BEAM PHASE AND RF FIELDS MONITORING SYSTEM USING LOCK-IN AMPLIFIER FOR RIKEN RIBF

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Abstract

We have developed beam-phase and RF-fields monitoring system using lock-in amplifier in order to obtain stable operation of RIKEN RI Beam Factory (RIBF). Our system monitors constantly fluctuations of voltages and phases of totally 25 RF-cavities and also output signals of eleven phase pickup probes placed at beam transport lines. Using this system, we have started to investigate stability of our accelerator complex and relations between fluctuations of RF-fields of accelerators and observed beam-phases instabilities. In addition, lock-in amplifiers are also used to obtain good isochronous magnetic fields of three cyclotrons newly constructed in the RIBF.

INTRODUCTION

The RIBF is a new-generation facility, which provides RI beams far from the stability valley [1]. The RIBF consists of three newly built ring cyclotrons in cascade together with the existing ring cyclotron and injectors. It accelerates all kinds of heavy ions over 345 MeV/nucleon with a high beam-intensity, the goal of which is 1 pμA. RI beams are produced via the projectile fragmentation of heavy ions or in-flight fission of uranium ions. After 10 years of construction, the RIBF started its operation. We succeeded in the first beam extraction of the RIBF on December 28th, 2006 which was a 345 MeV/nucleon aluminum beam, and also succeeded in the first uranium beam extraction with the energy of 345 MeV/nucleon on March 23rd, 2007 [2]. The first experimental result, production of a new isotope ^{125}Pd, was obtained [3] in June 2007.

OVERVIEW

The layout of the RIBF with the operational parameters in the case of 345 MeV/nucleon uranium acceleration is shown in Fig. 1. In the uranium acceleration, ions are accelerated by the RIKEN heavy-ion linac (RILAC), the RIKEN ring cyclotron (RRC), a fixed-frequency ring cyclotron (fRC), an intermediate-stage ring cyclotron (IRC), and a superconducting ring cyclotron (SRC). In addition, we have injection buncher, RFQ linac, and four re-bunchers as shown in Fig. 1. Two charge strippers are placed downstream of the RRC and the fRC.

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In such a multi-stage acceleration system, one of the most important factors for stable operation is to maintain the matching of beam-phases between accelerators. However, drifts of beam-phases have been frequently observed, reasons of which might be the fluctuation of RF-fields, variation of magnetic field, and so on. Hence, it is important to monitor beam-phases constantly, and we have developed a monitoring system using the commercial RF lock-in amplifier (LIA) model SR844 manufactured by Stanford Research Systems [4, 5]. In addition, the system for monitoring the RF-fields has also been developed to investigate its stability and the correlation with beam-phases. The beam-phases at eleven phase probes (PPs) installed in the beam transport lines and RF-fields of 25 cavities are monitored in a uranium acceleration as shown in Fig. 1.

DEVELOPED MONITORING SYSTEM

Both beam-phase and RF-fields are monitored using the system with basically the same configuration as shown in Fig. 2. All monitoring systems are controlled by the developed LabVIEW [6] program.

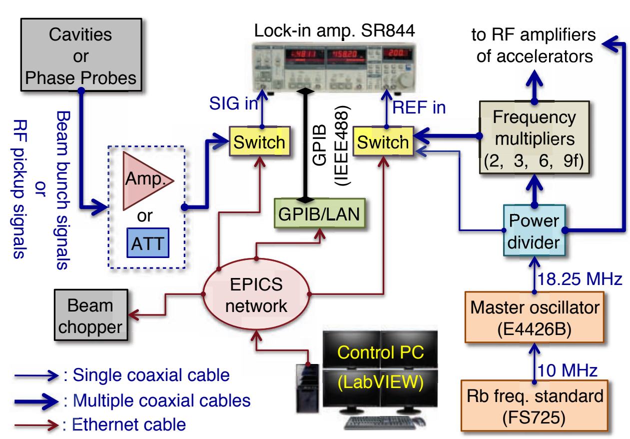

Figure 2: Schematic block diagram of developed monitoring system.

Beam-Phase-Monitoring System

Beam-phase monitoring system is divided into six groups, of which are downstream of RILAC (PPs-e11 and X51); around RRC (PPs-S71 and A01); around fRC (PPs-F51 and F01); beam transport (BT) line (PPs-D15 and

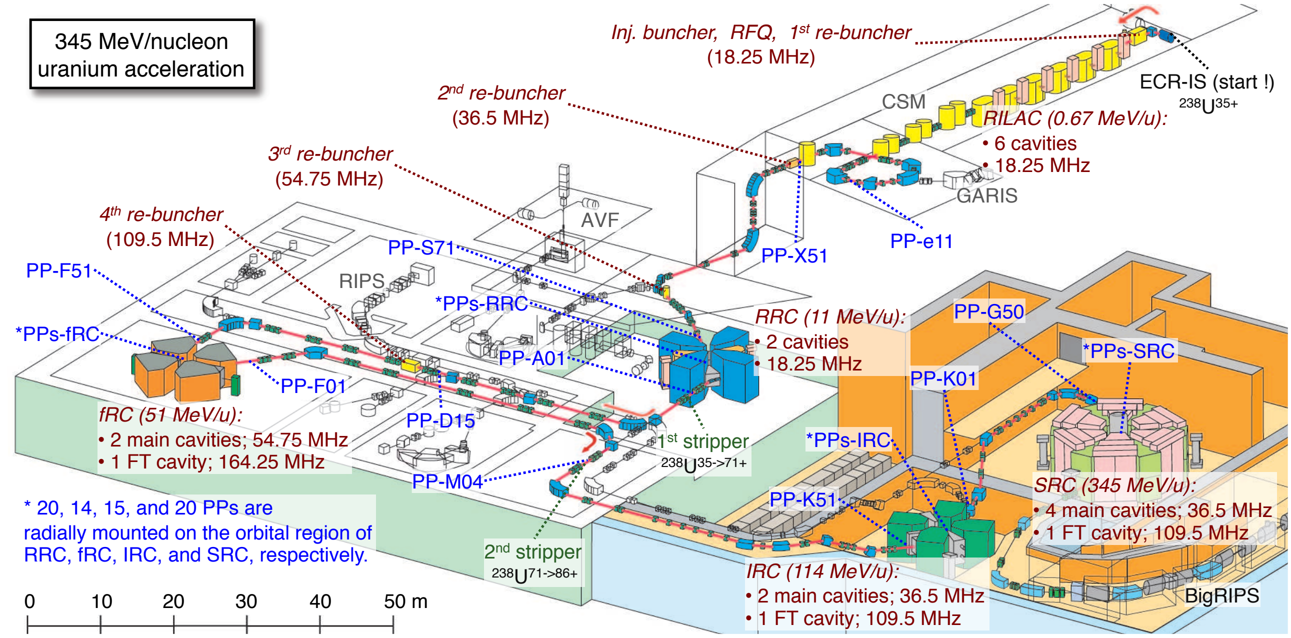

Figure 1: Layout of RIBF showing operational parameters for 345 MeV/nucleon uranium acceleration. The positions of phase probes (PPs) used for a beam-phase monitoring are also shown. PPs which are radially mounted on the acceleration region of cyclotrons (PPs-RRC, fRC, IRC, and SRC) are used for the tunings of isochronous magnetic field of cyclotrons.

M04); around IRC (PPs-K51 and K01); and around SRC (PP-G50). Each section has the monitoring system as it is shown in Fig. 2, and the beam bunch signals detected by those PPs are analyzed by the LIA via switching module.

It should be noted that the higher harmonics of the frequency of the RF-fields are used as the reference signal of the beam-phase monitoring system. Fig. 3 shows the frequency component of the signal from PP-RRC#1 as an example. PP-RRC#1 is the most inner PP of the twenty PPs mounted on the acceleration region of the RRC. The peaks

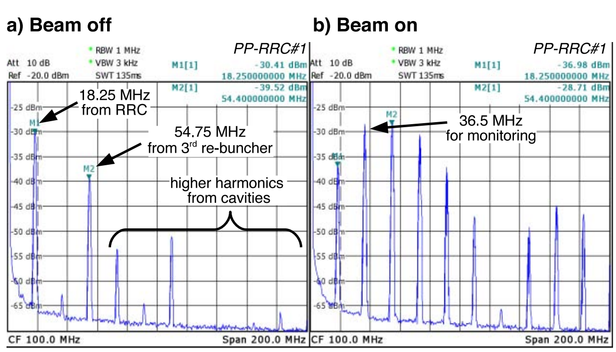

Figure 3: Frequency component of signal from PP-RRC#1 observed using spectrum analyzer under a) beam-off, and b) beam-on conditions.

observed under beam-off conditions correspond to leakage RF-fields of the RRC, third re-buncher and their higher harmonics. The beam bunch signal has a much larger harmonic component than the leakage RF-fields. Therefore, if we select a frequency with a high S/N ratio, we can perform measurements with high precision. In addition, signals other than the beam bunch signal, are rejected by numerically subtracting the I/Q component measured under beam-off conditions from that measured under beam-on conditions using the program of the developed LIA system. The reference frequencies of the beam-phase monitoring system for six sections in the uranium acceleration are summarized in Table 1.

Table 1: Reference frequencies of beam-phase-monitoring system for six sections in uranium acceleration. The frequencies of the main background (leakage RF) are also listed in the third row.

Sections	Ref. freq. [MHz]	Freq. of main background [MHz]
RILAC	54.75	18.25
RRC	36.5	18.25 and 54.75
fRC	109.5	54.75 and 164.25
BT-line	36.5	54.75 and 109.5
IRC	73	36.5 and 109.5
SRC	73	36.5 and 109.5

Acceleration-RF-Monitoring System

For the monitoring system of RF-fields, we divide the RIBF into four sections, which are the section around RILAC (injection buncher, RFQ linac, first re-buncher, and RILAC six cavities); that around RRC (second and third re-buncher and RRC two cavities); that around fRC (fourth re-buncher, fRC two main cavities, and fRC flat-top cavity); and that around IRC and SRC (IRC two main cavities, IRC flat-top cavity, SRC four main cavities, and SRC flat-top cavity). Each section has the monitoring system as it is shown in Fig. 2, and their RF-fields are analyzed by the LIA via switching module. The reference signals of LIA are also switched in accordance with the frequency of the RF-fields for monitoring as shown in Fig. 1.

ACQUIRED DATA USING DEVELOPED SYSTEMS

Correlation Between Observed Beam Phase and Acceleration RF

Fig. 4 shows an example of the phase drift of uranium beam and RF-fields which were observed on April 28, 2008. The sizable beam-phase drift of 0.6 nsec, which corresponds to 4 degrees in RRC-RF was observed at PPs-e11, X51 and S71 during 6 hours as shown in Fig. 4-a). At the same time, relatively large phase drift of RILAC-#5 was also observed among RILAC six cavities as shown in Fig. 4-b). The correlation between the observed beam-phase shift and instabilities of RF-field of RILAC-#5 is clearly understood as shown in Fig. 4-c). We have confirmed the accuracy of the developed system by feeding outputs from power divider (37.75 MHz, +10 dBm) into both signal and reference inputs of LIA via switching modules (see Fig. 2), and measuring its stability. The obtained stabilities of amplitude and phase during 24 hours were their average values $\pm 0.1\%$ and ± 0.1 degrees, respectively.

In order to reveal the cause of instability of the RF-field, we plan to perform the time series analysis using various data such as electric power, cooling water temperature, room temperature, and so on.

Isochronism of Cyclotron

The tuning of ischronous magnetic field of a cyclotron is also performed using the LIA system with the same configuration as beam-phase monitoring system. Signals are detected by the PPs which is radially mounted on the acceleration region of cyclotrons (PPs-RRC, fRC, IRC, and SRC), and analyzed by the LIA via switching module.

Fig. 5 describes the periodic arrival time of cyclic beam in each cyclotron (fRC, IRC, and SRC) as a function of the position along the radius vector. The result indicates that the isochronous condition of the magnetic field is attained to the acceptable level. Since the beam intensity was too low to obtain the precise data set with high S/N ratio, the isochronism of the SRC was poor. When the beam intensity will increases in future, the better isochronism of the SRC will be obtained. In addition, we have succeeded in improving the S/N ratio at the PPs-fRC using a technique based on the noise canceling. The open and closed circles in Fig. 5 are the isochronism before and after this improvement, respectively. It is expected that more precise data with improved S/N ratio for the IRC and SRC will be obtain by applying the same technique to them.

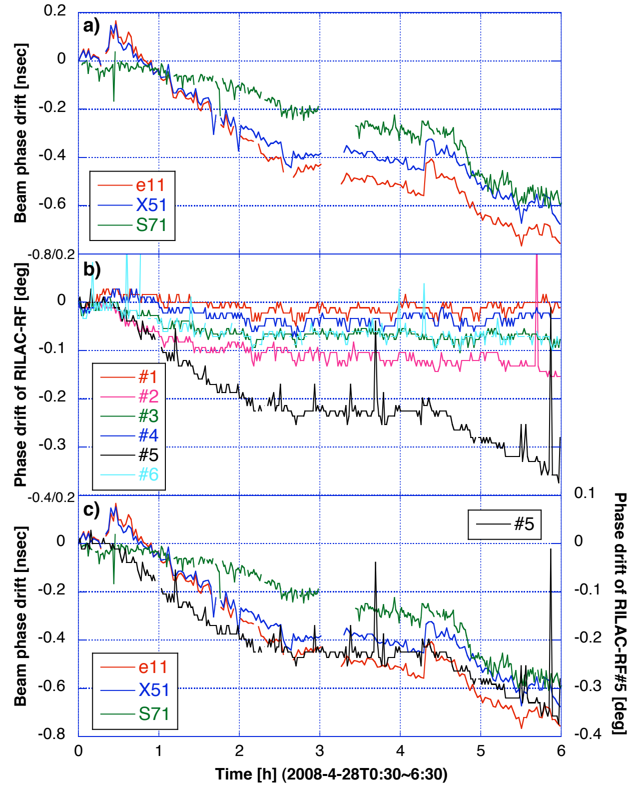

Figure 4: Phase drift of a) uranium beam, and b) RILAC-RF observed using developed SR844 systems. A correlation between RF phase of RILAC-#5 and beam-phases at PPs-e11, X51, and S71 was observed as shown in c).

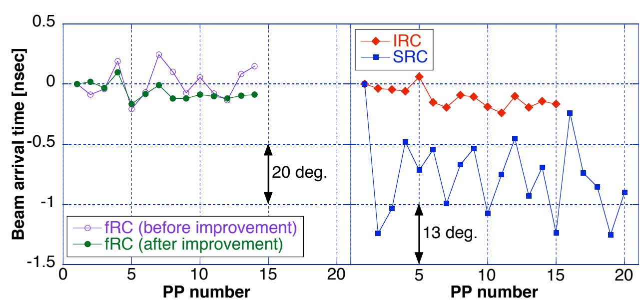

Figure 5: Isochronous condition of new cyclotrons in uranium acceleration.

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