MODEL STUDY OF A RESONATOR FOR A FLAT-TOP ACCELERATION SYSTEM IN THE RIKEN AVF CYCLOTRON

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A resonator for a flat-top acceleration system in the RIKEN AVF cyclotron is designed to improve the extraction efficiency and the energy spread of the beam. The fundamental-frequency range is from 12 to 23 MHz and its maximum accelerating voltage is 50 kV. In order to generate the flat-top accelerating voltage on the dee, an additional resonator is required, which is coupled to the main resonator with a coupling capacitor. The flat-top accelerating voltage is obtained by superimposition of the fundamental-frequency and the fifth-harmonic-frequency voltages. We performed a cold model test of the flat-top system using a full-scale model coupled to the main resonator. It was found that the fifth-harmonic mode was realized below 68.71 MHz, but not in the whole required range.

1 Introduction

The RIKEN Ring Cyclotron (RRC) can accelerate various kinds of ions ranging from proton to uranium in a wide energy region[1]. One of the two injectors of the RRC is the AVF cyclotron, which is used for ions mainly from proton to light heavy ions like Argon[2]. The rf system of the AVF cyclotron has been working well after its completion in March 1989[3].

A layout of the AVF cyclotron is shown in Fig. 1. The injection and the extraction radii are 1.64 cm and 71.4 cm, respectively. The initial phase of the beam is made less than $\pm 10^\circ$ with a phase defining slit. The AVF cyclotron has two resonators, each of which is the coaxial quarter-wave-length type with a dee angle of 83°. The frequency range is from 12 to 23 MHz. The required maximum accelerating voltage is 50 kV. A movable shorting plate is used for the coarse tuning of the fundamental frequency and a capacitive tuner for automatic fine tuning. The stroke of the movable shorting plate is 2 m.

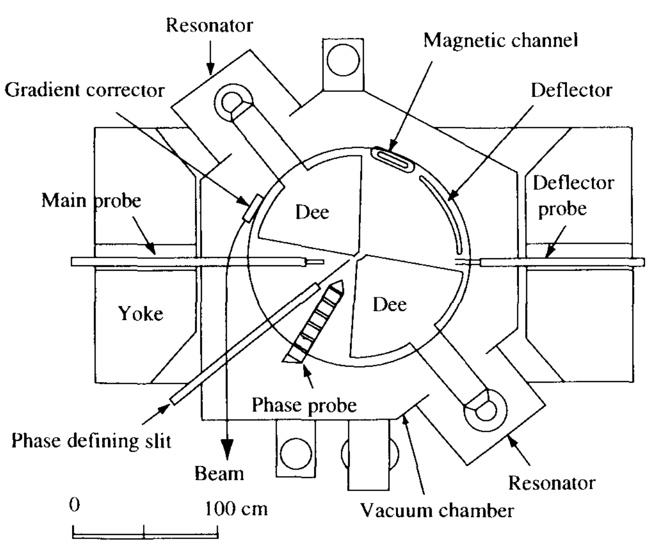

Figure 1: Layout of the AVF cyclotron.

The maximum frequency shift made with the capacitive tuner is about 500 kHz. A grounded-cathode tetrode (4CW50,000E) amplifier is capacitively coupled to the AVF resonator with a fixed vacuum coupling capacitor (16 pF). Its maximum output power is 20 kW.

In general, the required amplitude of the fifth-harmonic-frequency voltage is about 1/25 of the fundamental-frequency voltage when the voltage distribution of the acceleration gap is assumed to be flat along the radial direction. Therefore, on this assumption, the frequency range and maximum voltage of the fifth-harmonic-frequency system are estimated to be from 60 to 115 MHz and 2 kV, respectively. However, the actual voltage distribution is not flat, and it depends on the frequency. For example, the ratio of the voltage at the extraction radius to that at the injection radius is estimated to be 0.85 and 0.49 at 60 MHz and 115 MHz, respectively[4]. The required fifth-harmonic-frequency voltage at 115 MHz is, therefore, estimated to be 1/17 of the fundamental-frequency voltage; its maximum voltage of each resonator is to be 3 kV.

2 Structure of the resonator

A cross-sectional view of the additional resonator fabricated for the test of the flat-top acceleration system is shown in Fig. 2, which is based on the work by NAC people[5]. The additional resonator consists of a transmission line and a coupling capacitor (Cc). The shape of the coupling capacitor is like a half pipe and its size is 92 mm in radius and 155 mm in length. The capacitance of the coupling capacitor is about 30 pF when the position of the coupling capacitor is 12 mm. The fifth-harmonic resonant frequency is generated by adjusting both positions of the movable shorting plate (L5) and the coupling capacitance (Cc) of the additional resonator after the fundamental frequency of the main resonator is fixed by the movable shorting plate (Lavf).

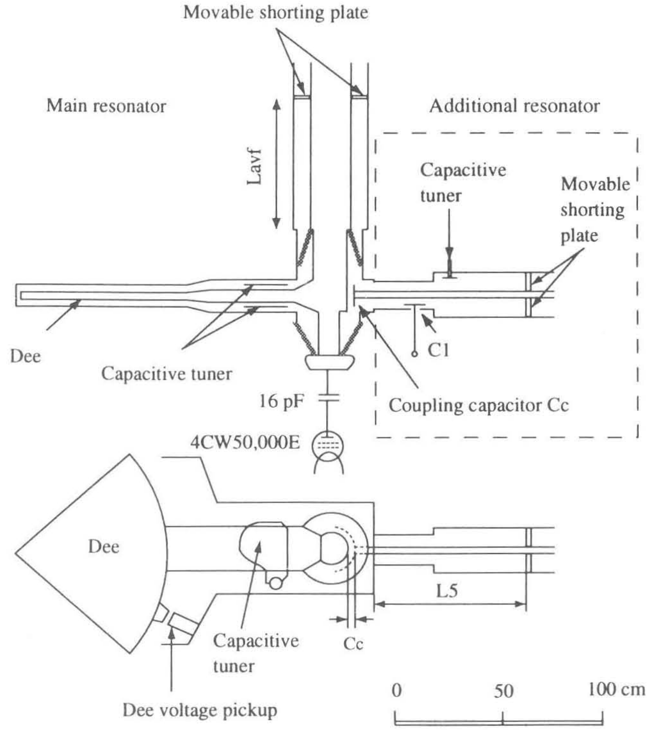

Figure 2: Cross-sectional view of the resonator for the flat-top acceleration system.

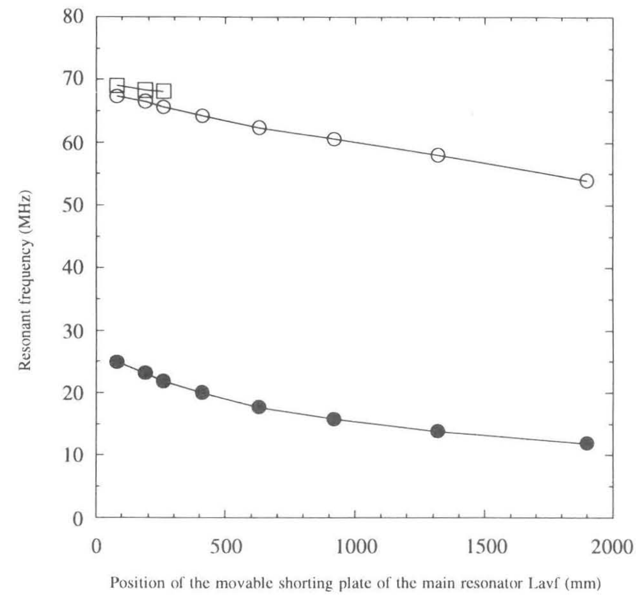

Figure 3: Resonant frequency of the main resonator as a function of position of the movable shorting plate of the main resonator. Closed circles represent the fundamental resonant frequency.

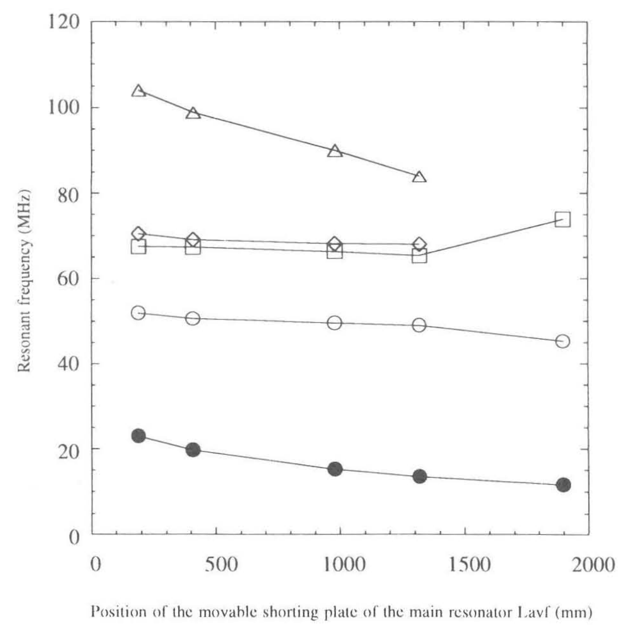

Figure 4: Resonant frequency of the flat-top resonator as a function of position of the movable shorting plate of the main resonator. Closed circles represent the fundamental resonant frequency.

3 Cold model test

Radio-frequency characteristics of the resonator was measured with low-level signals by using a network analyzer. The original resonant frequency of the main resonator without the additional resonator is shown in Fig. 3 as a function of the position of the movable shorting plate. In this measurement, the signal was fed into the resonator through the coupling capacitor (16 pF) and was monitored by the dee-voltage pickup. The resonant frequencies of the fundamental and two higher modes were measured.

In the next step, we measured the resonant frequency with the flat-top resonator being coupled to the main resonator, where the signal was fed into the flat-top resonator through the coupling capacitor (C1) and was monitored by the dee-voltage pickup. Four higher modes appeared above the fundamental frequency as shown in Fig. 4. One of them is used to the flat-topping acceleration, being shifted to exactly five times of the fundamental frequency.

In order to tune the resonant frequency of a higher mode to the fifth-harmonic frequency of the fundamental mode, the positions of the coupling capacitor (Cc) and the movable shorting plate (L5) of the additional resonator were adjusted after the position of the movable shorting plate (Lavf) of the main resonator was fixed. As the result, the fifth-harmonic resonant frequencies of 58.31, 62.93, 66.72, 68.71, and 98.73 MHz were realized on the dee along with the fundamental frequencies. Measured resonant frequencies, Q-values, and three parameters determining the resonant frequency are given in Table 1. The frequency difference (△f) between the fifth-harmonic frequency (f5) and the fundamental frequency multiplied by five (5×f1) could be made small by changing the position of the shorting plate and the coupling capacitor of the additional resonator. The Q-value (Q1) of the fundamental mode was from 2450 to 2700, while the Q-value (Q5) of the fifth-harmonic mode was from 150 to 780.

Because the lower limit of the movable shorting plate of the additional resonator is 332 mm, the fifth-harmonic resonant frequency did not appear on the dee when the fundamental resonant frequency was over 15 MHz. Typical resonant frequencies measured with the flat-top resonator are shown in Fig. 5 and Fig. 6, where closed circles represent the fundamental resonant frequency. Figure 5 shows that the resonant frequencies of the higher modes vary when the position of the movable shorting plate of the additional resonator is changed, without causing a large frequency-shift in the fundamental resonant frequency. It is recognized that the length L5 should be further decreased in order to realize the fifth-harmonic resonant frequency at this operation point. The effect of the position of the coupling capacitor (Cc) on the resonant frequency is shown in Fig. 6. Optimum position of the coupling capacitor would be about 40 mm.

Table 1: Measured resonant frequencies, Q-values, and three parameters determining the resonant frequency.

Lavf (mm)	Cc (mm)	L5 (mm)	f1 (MHz)	Q1	f5 (MHz)	Q5	Δf (kHz)
1900	11.5	445	11.66	2540	58.31	780	10
1610	19.5	403	12.59	2660	62.93	490	20
1500	19.5	336	13.34	2630	66.72	350	20
1320	29.5	355	13.74	2700	68.71	230	10
410	11.5	345	19.74	2450	98.73	150	30

4 Rf control system

A block diagram of the rf control system designed for the fifth-harmonic frequency is shown in Fig. 7. The system consists of power divider, fifth-frequency multiplier, low level circuits, and wide-band amplifier. The signal from a frequency synthesizer is split into the AVF, RRC, and bunchers systems with the power divider. The frequency of this signal is multiplied by five by the frequency multiplier. The phase shifter is used so as to adjust the phase of the fifth-harmonic-frequency voltage. The amplitude of the voltage is regulated with the amplitude modulator. The resonator is tuned automatically with a capacitive tuner by comparing the phases between the fifth-harmonic-frequency voltage and the reference voltage. The stabilities of the amplitude and the phase of the voltage should be less than 1×10^{-3} and 0.5°, respectively.

5 Conclusion

We performed a cold model test of a flat-top acceleration system of the AVF cyclotron. The fifth-harmonic resonant frequency was found to be realized on the dee in the fifth-harmonic frequency less than 68.71 MHz. The frequency

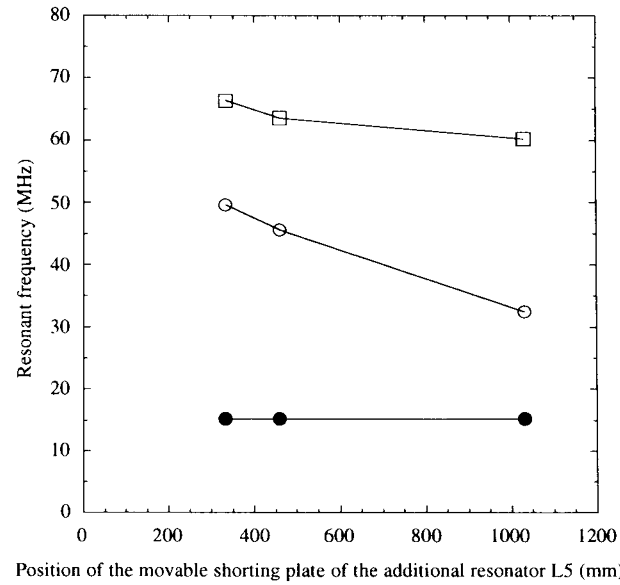

Figure 5: Resonant frequency of the flat-top resonator as a function of position of the movable shorting plate of the additional resonator. The position of the coupling capacitor (Cc) is 11.5 mm. The fundamental frequency is 15 MHz.

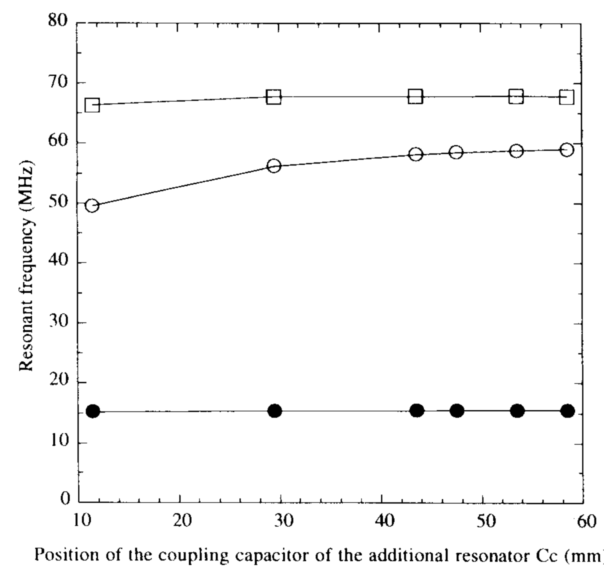

Figure 6: Resonant frequency of the flat-top resonator as a function of position of the coupling capacitor of the additional resonator. The position of the movable shorting plate (L5) is 332 mm.

difference between the fifth-harmonic resonant frequency and the fundamental frequency multiplied by five could be made small. The position of the movable shorting plate of the additional resonator changes the frequency of the higher modes effectively without changing the fundamental frequency. However, the fifth-harmonic resonant frequency over 69 MHz was not obtained, except for 98.73 MHz. In order to generate the fifth-harmonic mode over 70 MHz, the lower limit of the movable shorting plate of the additional resonator should be set less than 332 mm. Further tests of the flat-top system will be performed during the summer overhaul period.

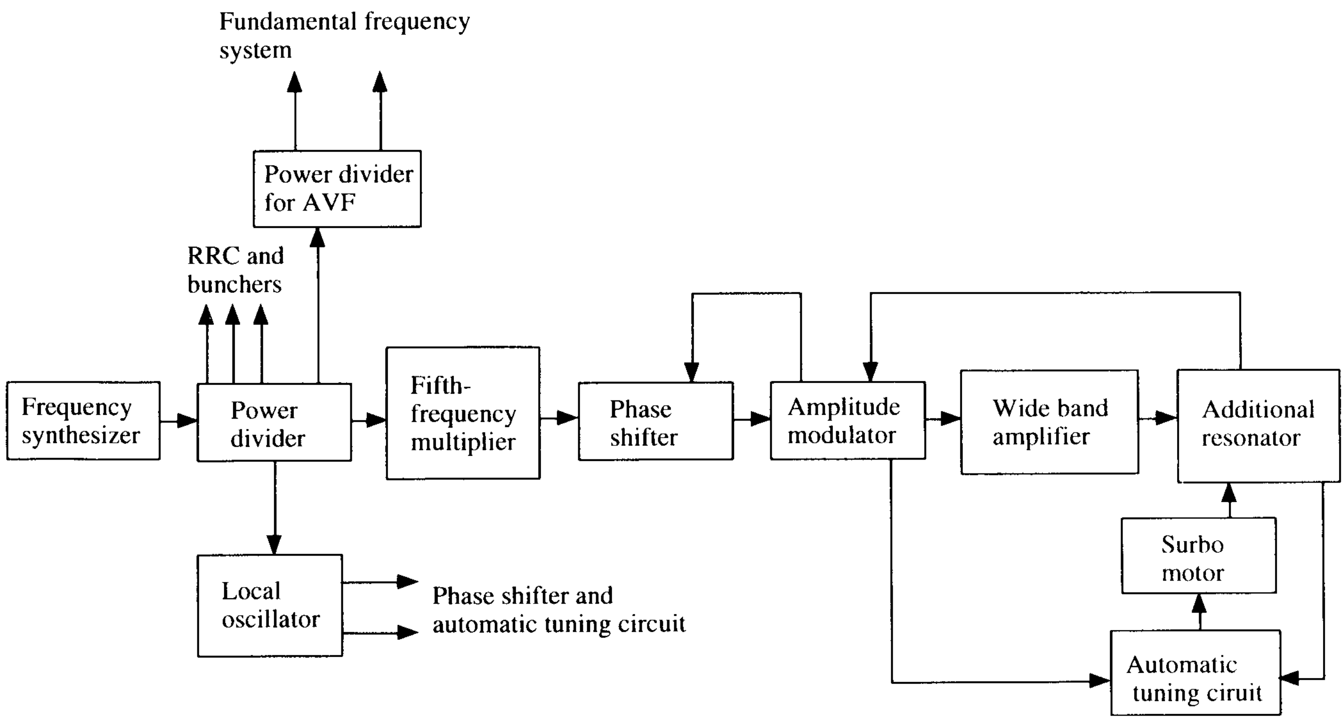

Figure 7: Block diagram of the rf control system for the fifth-harmonic frequency.

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