is for the readout of faraday cups. The beam current is detected about three times higher than the one estimated from the count of plastic scintillator due to many secondary-electrons. New faraday cups enforced by a "deep" cup and longitudinally extensive suppressor will be installed in October 2007. The baffle slit mounted on the EBM will be remaked to a faraday cup in order to obtain the reference value of beam current, because the intensive magnetic field of 2 T effectively suppress the secondary-electron. The data plot of faraday cups is also unsteady due to noises. The logarithmic amplifier will be replaced to the optimal one.

The influence of secondary-electron is critical for radial probes. As shown in Fig. 5, turn pattern at the outside region is irregular because the secondary-electron from other electrodes hits each other and the incongruence of tips angle with the beam trajectory inhibits the beam to reach the "DIFFERENTIAL" electrodes. In order to extract the proper information of turn pattern, the large roof to suppress the secondary-electron and the new electrode discontiguous from the copper block will be provided for radial probes. The improvement of the faraday cup and radial probe will be confirmed by the study in October 2007.

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