Construction of the Charge-State Multiplier System for the RIKEN RI-Beam Factory

Osamu Kamigaito, Masayuki Kase, Yoshitoshi Miyazawa, Toshiya Chiba, Masatake Hemmi,
Naruhiko Sakamoto, Shigeo Kohara, Eiji Ikezawa, Akira Goto, and Yasushige Yano
RIKEN (The Institute of Physical and Chemical Research)
2-1 Hirosawa, Wako-shi, Saitama 351-0198, Japan

Abstract

In the RIKEN RI-beam factory project, a Charge-State Multiplier system (CSM) is planned to be placed between the existing heavy ion linac (RILAC) and the ring cyclotron (RRC). It consists of an accelerator, a charge stripper and a decelerator. The accelerator section increases the stripping energy further and the decelerator section brings the beam energy down to the initial value. By use of this system, the charge-to-mass ratio (q/A) of the heavy-ion beams will be increased so that the ring cyclotrons can accept the beams without changing the injection radius of the RRC. For the accelerator and decelerator sections, drift tube linacs of variable-frequency type will be used, whose rf-frequency is varied from 36 to 76 MHz. The total accelerating voltage required for the accelerator section is about 26 MV and that for the decelerator section is about 13 MV. Construction of the low energy part is almost finished. Preliminary results of the low power measurement is described in this paper.

1 Introduction

In the on-going RI-beam Factory project[1], a cascade of a K930-MeV ring cyclotron (IRC)[2] and a K2500-MeV superconducting ring cyclotron (SRC)[3] will be constructed as an energy booster of the existing K-540 ring cyclotron (RRC). The final energy will be increased up to 400 MeV/u for light ions such as oxygen and 150 MeV/u for uranium. As the injector for the accelerator complex, the existing heavy-ion linac (RILAC) will be used. The intended beam intensity is 1 pμA for light ions and 100 pnA for heavy ions. The fundamental rf-frequency is varied from 18.0 to 38.2 MHz.

For heavy ions, a charge-stripping process before the RRC is necessary so that the cyclotrons can accept the beams by reducing the magnetic rigidity. There is, however, a significant problem that the beam energy from the RILAC is too low to provide the required charge state with the existing charge-stripper between the RILAC and the RRC.

Let us consider acceleration of uranium as an example. In the present design, the final energy of 150 MeV/u from the SRC is obtained at the rf-frequency of 27.2 MHz. The required charged state of the uranium ions is at least 58+. However, the most probable charge-state after the present stripper will be 42+[4], because the output energy of the RILAC at this frequency is 1.48 MeV/u. Consequently, the production rate of 58+ is almost zero.

The Charge-State Multiplier (CSM) system, whose principle is illustrated in Fig. 1, has been proposed to solve this problem[1]. First, the output beam from the RILAC is accelerated further up to 3.84 MeV/u. Second, the charge state is increased by a charge-stripper at this energy where the production rate of 58+ is sufficiently high. Last, the obtained ions are decelerated to the initial energy. It should be noticed that the injection radius of the RRC need not be changed because the input speed to the RRC remains the same.

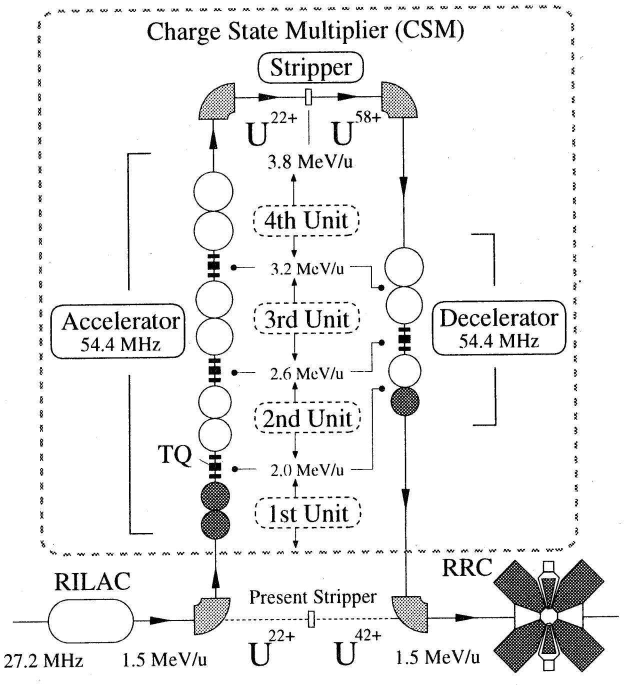

Fig. 1 Conceptual drawing of the CSM. Beam energy at the fundamental frequency of 27.2 MHz is indicated.

The total voltage-gain required for the accelerator section is 26 MV. The required gain for the decelerator section strongly depends on the ion-species and the frequency: the maximum value is 13 MV.

As shown in Fig. 1, the CSM is divided into four units, each of which consists of two accelerating cavities and one decelerating cavity[5]. The resonant cavities are independently operated. The frequency has been chosen to be twice of the fundamental rf-frequency, in order to make the whole structure smaller. Therefore, the frequency of the CSM should vary from 36 MHz to 76.4 MHz. A quadrupole-triplet is placed between every two tanks. The total length of the accelerator and that of the decelerator will be about 16 and 8 meters, respectively.

2 First Unit of CSM

2.1 Resonator Design

Construction of the first unit has been started since 1998. The first unit has three resonators, as indicated by the hatched circles in Fig. 1. The output energy of the accelerator section of this unit is chosen 2 MeV/u at the fundamental frequency of 27.2 MHz.

The resonator is based on a $\lambda/4$-coaxial type with a movable shorting plate, as shown in Fig. 2. All the three have the same dimensions except for the drift tubes and their stems. The rf-power is fed through a capacitive feeder. A capacitive tuner is used for the fine tuning of the frequency.

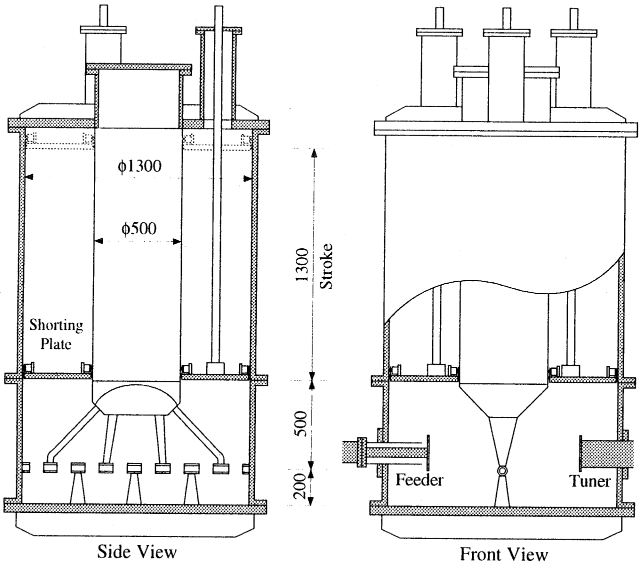

Fig. 2 Schematic drawing of the resonator of the first unit.

The rf-characteristic of the resonators has been studied with the MAFIA code. The size of the coaxial part as well as the shape of the stems for the first and last drift tubes are optimized so that the current density on the sliding contact could be as small as possible. The calculation predicts that a stroke of 1300 mm of the movable shorting plate covers the required frequency-range from 36 to 76.4 MHz in the three tanks. The current density on the sliding contacts is estimated to be 60 A/cm at the maximum gap voltage of 450 kV. The designed values are summarized in Table 1.

Cooling is one of the most important problems in these resonators. According to the calculation, the power loss in each stem for the end drift tube is 9 kW at the maximum gap voltage. The arrangement of the cooling channels has been designed based on the heat analysis.

The voltage distribution is not flat along the accelerating cells in these resonators, particularly in the high frequency region: the gap voltage at the end cells is about 80 % of that of the inner cells at the highest frequency. The effect of this voltage distribution on the beam transmission has been estimated with a first-order calculation. According to that, the transmission will be good enough when the average gap voltage is larger than the designed voltage.

Table 1
Designed parameters of the first unit

Tank	Accel.1	Accel.2	Decel.
Frequency (MHz)	36 - 76	36 - 76	36 - 76
m/q	26 - 6	26 - 6	12 - 2.7
E_{in} (MeV/u)^a	1.48	1.74	2.01
E_{out} (MeV/u)^a	1.74	2.01	1.48
Number of gaps	8	8	8
Gap voltage (kV)	450	450	450
Synchronous phase	-25°	-25°	+25°
Bore radius (cm)	1.75	1.75	1.75
Inner length (m)	1.3	1.3	1.3
Power loss (kW)^b	58	61	58
Z_s (MΩ/m)^{a,b}	147	152	146

a: At 54.4 MHz *b*: MAFIA prediction

2.2 Low-Power Tests

In July 1999, we performed low-power tests of the three resonators. Figure 3 shows the resonant frequency of the fundamental mode in the first accelerating tank. As shown in the figure, the frequency varies from 35 to 81 MHz, which covers the required range of the frequency. It is also shown that the measured results are in good agreement with the MAFIA prediction. Good results have been obtained also in the other two resonators. We have also seen that the frequencies of the higher modes are well reproduced by the MAFIA calculation.

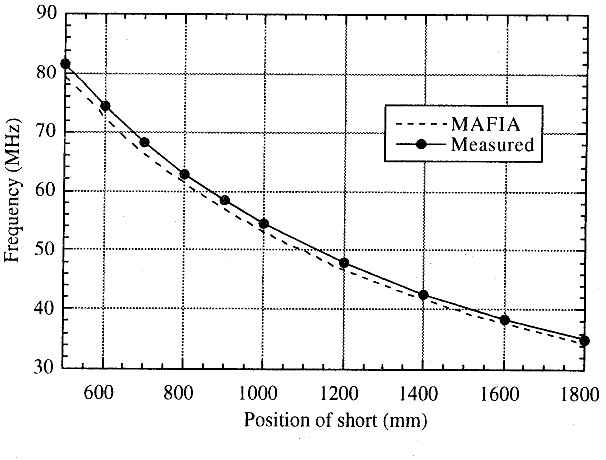

Fig. 3 Measured resonant frequency of the first accelerating tank along with the MAFIA calculations.

The measured Q-values of the first accelerating tank are shown in Fig. 4 along with the MAFIA calculations. As shown in the figure, the measured values are around 20,000. They are about 65 - 70 % of the calculated ones.

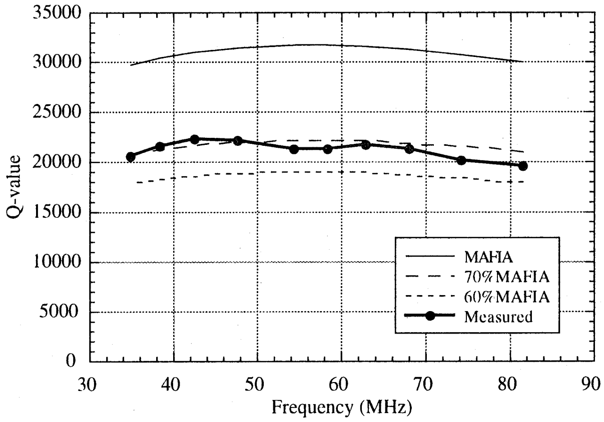

Fig. 4 Measured Q-values of the first accelerating tank along with the MAFIA calculations.

We also measured the parallel shunt resistance of the resonators. The results are about two-thirds of the calculated values, which means that the required rf-power will be about 90 kW at maximum.

Figure 5 shows the electric-field distribution of the fundamental mode on the accelerating axis, which was measured by means of a perturbation method. Since the rf-gap is wide in this resonator, the field-strength has the minimum at the center of each gap. In addition, strength on the upper drift tubes is larger than that of the lower ones, which reflects the vertical asymmetry of the cavity structure. These results are well reproduced by the MAFIA calculations, as shown in the figure.

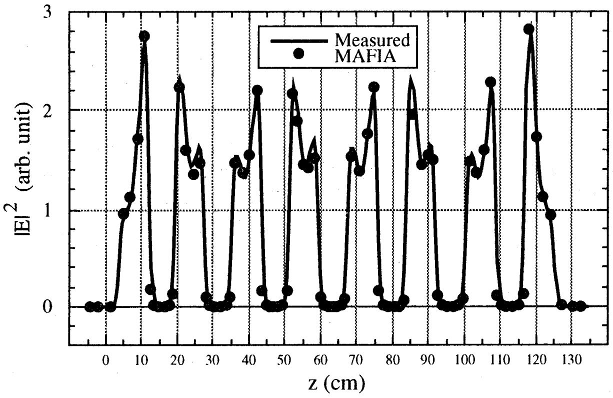

Fig. 5 Electric-field distribution on the acceleration axis measured for the fundamental mode at the lowest frequency (34 MHz). The solid curve shows the measured data. MAFIA prediction is indicated by closed circles.

2.3 Power Amplifiers

The power amplifiers have been fabricated based on a tetrode tube, SIEMENS RS2058CJ. The output power of 100 kW has been successfully achieved in the whole frequency-range required for the operation. Details of the amplifiers are described in ref [6].

3 Outlook

The three tanks will be installed in the beam line between the RILAC and the RRC by the end of this year. The rest of the CSM resonators will be designed and constructed based on the acceleration tests of the first unit.

Acknowledgement

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