DESIGN OF A CHARGE-STATE MULTIPLIER SYSTEM FOR THE RIKEN RI-BEAM FACTORY

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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. Initial design of the low energy part of the CSM, based on a quarter wavelength resonator with a movable shorting plate, 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) and a K2500-MeV superconducting ring cyclotron (SRC) 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 with this new cyclotron system. As the injector for the accelerator complex, the existing heavy-ion linac (RILAC) will be used, whose pre-injector has been recently upgraded[2]. The intended beam intensity is 1 pμA for light ions and 100 pnA for heavy ions.

For very heavy ions, a charge-stripping process is necessary before the RRC 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.

We illustrate this problem in Fig. 1 by taking the case of Uranium acceleration as an example. If the beam is accelerated to 150 MeV/u with the SRC, the corresponding rf-frequency and the output energy of the RILAC are 27.2 MHz and 1.48 MeV/u, respectively. To be accepted in the IRC and the SRC, the charge state must be at least 58^+. The most probable charge state at this energy is, however, 42^+ and the production rate of 58^+ is almost zero[3].

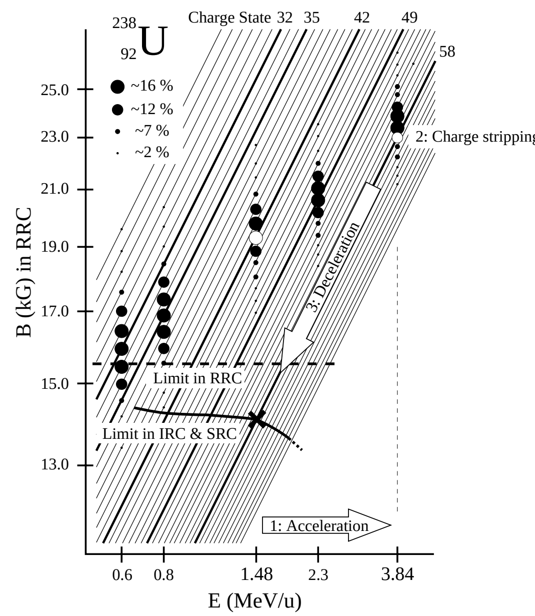

Figure 1: Principle of the CSM. The size of the dots corresponds to the production rate of Uranium ions with respective charge state at the stripping energy, E, when using a carbon foil for the stripper. The ordinate represents the necessary bending power in the RRC. The bending limit in the IRC and SRC is also indicated.

The proposed method[1] to solve this problem is also described in Fig. 1. The output beam from the RILAC is accelerated further up to 3.84 MeV/u. After charge-stripping at this energy, where the production rate of 58^+ is sufficiently high, 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 remains the same. This is the principle of the Charge-State Multiplier (CSM) system.

The CSM consists of an accelerator, a charge-stripper, and a decelerator as described above. Several designs have been proposed for the drift tube linacs used in the accelerator and the decelerator sections[4,5]. In the recent design[5], four accelerating tanks and two decelerating tanks are proposed, where 16 or 18 gaps are included in each tank. The resonator is based on the Interdigital H-mode (IH) structure with a movable shorting plate, whose rf-frequency is twice the fundamental frequency. In order to put the whole CSM in a present experimental room, the maximum gap voltage is chosen to be 430 kV. However, the power consumption per tank is estimated to exceed 100 kW and the calculated current density reaches 90 A/cm on the sliding contact around the corner of the ridge of the IH structure. This design has another problem that the tank becomes too long to make the structure rigid especially in the high energy part.

2 CSM DESIGN

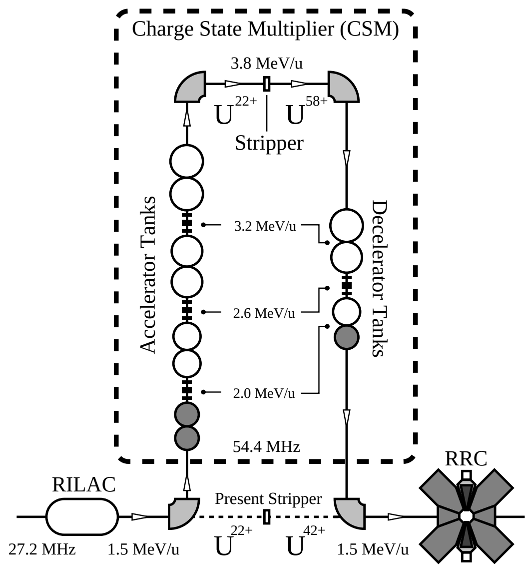

Figure 2: Schematic layout of the CSM. The energies at the fundamental frequency of 27.2 MHz are also indicated.

Figure 2 shows the schematic layout of the present configuration of the CSM. We plan to put eight tanks in the accelerator and four tanks in the decelerator. The tanks are independently operated at the doubled frequency of the fundamental one, which means that the required frequency for the CSM ranges from 36 MHz to 76 MHz. The synchronous phase of the accelerator tanks has been chosen to be -25° while that of the decelerator tanks has been 25°, in order to maintain the longitudinal focusing in the tanks. Each tank has eight gaps in it. The maximum gap voltage is chosen to be about 500 kV. The power consumption per tank will be made less than 100 kW by adopting this configuration.

The last tank of the decelerator covers the same energy-range as the first two tanks of the accelerator. In the same way, there are a pair of accelerator tanks and a decelerator tank which work in the same energy-range. Quadrupole triplets are placed between every two tanks. The total length of the accelerator and that of the decelerator will be about 16 meters and 8 meters, respectively.

Table 1: Main Parameters of the Low Energy Part of the CSM

Tank	Acc.1	Acc.2	Dec.
Frequency (MHz)	36-76	36-76	36-76
Mass to charge (m/q)	26-6	26-6	12-2.7
Input energy* (MeV/u)	1.48	1.74	2.01
Output energy* (MeV/u)	1.74	2.01	1.48
Inner length (m)	1.3	1.3	1.3
Number of gaps	8	8	8
Bore radius (cm)	1.75	1.75	1.75
Synchronous phase (ϕs)	-25°	-25°	+25°
Max. gap voltage (kV)	450	450	450
Max. power loss (kW)	50	52	50
Z_{eff} (MΩ/m)*	148	154	146
Max. current (A/cm)**	58	61	58

* : At 54.4 MHz.
**: Maximum current density on the sliding contacts.

Construction of the low energy part, indicated by the hatched circles in Fig. 2, has started and the mechanical design of the resonators is under progress. The main parameters are listed in Table 1. The output energy of the accelerator section of this part is 2 MeV/u at the fundamental frequency of 27.2 MHz.

The resonator of the low energy part is based on a quarter-wavelength resonator of circular cylinder, as shown in Fig. 3. All the three resonators have the same dimensions except for the drift tubes and their stems. The resonant frequency is changed by a movable shorting plate. The rf-power is fed through a capacitive feeder. A capacitive tuner is used for the fine tuning of the frequency.

The rf-characteristic of the resonators has been studied with the MAFIA code[6]. The size of the coaxial part as well as the shape of the stems for the first and final drift

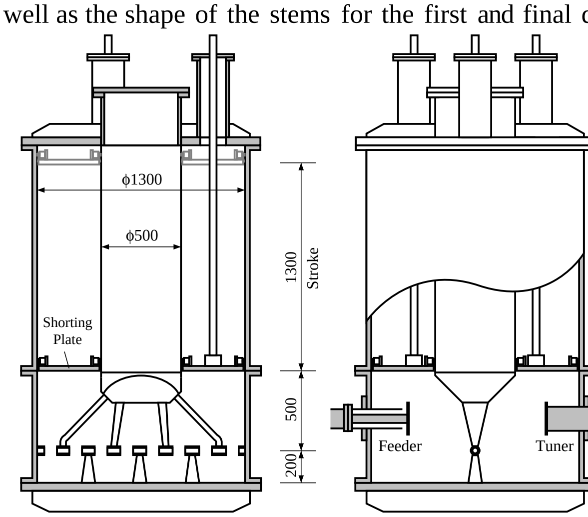

Figure 3: Schematic drawing of the resonator.

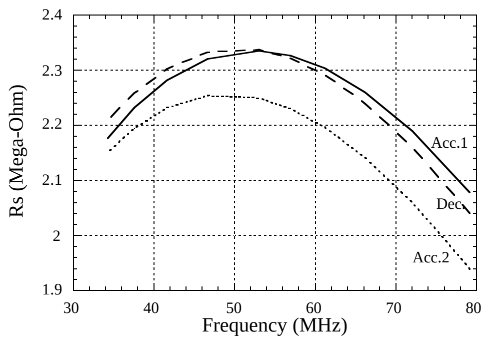

Fig. 4: Shunt impedances of the tanks of the low energy part. The solid, dotted and dashed curves represent the impedance of the first, second and the last tank of the CSM, respectively.

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 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.

Figure 4 shows the calculated shunt impedances. The shunt impedance R_s is defined in this paper by $V^2/(2P)$, where P is the rf-power consumption and V is the peak value of the gap voltage. From this result, the maximum power loss is calculated to be about 50 kW per tank. The calculated Q-values are about 30000 and they are almost constant in the frequency range.

The actual shunt impedances of the resonators will be less than the calculated ones mainly due to the sliding contacts used around the stem. Therefore, we are planning to construct the amplifiers whose maximum power is 100 kW in the required frequency-range.

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

The voltage distribution is not flat along the accelerating cells in these resonators, particularly in the high frequency region. A calculated example is shown in Fig. 5 for the second tank. As shown in the figure, 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.

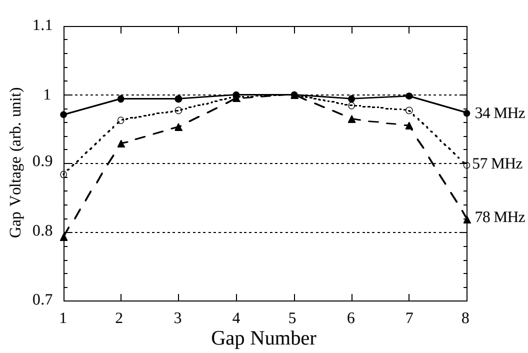

Fig. 5: Calculated gap voltage of the second tank of the CSM.

3 SUMMARY AND OUTLOOK

A design for the CSM has been proposed consisting of eight accelerator tanks and four decelerator tanks, independently operated in the frequency range from 36 MHz to 76 MHz. Three tanks of the low energy part of the CSM are under design based on a quarter-wavelength structure of circular cylinder with a movable shorting plate.

The construction of the low energy part will be completed in 1999. The three tanks will be installed and tested in the beam line between the RILAC and the RRC in the same year. The rest of the CSM tanks will be designed and constructed based on the test of the low energy part.

In parallel with the resonator design, study on the charge-stripper should be done, which can withstand the intended high intensity beams.

4 ACKNOWLEGDEMENT

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