RF CAVITIES OF THE RIKEN CHARGE-STATE MULTIPLIER

O. Kamigaito[1], N. Sakamoto, M. Kase, E. Ikezawa, S. Kohara, Y. Miyazawa,
T. Chiba, M. Hemmi, Y. Chiba, A. Goto, and Y. Yano,
RIKEN, Wako-shi, Saitama, 351-0198, Japan

Abstract

The RIKEN heavy-ion linac has been upgraded for nuclear physics experiments, by adding six booster cavities followed by a new beam line with six experimental courses. Using the booster, intense beams of heavy ions having mass-to-charge ratio of less than 5.6 will be accelerated up to 5.8 MeV/u. A decelerator cavity has been also installed in the injection line to the ring cyclotron. The detailed structure of the cavities, as well as the rf characteristics, are described in this paper.

1 INTRODUCTION

In the RI-beam factory project, a system called "charge-state multiplier (CSM)" has been proposed to extend the energy range of heavy-ion beams[1]. It is a combination of a booster linac, a charge stripper and a decelerator linac, which is placed between the heavy-ion linac (RILAC) and the ring cyclotron (RRC). By use of this system, the most probable charge-state of the beam after the stripper is shifted upwards, and the beam energy from the RRC can be extended to a higher value than that obtained with the present stripper. The total accelerating voltage required for the booster is 16 MV and that for the decelerator is 8 MV.

The design study of the CSM started in 1997. The most significant problem was that the area for the installation is quite limited, whereas the required energy gain is considerably high as mentioned above. Firstly, therefore, the frequency of the CSM was chosen to be twice the RILAC frequency in order to shorten the rf cavities. Secondly, the separated-type drift tube structure has been adopted for the cavities so that the rf power losses could be reduced; all the focusing elements are put outside of the cavities. Under these conditions, the optimization has been done by iterative simulations both for the beam dynamics and for the cavities.

The final configuration is illustrated in Fig. 1. The booster and decelerator are divided into three "units", each of which contains two rf cavities of the booster and one cavity of the decelerator. The three cavities in the same unit have the same shape and dimensions except for the drift tubes.

In 1999, three cavities of the low-energy part were constructed, which have shown good rf characteristics such as a wide variability of the frequency and high *Q*-values[2]. In the same year, construction of the booster

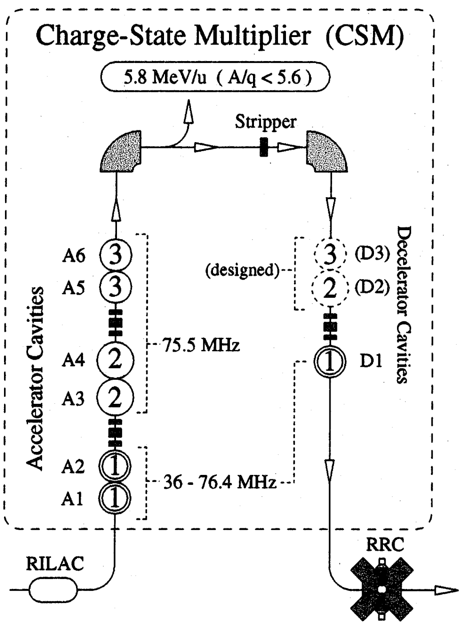

Figure 1: Conceptual drawing of the CSM. The cavities are represented by circles. The numbers in the circles indicate the "unit" of the CSM.

cavities of the high-energy part started, prior to making the full structure of the CSM. The aim of this decision is to initiate the experiments as soon as possible, using very intense beams from the booster with energies around the coulomb barrier of atomic nuclei. Since the beam energy for these experiments should be as high as possible, the four cavities of the booster are operated at almost the highest frequency.

The present status of the CSM is also indicated in Fig. 1; six booster cavities and one decelerator cavity have been installed between the RILAC and the RRC[3,4]. The detailed structure of the cavities, as well as the rf characteristics, are described below.

2 DESIGN

2.1 Main Parameters

The acceptable mass-to-charge ratio (A/q) of the booster was chosen to be the same as that of the RILAC; using the CSM frequency f, A/q of the booster is expressed as $A/q=32{,}000/f^2$. On the other hand, that for the decelerator is given by $A/q=16{,}000/f^2$.

[1] kamigait@postman.riken.go.jp

Table 1: Design parameters of the cavities.

Cavity	C_{in} a)	C_{out} b)	V_{gap} (kV)	L_{gap} (mm)	gap	ϕ_s (deg)
A1	5.00	5.88	450	80	8	-25
A2	5.88	6.78	450	87	8	-25
D1	6.78	5.00	450	83	8	-155
A3	6.78	7.71	470	93	8	-25
A4	7.71	8.65	470	99	8	-25
D2	8.65	6.78	470	96	8	-155
A5	8.65	9.40	500	104	6	-25
A6	9.40	10.16	500	108	6	-25
D3	10.16	8.65	500	106	6	-155

a) The input energy is given by
E_{in} (MeV/u) = $C_{in} \times f^2 \times 10^{-4}$,
where f is the CSM frequency in MHz.
b) Same as a) but for the output energy.

Table 1 summarizes the main parameters of the cavities. Based on the beam dynamics calculations, the inner diameter of the drift tubes is chosen to be 35 mm. The outer diameter is 55 mm, which has been determined by numerical simulations with MAFIA code. The gap length between the drift tubes is kept constant through each cavity, which is about one half of the cell length at the middle of the cavity. The number of gaps of the third-unit cavities is chosen to be six so that the cavity length can be made less than 1.3 m. The required gap voltages are approximately 500 kV, as shown in Table 1, and the surface electric field is about 16 MV/m at maximum. The input and output energies of each cavity are proportional to the square of the frequency. The coefficients of this relationship are also listed in Table I.

2.2 Simulations

The designed structure is based on the quarter-wavelength resonator with a movable shorting plate. Using the computer code MAFIA, the dimensions were optimized so that the frequency range from 36 to 76.4 MHz could be covered, while keeping power losses and the electric current on the inner boundaries of the shorting plates as small as possible. The surface electric field on the drift tubes was also taken into account.

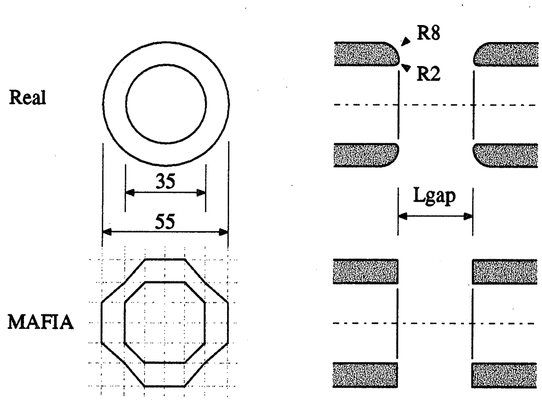

Figure 2: The real drift tube and its substitute. The octagonal cross section is discretized with three radial cells.

The number of the mesh points adopted in the simulations were 90,000 – 190,000, depending on the resonant frequency. The drift tubes are approximated by a octagonal cylinder as shown in Fig. 2. For the drift tube gaps, real values were used in the simulations.

Figure 3 shows the cavity structure. Although the variable-frequency cavities with the shorting plates have been designed for the high-energy units, only the lower parts were constructed as mentioned above. They are equipped with block tuners on the ceiling plates for the precise adjustment of the resonant frequency.

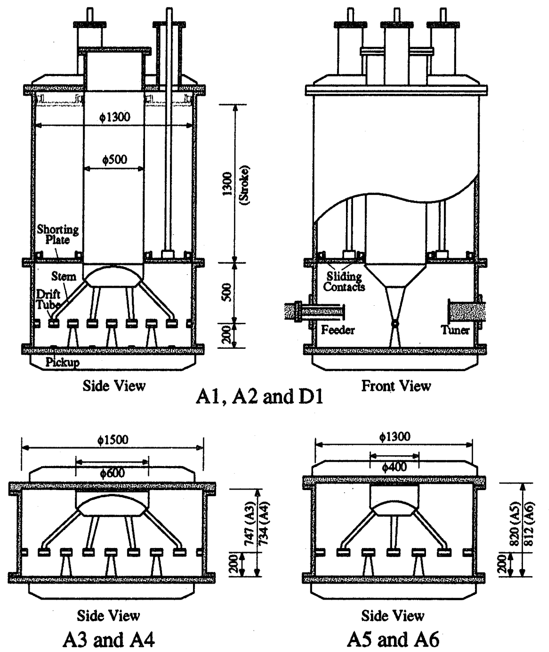

Figure 3: Schematic drawing of the CSM cavities.

2.3 Mechanical Structure

Almost all the components are made of oxygen-free copper. A remarkable point is that the side wall is cut from a single piece of copper block in every cavity of the high-energy units, in order to avoid possible vacuum leakage and to keep the machining accuracy. The base plates are made of steel and plated with copper by 50 µm. The drift tubes are aligned within an accuracy of +/- 0.15 mm.

The water channels are arranged based on the heat analyses. The total water flow per cavity is 600 l/min. Each cavity is equipped with a turbomolecular pump of 520 l/s and a cryogenic pump of 4000 l/s. The vacuum stays in the range of 0.5 – 1.0 $\times 10^{-7}$ Torr in the cw-mode operation.

3 RF ASPECTS

3.1 Low Power Tests

Table 2 summarizes the rf characteristics of the cavities. From the measurement, it was found that the measured frequencies are greater than the predicted values by the MAFIA code by 3 %.

The measured Q-values are 60 - 80 % of the calculated ones, which is considerably good in spite of the complicated structure of the cavities. One of the reasons for this is that we have inserted rf contacts of spring type into every joint between the metallic components. The estimated power losses per cavity are 60 - 90 kW at maximum.

Table 2: Rf characteristics of the cavities

Cavity	f (MHz)	Q-value	Qratio[a)]	P [b)] (kW)
A1	76.4 - 36.0	19,000 – 22,700	0.64 – 0.72	80 – 63
A2	76.4 - 36.0	18,500 – 22,500	0.64 – 0.72	86 – 64
D1	76.4 - 36.0	18,600 – 22,600	0.63 – 0.73	84 – 62
A3	75.5	25,000	0.78	67
A4	75.5	24,200	0.78	72
A5	75.5	23,700	0.76	63
A6	75.5	23,100	0.77	67

a) Ratio of the measured Q-value to the calculated one.
b) Power loss estimated at the maximum gap voltage given in Table 1.

3.2 High Power Tests

High-power tests of the cavities have been performed since September 2000, using the power amplifier of 100 kW[5]. So far, 70 % of the maximum voltage has been achieved in the cw-mode operation without any significant problems.

The open-loop transfer function of amplitude modulation was measured in the cw mode operation at various gap voltages. The measurement has shown that the system meets the requirements of the stability condition; the phase margin is around 30 degree, as shown in Fig. 4.

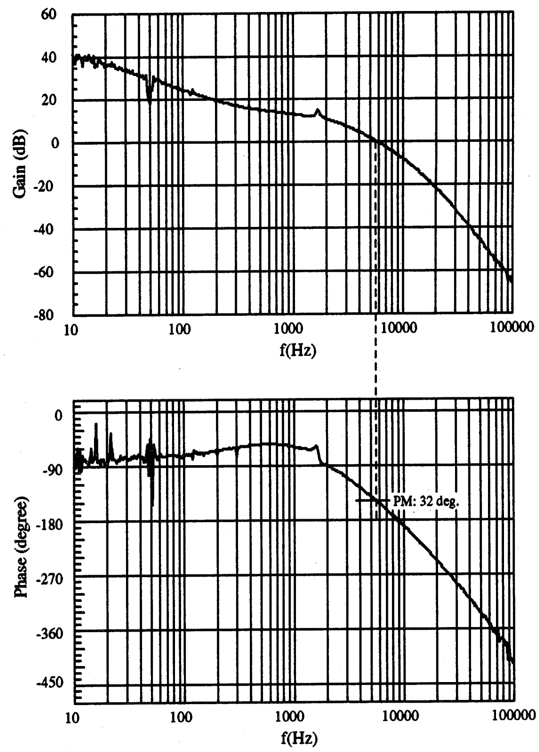

Figure 4: Bode diagram of the open-loop transfer function of the amplitude modulation, measured for the A3 cavity at the gap voltage of 180 kV. The horizontal axis represents the modulation frequency in Hz. The phase margin is 32 degree.

4 ACCELERATION TESTS

The first beam test of the booster was performed using a carbon beam on May 22, 2001. Since then, carbon and argon beams have been accelerated up to 5.8 MeV/u. The maximum intensity of the Ar^{11+} beam ever achieved is 4.8 pμA, which corresponds to the beam power of 1 kW. When the boosters are fully excited at the maximum voltage, the ion beams having mass-to-charge ratio of less than 5.6 will be accelerated up to that energy.

5 ACKNOWLEDGMENT

The fabrication and heat analyses of the cavities, as well as the design and fabrication of the rf amplifiers, were done by Sumitomo Heavy Industries, Ltd. (SHI). The authors are grateful to Mr. K. Uno at SHI for the detailed design of the cavities. They are also indebted to Mr. Y. Murakami at SHI and to Mr. T. Takai at Thamway Co. Ltd. at the commissioning of the rf systems. This work has been done in collaboration with the Center for Nuclear Study, Tokyo University.

REFERENCES

[1] Y. Yano et al.: Proc. 1997 Particle Accelerator Conference, Vancouver, May 12-16, 1997, p. 930.
[2] O. Kamigaito et al.: Proc. 12th Symp. on Accelerator Science and Technology, October 27-29, 1999, p. 233.
[3] O. Kamigaito et al.: Proc. 26th Linear Accelerator Meeting in Japan, August 1-3, 2001, p. 43.
[4] E. Ikezawa et al.: *in this proceedings*.
[5] Y. Murakami et al.: Proc. 12th Symp. on Accelerator Science and Technology, October 27-29, 1999, p. 239.