STABLE OPERATION OF RF SYSTEMS FOR RIBF

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Abstract

At RIKEN RI-Beam Factory (RIBF), very heavy ion beams like uranium are accelerated up to 345 MeV/u by the RIKEN heavy ion linac (RILAC) and four ring cyclotrons, the RIKEN Ring Cyclotron (RRC), the fixed-frequency ring cyclotron (fRC), the intermediate-stage ring cyclotron (IRC), and the superconducting ring cyclotron (SRC) [1]. In order to provide high intensity beams up to 1 pμA, all the RF systems must be stable enough for a long term (a few weeks) within $\pm$ 0.1% in voltages and $\pm$0.1 degrees in phases. For a stable operation of RIBF, we have started to investigate a degree of stability of the RF systems using a newly developed monitoring system [2]. The efforts to improve the stability will be described.

INTRODUCTION

Since the first beam extraction from SRC in December 2006 [3], intense efforts has been made to increase intensities of several heavy ion beams (^{238}U and ^{20}Ca) with an energy of 345 MeV/u. The goal of beam intensity is 1 puA, whereas maximum beam intensity so far achieved is 0.8 pμA for ^{238}U. In order to achieve this goal, the loss of beams during the acceleration must be minimized. One of the most important factor which makes beams unstable is a fluctuation of accelerating RF. All the RF systems must be stable enough for a few weeks (during a period of operations) within $\pm$ 0.1% in voltages and $\pm$0.1 degrees in phases.

RF CONTROL SYSTEM

Injector Linac RILAC

RILAC consists of 6 tanks [4], and used as an injector for the accelerator complex of RIBF. A block diagram of the RF control system is shown in Fig. 1, which is similar as that for SRC [5]. The reference signal from a master oscillator is divided by a power divider, and is delivered to each tank of RILAC. The RF phase and voltage are stabilized by Auto Phase Control (APC) and Auto Gain Control (AGC), respectively. The grid and plate pickup signals are used to tune a resonant frequency of the tanks through Auto Tune Control (ATC). The main parts of the feedback control circuits (AGCs for tank #5 and #6, and all the APCs) are temperature regulated so that the circuits operates stably. These low level circuits for RILAC were designed to have a stability of $\pm$ 0.1% in voltages and $\pm$0.1 degrees in phases, which is the same specification as that for SRC. Four old type AGSs, which were without temperature control, were upgraded to the new type (the same as that used for #5 and #6) by September 2009.

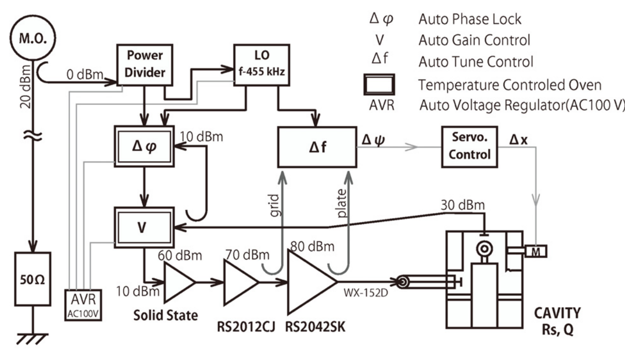

Figure 1: Block diagram of the RF system for RILAC.

Four Cyclotrons, RRC, fRC, IRC, and SRC

In the case of RRC, the low level circuits designed when RRC was constructed (in 1986) had been used until 2008. In order to maintain a relative RF phase between two cavities (#1 and #2), the phase of #1 is locked to the pickup phase of #2. This method was not applied for the other cyclotrons (each cavity is self-locked). It was found that this phase lock system for RRC fails to maintain relative phase in the uranium acceleration (see Fig. 5), which is partly due to a low dee voltage ($\sim$ 70 kV/gap) and low pickup signal. Therefore, all the low level circuits were upgraded to fulfill the stability requirement in September 2008.

The RF control systems for SRC, IRC, and fRC are essentially the same. For details of SRC, refer to Ref. [6].

MONITORING SYSTEM OF RF VOLTAGES AND PHASES

Since several accelerators are used in cascade at RIBF, it is important to maintain the accelerating RF and the matching of beam phases between accelerators. For a stable operation of accelerators in RIBF, a monitoring system using Lock-In-Amplifiers (LIA) SR844 [7] was developed to monitor continuously all the RF voltages and phases as well as the beam intensities and phases [2]. SR844 has a bandwidth of 25 kHz to 200 MHz, which is suitable for the operational RF frequency from 18 to 165 MHz at RIBF. The resolution of LIA was evaluated to be $\pm$ 0.1% in voltage and $\pm$0.03 degrees in phase.

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REFERENCE SIGNAL DISTRIBUTION

Schematic diagram of the reference signal distribution is shown in Fig. 2. The upper panel shows the system used

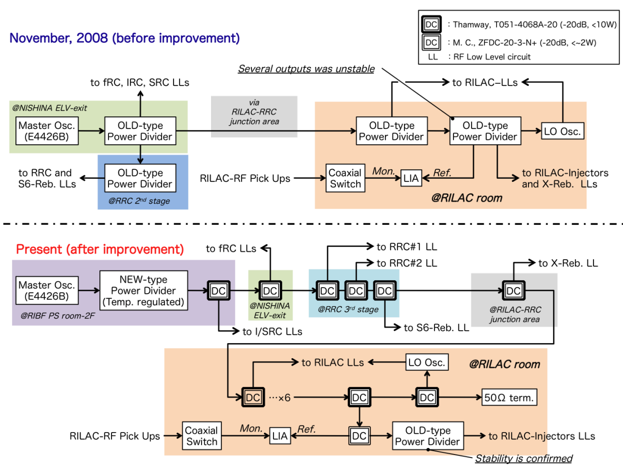

Figure 2: Schematic diagram of reference signal distribution. Upper and lower panel shows the method used in November 2008, and December 2009, respectively.

until 2008. The reference signal from the master oscillator was divided by the power divider and delivered to low level circuits of each accelerator. The master oscillator and the power divider of the first stage was located at where a large change of room temperature occurs ($\sim \pm 2°$C), and the power divider was not temperature regulated. Therefore, the output phases and voltages from power divider fluctuated depending on room temperature. As a consequence, a sudden change of RF phases for fRC was observed during the operation of RIBF on November 2008 [2].

Based on this experience, we have performed several modifications as follows: (a) relocate master oscillator to the room where low level circuits for SRC were placed [5]. The variation in room temperature was typically within $\pm 0.5°$C. (b) a temperature-controlled amplifier was introduced in the same room of (a) so that the reference signal from the master oscillator can be amplified up to 10 W. The output signal is delivered by a single, low-loss coaxial cable shielded by an aluminum pipe, and several single-port directional couplers are used to divide the signal for accelerators.

STABILITY OF RF PICKUP VOLTAGES AND PHASES

In the followings, the stability data for RILAC, RRC, and SRC obtained during uranium acceleration are shown. Figure 3 shows a long-term ($\sim$ 14 h) deviation of RF pickup voltages and phases in six tanks of RILAC observed in July 2008. The voltages for the last two tanks (#5 and #6) were relatively stable within 0.05%, whereas that for the rest tanks deviate more than 0.1%. The newer AGCs for #5 and #6 showed a better stability than others. The

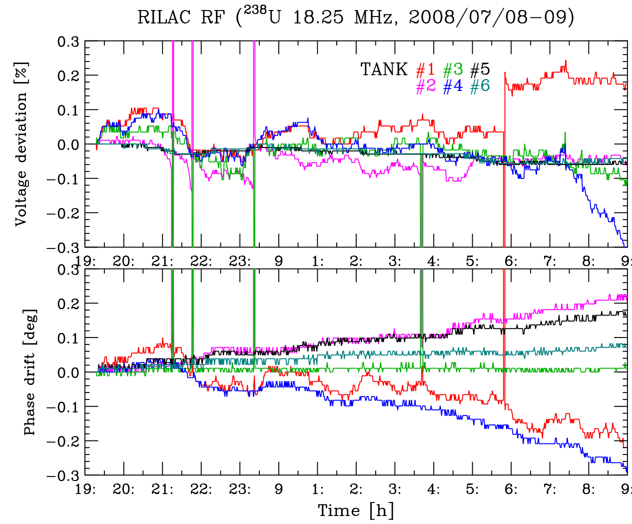

Figure 3: RF voltages and phases for 6 tanks of RILAC observed in July 2008.

phases were nearly monotonically increasing or decreasing. This instability was often observed, and it might be due to the temperature dependence of the power divider used for RILAC. After the modification mentioned above, the RF system of RILAC has been considerably stabilized in November 2009 as shown in Fig. 4. The deviation of

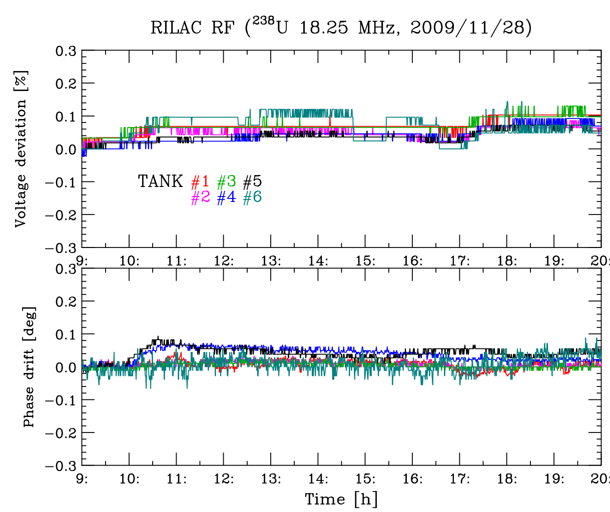

Figure 4: Same as in Fig.3, but observed in November 2009.

RF was within $\pm$ 0.05% in voltages and $\pm$ 0.08 degrees in phases for all tanks.

Figures 5 and 6 compare the data for RRC. Owing to the upgrade of low level circuits, a phase lock of the cavity #1 against #2 was improved, however, the stability became worse ($\pm$ 0.3% in voltage and ± 0.4 degrees in phase). The RF deviations of both voltages and phases between two cavities show inverse correlation. The further investigation is required to determine the source of this instability.

Figures 7 and 8 shows the data for SRC, observed in

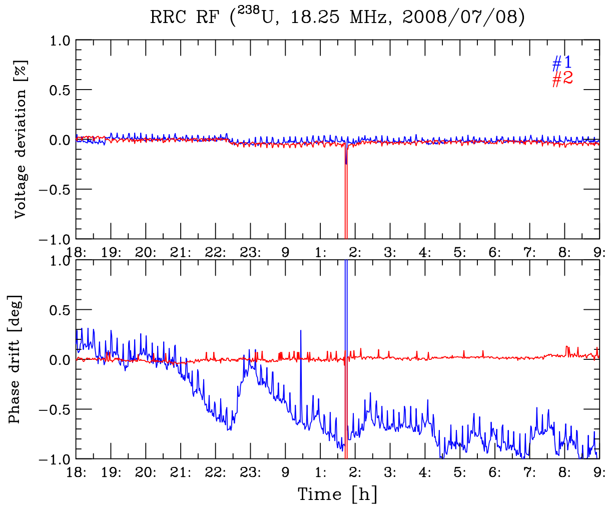

Figure 5: RF voltages and phases for 2 cavities of RRC observed in July 2008.

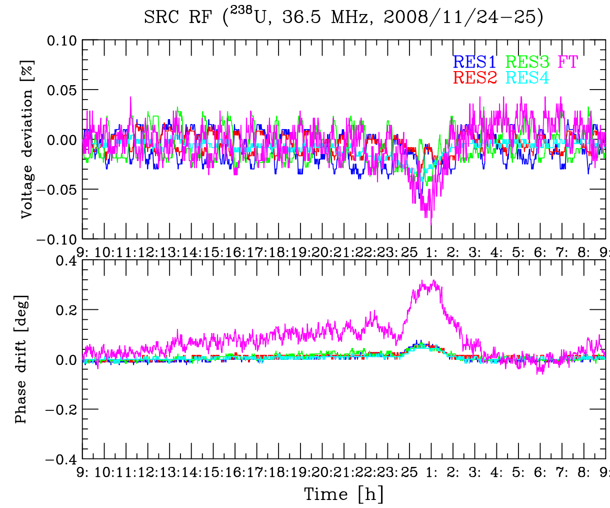

Figure 7: RF voltages and phases for 5 cavities of SRC observed in November 2008.

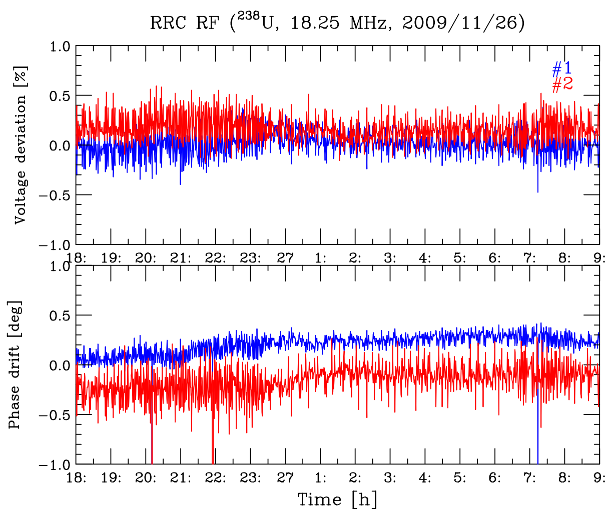

Figure 6: Same as in Fig. 5, but observed in November 2009.

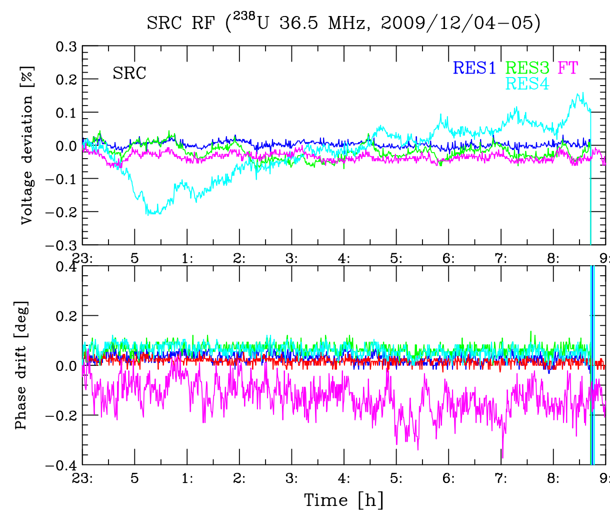

Figure 8: Same as in Fig. 7, but observed in December 2009.

November 2008 and December 2009, respectively. The four main cavities operated at the second harmonic (2f = 36.5 MHz), and one flattop cavity (FT) at the sixth harmonic (6f = 109.5 MHz). In Fig 8, the data for one of the main cavities, RES2 is missing because it was not operational due to a water leak from a tuner panel into vacuum. The instability of the voltage for RES4, and the phase for FT might be attributed to a failure of low level circuits.

PERSPECTIVE

Further modification of the reference signal distribution system is in progress. The local oscillator signal (LO), the 2f, and its LO (2f-LO) signals will be also distributed in the same manner as the reference signal. An eight-port directional coupler was introduced instead of using several single-port ones in series so that the number of connection and return loss are reduced. At first, two units were installed for the reference signal and LO to the low level circuits for SRC.

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