Construction of the Flat-Top Acceleration System in the RIKEN AVF Cyclotron

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Abstract

The flat-top acceleration system in the RIKEN AVF Cyclotron was constructed and installed with the main resonator in order to improve the extraction efficiency and energy spread of the beam in August 2001. The flat-top accelerating voltage is generated by a superimposition of the fundamental-frequency and 3rd-harmonic-frequency voltages. The fundamental-frequency range is from 12 to 24 MHz; the 3rd-harmonic-frequency is used, from 36 to 72 MHz. Results of the test performed with the flat-top acceleration system are described.

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 AVF Cyclotron has two resonators, each of which is the coaxial quarter-wave-length type with a dee angle of 83°. A grounded-cathode tetrode amplifier is capacitively coupled to each resonator with a fixed vacuum coupling capacitor. Its maximum output power is 20 kW. The rf system of the AVF Cyclotron has been working well after its completion in March 1989 [3]. The flat-top acceleration system in the AVF Cyclotron has been planned to obtain better quality beam.

The result of the cold model test for the 5th-harmonic-frequency mode was reported elsewhere [4]. As the result, the flat-top accelerating voltage was generated in the whole frequency range. But the power loss of the resonator was not measured when the rf characteristic measurement of the 5th-harmonic-frequency mode was carried out. The rf characteristics of the resonator were measured again in detail in order to design a power amplifier after the construction of the real resonator was planned. In general, the power loss can be less for the 5th-harmonic frequency than for the 3rd-harmonic frequency, since the required amplitude of the 5th-harmonic-frequency voltage is about 1/25 of the fundamental-frequency voltage, while that of the 3rd-harmonic-frequency voltage is about 1/9 of the fundamental-frequency voltage. However, we found that the power loss for the 3rd-harmonic frequency was actually less than that for the 5th-harmonic frequency. So we have decided to adopt the 3rd-harmonic frequency mode instead of the 5th-harmonic frequency mode.

2 Structure of the resonator

The cross-sectional views of the main resonator and flat-top resonator are shown in Fig. 1. The size of the flat-top resonator is 1 m in length, 50 mm in outer diameter of the inner conductor of the coaxial resonator and 250 mm in inside diameter of the outer conductor of the coaxial resonator.

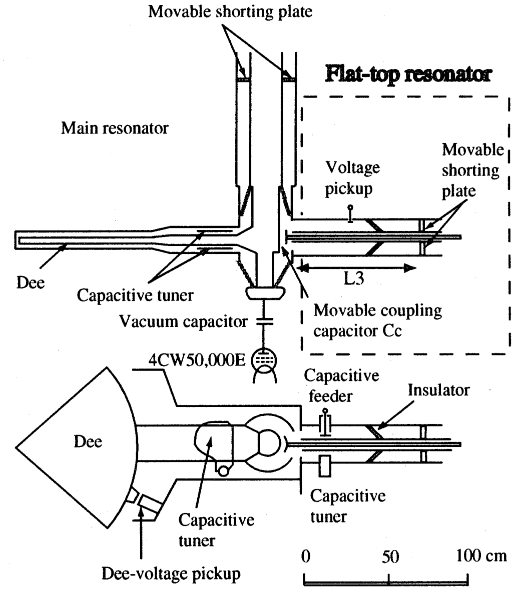

Fig. 1 Cross-sectional view of the flat-top acceleration system for the RIKEN AVF Cyclotron.

The flat-top accelerating voltage is generated on the dee by adjusting both the movable shorting plate (L3) and the movable coupling capacitor (Cc). The strokes of the movable shorting plate and the movable coupling capacitor are 400 mm and 50 mm, respectively. The size of the coupling capacitor is 150 mm in width and 150 mm in height. The capacitive feeder is used to match the input impedance of the flat-top resonator to the impedance of the feeder (50 Ω). The stroke of the capacitive feeder is 30 mm. The resonator is tuned automatically with the capacitive tuner by detecting incident and reflected waves on the feeder line. The stroke of the capacitive tuner is 50 mm. A ceramics insulator is used for support of the inner conductor of the coaxial resonator as well as vacuum seal. Total coolant water of each flat-top resonator is 9 l/min. A photograph of the flat-top resonator installed on the existing main resonator is shown in Fig. 2.

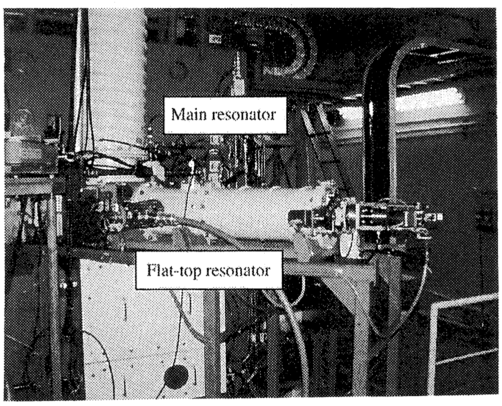

Fig. 2 Photograph of the flat-top resonator installed on the existing main resonator.

3 Cold test of the resonator

Radio-frequency characteristics of the resonator were measured with low-level signals by using a network analyzer. The resonant frequencies with the flat-top resonator being coupled to the main resonator were measured. In this measurement, the signal was fed into the flat-top resonator through the capacitive feeder and was monitored by the dee-voltage pickup. The measured position of the movable shorting plate and the movable coupling capacitor of the flat-top resonator are shown in Fig. 3 as a function of the 3rd-harmonic-resonant frequency. It was found that the 3rd-harmonic mode was realized below 63.3 MHz, but not in the whole required-frequency range. The measured Q-values of the fundamental and the 3rd-harmonic modes as a function of the resonant frequency are shown in Fig. 4 (a) and (b), respectively. Figure 5 shows the measured transmission (S21) of the flat-top resonator of the 3rd-harmonic mode. In the measurement, the input impedance of the flat-top resonator was matched to the impedance of the feeder and the dee-voltage pickup was calibrated. The estimated power loss and the required voltage of the 3rd-harmonic mode are shown in Fig. 6, respectively. The power loss of the 3rd-harmonic mode was estimated by the measured value of the transmission and the required voltage. The frequency-change rate measured of the capacitive tuner was about 1 %. The measured result shows that the performance of the No. 2 resonator is better than that of the No. 1 resonator. The differences of the measured results between the No.1 and the No.2 resonators are under investigation.

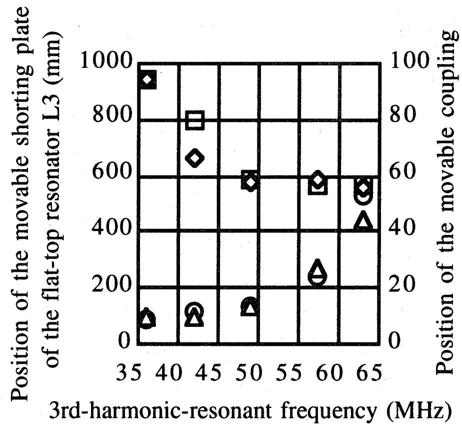

Fig. 3 Position of the movable shorting plate and coupling capacitor as a function of the 3rd-harmonic-resonant frequency. Squares and circles represent the position of the shorting plate and the coupling capacitor of the No.1 resonator, respectively. Diamonds and triangles represent the position of the shorting plate and the coupling capacitor of the No.2 resonator, respectively.

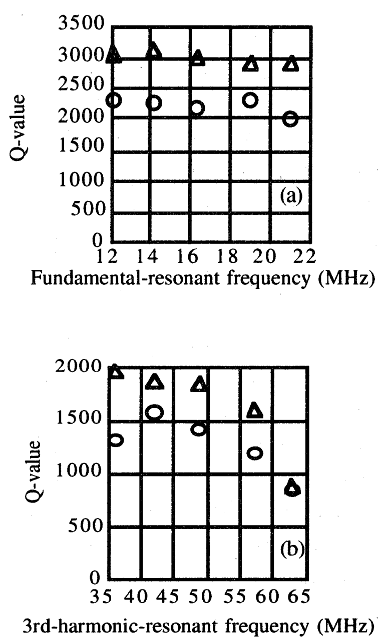

Fig. 4 (a) Q-value of the fundamental mode as a function of the resonant frequency. (b) Q-value of the 3rd-harmonic mode as a function of the resonant frequency. Circles represent the Q-values of the No. 1 resonator and triangles represent the Q-values of the No. 2 resonator.

4 Power test

In the first step, the power test of the 3rd-harmonic mode was carried out to estimate the required output power of the 3rd-harmonic amplifier. The output power of the fundamental amplifier was not fed into the main resonator in this power test. The parameters of the flat-top resonator were set each position as shown in Fig. 3. The required output power of the 3rd-harmonic amplifier is shown in Fig. 7. The required power was estimated by the measured dee voltage and output power of the 3rd-harmonic amplifier and the required voltage. The voltage of the 3rd-harmonic mode was generated below 57.3 MHz in the No. 1 resonator. The power test of the No. 2 resonator was not carried out because its 3rd-harmonic power amplifier was breakdown.

In the next step, the power of the fundamental and the 3rd-harmonic frequencies were fed into the resonator at the same time to generate the flat-top voltage on the dee. The typical waveform of the flat-top voltage is shown in Fig. 8.

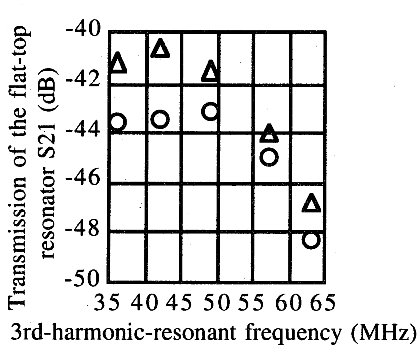

Fig. 5 Transmission of the flat-top resonator of the 3rd-harmonic mode. Circles represent the transmission of the No. 1 resonator and triangles represent the transmission of the No. 2 resonator.

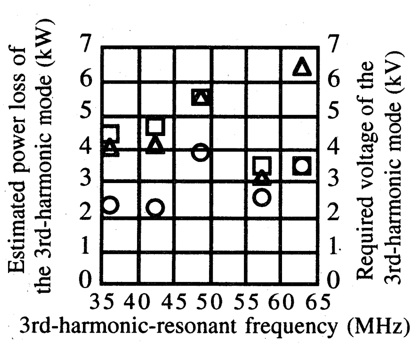

Fig. 6 Estimated power loss and the required voltage of the 3rd-harmonic mode. Triangles represent the estimated power loss of the No. 1 resonator. Circles represent the estimated power loss of the No. 2 resonator. Squares represent the required voltage of the 3rd-harmonic mode.

5 Conclusion

The flat-top acceleration system in the RIKEN AVF Cyclotron was manufactured and installed with the main resonator. The length of the flat-top resonator is 1 m and the stroke of the movable shorting plate is 400 mm. In the test, the flat-top voltage was generated below about 60 MHz. For the frequencies higher than 60 MHz, we plan to retest by changing (reducing) the size of the coupling capacitor (Cc). A beam test employed the flat-top acceleration system will be performed in the near future to obtain better quality beam after the power test of the No. 2 resonator will be carried out.

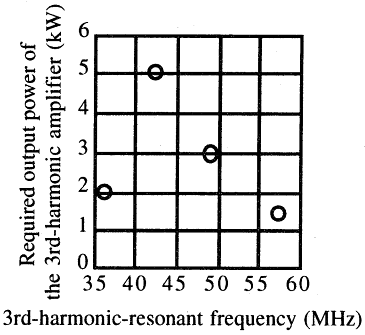

Fig. 7 Required output power of the 3rd-harmonic amplifier.

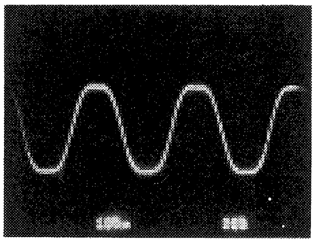

Fig. 8 Typical waveform of the flat-top voltage measured by the dee-voltage pickup. The fundamental frequency was 14.05 MHz and the 3rd-harmonic frequency was 42.15 MHz. The fundamental voltage was 29 kV.

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