STATUS REPORT OF RF SYSTEMS IN RIKEN RIBF

N. Sakamoto*, M. Fujimaki, A. Goto, O. Kamigaito, M. Kase, R. Koyama, K. Suda,
K. Yamada, and S. Yokouchi
RIBF, RIKEN, Wako, Saitama, Japan

理研 RIBF 高周波系の現状

Abstract

Since the first beam from RIKEN Superconducting Ring Cyclotron (SRC) in the end of 2006, improvements have been made to make the rf field much more stable and make the system itself much reliable. Finally feedback low level system obtained the stability of $\pm 0.03°$ in phase and $\pm 0.03\%$ in amplitude. In the case of breakdown of rf voltage, automatic recovery sequence work well to minimize the beam off time. In this report the present status of the rf system built for RIBF cyclotron complex is described.

OUTLINE OF RF SYSTEM

At RIKEN RIB-factory(RIBF) an accelerator complex as an energy booster which consists of superconducting ring cyclotron (SRC), intermediate-stage ring cyclotron (IRC) and fixed-frequency ring cyclotron (FRC) provides very heavy ion beams like uranium with an energy of 345 MeV/u [1]. The total beam power obtained up to now at the SRC is as high as 3 kW in the case of ^{48}Ca with an intensity of 170 pnA. Recently we have succeeded in achieving stable and reliable operation of rf system for new cyclotrons. Three cyclotrons have been designed and built to boost the energy of the beam accelerated by RIKEN Ring Cyclotron (RRC) [2] for RI-Beam production.

There we have three acceleration modes. In Fig. , it is shown how to accelerate various ions with various energy. The operation frequencies for cavities are denoted by 1f,2f,3f and so on. In the end of 2006, ^{27}Al was accelerated in the mode 1 with an energy of 345 MeV/u as the first beam from the SRC. After that ^{238}U acceleration test in the mode 2 was performed extensively and the beam current of 0.4 pnA was provided to a new-isotope search experiment. A high intensity beam of ^{48}Ca was accelerated in the mode 1 with a beam power of 3 kW. In the mode 3, ions whose mass number A is less than 40 can be accelerated with an energy of 440 MeV/u to the maximum. This year ^{14}N and polarized deuteron beams have been accelerated with an energy of 250 MeV/u in this mode.

The frequency range for new cyclotrons, SRC and IRC, are 18 $\sim$ 42 MHz to meet that of the RRC. The FRC has been designed with a fixed frequency of 54.75 MHz to aim at an uranium acceleration with an energy of 345 MeV/u, while in the mode 1 the maximum energy of the uranium is 150 MeV/u.

In the acceleration mode 1 and 2, charge conversions getting a higher charge state are necessary to accept the beam due to the limitation of the magnetic rigidity of the

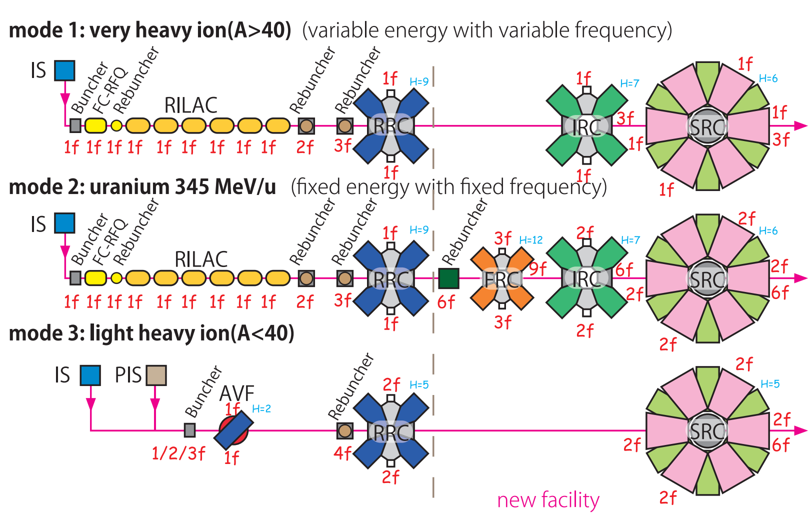

Fig.1 Acceleration modes of the accelerator complex of RIBF

* nsakamot@ribf.riken.jp

succeeding cyclotrons. The conversion is made by using charge stripper (carbon foil) at the sacrifice of longitudinal emittance growth. Therefore the flattopping systems in the cyclotrons are essential. The third harmonic rf make the longitudinal acceptance as large as $\pm 16°$.

In the operational aspect, stability of the acceleration field is a key issue and trouble-free is desirable. With stable rf system it is possible to make fine tuning of the accelerator cascades and to maintain the beam quality and the intensity during a long term physics experiment. To obtain much more reliability, improvement of the rf system has been made by fixing the problems turned out since the commissioning as described below.

STABILITY

Stability of the voltage and the phase of acceleration field of rf cavities is one of the most important issues for reliable operation of cyclotrons. An unstable rf field causes emittance growth of the beams during acceleration because energy gain per turn varies according to the rf field deviations, and the radius of the beam orbit changes, resulting in beam losses especially at the extraction device. Stable rf means not only constant amplitude and locked phase with reference to the rf signal from the master oscillator but also minimum interruption to providing beams due to rf breakdown which occurs due to sparks on the cavity surface.

The unstable of the rf field can be categorized into modulation and drift. Modulations of voltage and phase are caused mainly by ripple in the d.c. power supplies of amplifiers. Power supply ripples have main frequency components of 300 Hz and appear as an amplitude modulation and a phase modulation with a frequency of 300 Hz. Modulation of the rf signal can be observed as a side-band spectrum by using a spectrum analyzer. For example, an amplitude modulation of $\pm 5 \times 10^{-4}$ and a phase modulation of $\pm 0.1°$ correspond to spectrum levels of -72 dBc and -61 dBc, respectively. This modulation will be removed/minimized by tuning a feed-back loop (i.e., choosing a gain and a time constant) while observing strength of the side-band spectrum. After careful tuning of the feedback loop the sideband of 300 Hz ripple was reduced to -76 dBc.

On the other hand, drift of the rf voltage and phase occurs due to change in atmosphere temperature and change power supply. The temperature control oven system is equipped for the feed-back control. The temperature of the oven is controlled within $|\Delta T| < 0.5°$C. In addition, an automatic voltage regulated power supply was introduced to the Auto Gain Control and Phase Lock Loop.

Finally the stability shown in Fig. 1 was achieved. Phase drift of only 0.05° of RES3 was observed over 14 hours. The others were well stabilized within 0.1% and 0.1°. Fig. 1 plots records of the amplitude and phase of 4 acceleration and 1 flattop cavities of the SRC during acceleration of ^{14}N with an energy of 250 MeV/u (f = 27.4 MHz). The gap voltage/rf power of acceleration cavities (RES1∼4) and flattop cavity (FT) of the SRC were 440 kV/100 kW and 200 kV/12 kW, respectively. The measurements were made by using a new rf-monitor system.[6, 7] While the old vector voltmeter system had resolutions of 0.1 % and 0.1°, the voltage and phase resolutions of the new monitor are 0.01 % and 0.02°, respectively.

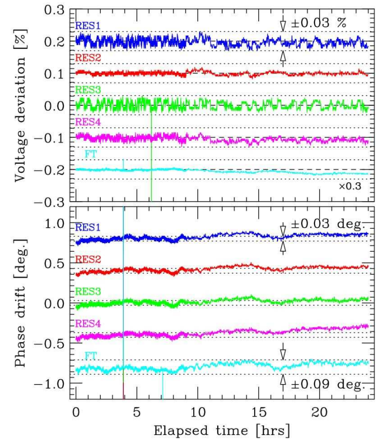

Figure 1: Amplitude and phase measured for 24 hrs.

In the case of rf voltage control breakdown due to a spark, it is important to recover rf voltage as soon as possible, otherwise it takes more than half an hour to manually recover by adjusting tuner a few cm, due to thermal deformation of the cavity by a cooling water.

The low level system has an automatic recovery mode which turns the rf input to the rf amplifier into pulse mode. The pulse mode has very fast $\Delta V/\Delta t$ of a few μs, and is crucial for overcoming the multipactor of the cavity in the recovery process. The rise-time of the cavity voltage is defined by the cavity and amplifier response. Therefore, in order to obtain fast pulse, large amplitude pre-pulse with a length of 100 μs is introduced to the normal pulse to obtain

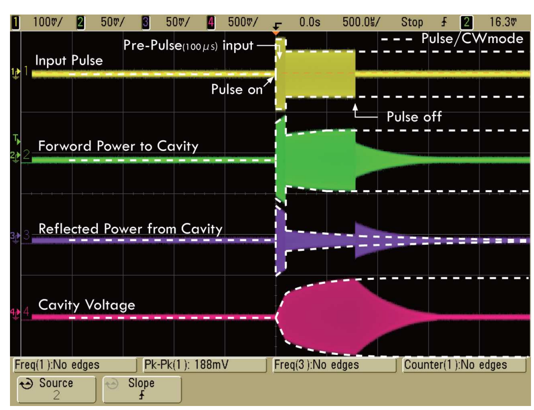

Figure 2: Pre-pulse is introduced to pulse-mode to overcome multipactor of the cavity. a) envelope of input signal to amplifier. b),c) forward and reflected power at coaxial feeder line, respectively. d)pickup signal of cavity.

a fast pulse. Fig. 2 shows the envelopes of the input pulse, forwarded power, reflected power and cavity pickup signal. It has been found that the fast $\Delta V/\Delta t$ pulse successfully overcome the multipactor with a pre-pulse and consequently restores normal power to the safe level for power supplies of amplifier and the cavity itself. In automatic-recovery mode, the cavity voltage will be recovered along the dashed line within a few ms. Therefore no voltage down of RES4 was observed during the stability measurements shown in Fig. 1.

OPERATION EXPERIENCES

Multipactor

In the initial stage of the commissioning of the SRC, the acceleration cavities were very difficult to be switched on due to a strong multipactor with the presence of the magnetic stray fields of the sector magnets. For the FRC and the IRC the multipactor was cleared by using a pulse excitation technique to pass through the voltage levels of multipactor, following dashed lines in Fig. 3. The levels of multipactor depend on the structure of resonator. For the

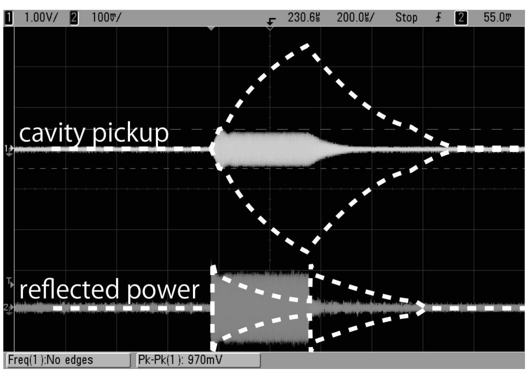

Figure 3: Profiles of the pickup signal from a cavity and the reflected power by a directional coupler on the feeder line. A full reflection occurs while the cavity voltage stopped at a certain level with a pulsed power. If we put a pulse with much more amplitude, then the cavity voltage grow up following dashed lines and reflected power is going to be zero.

SRC the multipactor was much more severe and it took more than one day to overcome it. In order to make the startup time shorter, conditioning with low power cw wave (cw) was tested instead of pulse and it turned out the new method works very well. By observing the level of the cavity pickup, the reflected power and the vacuum pressure, the level of the rf power is increased step by step until the cavity voltage becomes around 100 kV. Ordinary it takes only a few hours. It is enough to take 12 hrs for a careful conditioning. After the conditioning the cavity will be excited by a cw/pulse mode which recovers the voltage breakdown automatically turning the cw rf power to pulse mode to recover instantly in the case of voltage breakdown. If we see Fig. 1 carefully, sporadic losses of gap voltage are

Table 1: Summary of rf breakdowns during an experiment from May 1 to May 7(27.4 MHz. 100 kW/cavity).

day	RES1	RES2	RES3	RES4	FT	all
5th	0	0	1	0	2	3
6th	0	0	0	1	0	1
7th	0	0	0	1(1)	1	2
8th	1	2(1)	2	1	3	9
9th	3(1)	3	1	2	1	10
10th	0	2	1	5(1)	1	9
11th	2	8(1)	1	4	2	17
total	6	15	6	14	10	51(5)

observed together with a breakdown of phase lock. It was caused by rf breakdowns in the cavity and automatically recovered within a few seconds.

The statics of such breakdowns were counted and listed in Table 1. The number in round bracket counts the long loss when a manual recovery was needed. Until on the 7th day after the initial conditioning the count per day was small. From the day of 8th the counts increased extraordinarily and finally, after 11 days, it was required to have a cw conditioning for three hours. This is one of the major problem with the SRC cavities which disturbs providing beams for an experiment longer than 2 weeks.

SUMMARY

The rf system for new three cyclotrons achieved the designed performance. The amplitude and phase stabilities obtained are $\pm 0.3\%$ and $\pm 0.3°$, respectively. In this November it is planned to provide 3 kW ^{48}Ca beams to the experiments of BigRIPS.

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