

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

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Abstract

We have developed beam-phase and RF-fields monitoring system using lock-in amplifiers 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 11 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.

理研RIビームファクトリーにおける ロックインアンプを用いたビーム位相及び加速RF監視システム

1. 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 its injectors. It accelerates all kinds of heavy ions over 345 MeV/nucleon with a high beam-intensity, the goal of which is 1 μ A.

2. Developed monitoring system

2.1 Uranium acceleration in RIBF

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 an injection buncher, a RFQ linac, and four re-bunchers as shown in Fig.1. Two charge strippers are placed downstream of the RRC and the fRC.

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 fluctuations of RF-fields,

variation of magnetic fields of the cyclotrons, and so on. Hence, it is important to monitor stabilities of accelerators constantly in addition to beam-phases, and we have developed a monitoring system for both beam-phases and RF fields using commercial RF lock-in amplifiers (LIAs) SR844 manufactured by Stanford Research Systems^[2]. The system monitors beam-phases at 11 phase probes (PPs) installed in the beam transport lines and RF-fields of 25 cavities in the case of a uranium acceleration as shown in Fig.1. Using the system, we can investigate correlations between observed beam-phase instabilities and RF-field fluctuations.

2.2 Configuration of monitoring system

Both beam-phase and RF-fields monitoring system is divided into 5 sections, which are around RILAC, RRC, fRC, IRC, and SRC. Each section has the monitoring system with basically the same configuration shown in Fig.2. The beam-bunch signals and RF-fields are analyzed by the LIA via switching modules. All the systems are controlled by the LabVIEW program developed by one of the authors (R. K.).

It should be noted that the selection of the reference frequency of the LIA is important to obtain good signal-to-noise (S/N) ratio when we measure beam-phases. Fig.3 shows the frequency component of the signal from PP-S71 which is installed in the injection channel of the RRC as an example. The peaks observed under the beam-off

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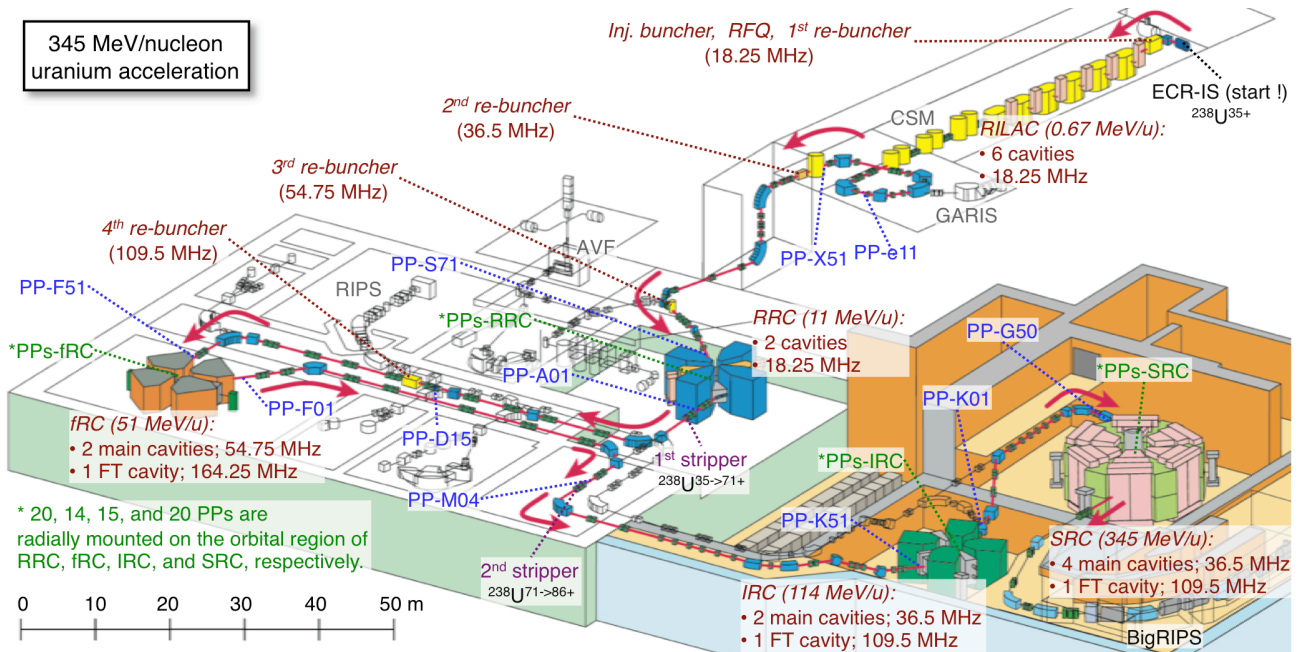


Fig. 1: Schematic layout of RIBF with operational parameters for 345 MeV/nucleon uranium acceleration. The positions of phase probes (PPs) used for a beam-phase monitoring are also shown. PPs which are radially mounted on the acceleration region of cyclotrons (PPs-RRC, fIRC, IRC, and SRC) are used for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

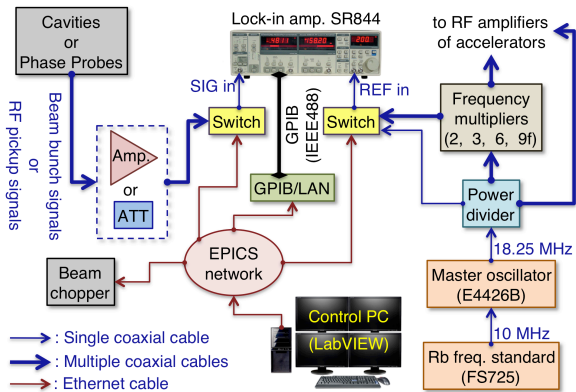


Fig. 2: Block diagram of developed monitoring system.

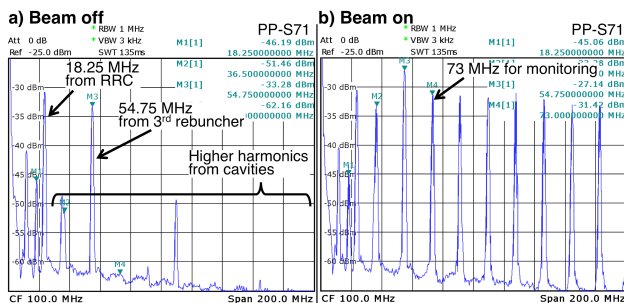


Fig. 3: Frequency component of signal from PP-S71 observed using spectrum analyzer under a) beam-off, and b) beam-on conditions.

condition 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 condition from that measured under beam-on condition using the developed program of the 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 5 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 backgrounds [MHz]
RILAC	54.75	18.25
RRC	36.5 or 73	18.25 and 54.75
fIRC	91.25	54.75, 109.5 and 164.25
IRC, SRC	73	36.5 and 109.5

2.3 Phase resolution of LIA

We investigated the phase resolution of LIAs using a commercial function generator AFG3252 manufactured by Tektronix. AFG3252 has two output channels and is able to generate two output signals with precisely the same frequency and an arbitrary phase shift. Fig. 4-a) shows the output phases of the LIA when the output phase of channel 1 of AFG3252 is shifted with 0.01 - 0.10 degree steps for every 3 minutes using the setup shown in Fig. 4-b). Fig. 5 summarizes the 3 minutes average of output phase plotted in Fig. 4-a) as a function of the phase shift generated by the AFG3252. The resolution of the LIA is determined to 0.03 degree in the present investigation. We plan more accurate measurement using an RF phase shifter (trombone type) instead of the use of

AFG3252, because the phases of the two output signals generated by the AFG3252 might be fluctuate each other.

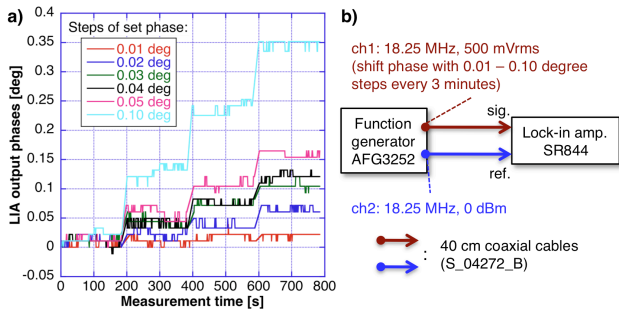


Fig.4: Investigation of phase resolution of LIA; a) is results of measurement and b) is measurement setup.

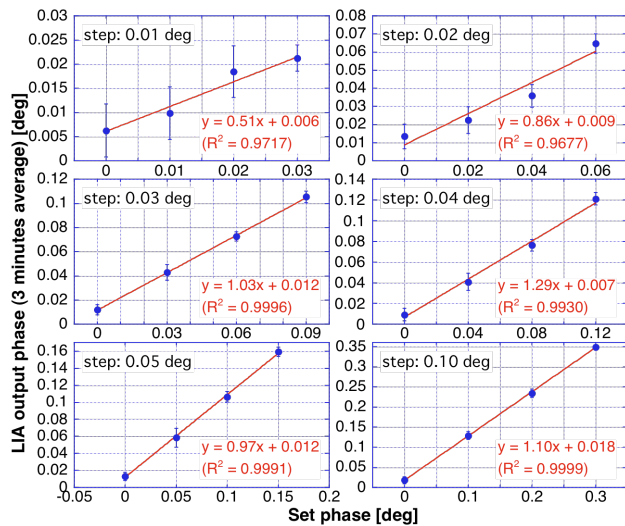


Fig.5: Every 3 minutes average of output phase plotted in Fig. 4-a) for each step of set phase.

2.4 Phase stability of multi-channel power divider

In the RIBF, a chain of multi-channel power dividers (PDs) is used for distributing the reference signal from the master oscillator. Some signals from other output channels of PD are also used as reference signals of the LIA system. Hence, we have to investigate the relative phase stability between output channels of PDs in order to estimate the phase accuracy of LIA system. Fig.6-a) shows the relative phase drift between two output channels of the PD measured using the setup shown in Fig.6-c). This PD is the first PD just downstream of the master oscillator of the RIBF. The observed phase drift was about 0.06 degree. Fig.6-b) shows the large phase drift of 0.08 degree when the equipment hatch near the PD was opened. This phase drift may be correlated with air temperature around PD, so it is planned to measure correlation between the phase drift and air temperature.

3. Examples of acquired data

Fig.7 shows an example of the phase drift of uranium beam and RF-fields, which were observed on April 28, 2008 using the LIA system. The sizable beam-phase drift of 0.6 nsec, which corresponds to 4 degrees in RRC-RF,

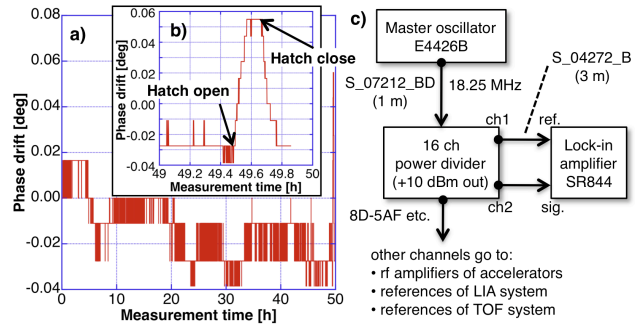


Fig.6: Relative phase drift between two output channels of PD.

was observed at PPs-e11, X51 and S71 during 6 hours. At the same time, relatively large phase drift of RILAC-#5 was also observed among RILAC 6 cavities. The correlation between the observed beam-phase drift and instabilities of RF-field of RILAC-#5 is clearly understood as shown in this figure. For more detail analysis on the observed beam-phase instabilities and RF-field fluctuations, see reference [3]. In order to reveal reasons of instabilities of the RF-field, the time series analysis using various data such as electric power, cooling water temperature, room temperature and so on, is planned.

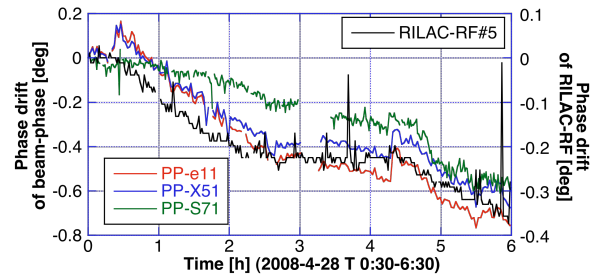


Fig.7: Phase drift of beam-phases and RILAC-RF#5.

Fig.8 shows the periodic arrival time of cyclic beam in each cyclotron (fRC, IRC, and SRC) observed by the PPs placed in the acceleration region. The results indicate that good isochronisms were obtained except for the SRC. 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 increase in future, the better isochronism of the SRC will be obtained.

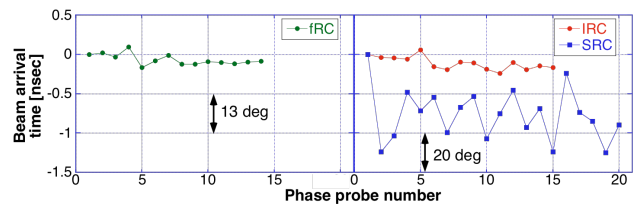


Fig.8: Isochronous condition of new cyclotrons in uranium acceleration.

References

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