DESIGN OF THE RF RESONATORS FOR THE NEW BOOSTER RING CYCLOTORONS IN THE RIKEN RI BEAM FACTORY

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The acceleration and flattop rf resonators for the new booster ring cyclotrons in the RIKEN RI beam factory are required to work in a wide frequency range from 18 to 38.2 MHz and 54 to 114.6 MHz, respectively, with a high acceleration voltage. To satisfy the requirement, the design study has been made by using a three dimensional rf calculation code, MAFIA. The present design of the acceleration resonator is a modified version of the single-gap resonator of the RCNP Ring Cyclotron. A test with a 1/10 scaled model of the acceleration rf resonator for the SRC has been made to study its rf characteristics.

I. INTRODUCTION

For the RIKEN RI-Beam factory (RIBF) [1] the new booster ring cyclotrons [2], intermediate-stage ring cyclotron (IRC) and superconducting ring cyclotron (SRC), are planned to be constructed to boost the energy of heavy ion beams from the RIKEN ring cyclotron (RRC) to the energy region from 60 MeV/u to 400 MeV/u.

The new cyclotrons, IRC and SRC which are four- and six-separated sector ring cyclotron, respectively, require acceleration radio frequency (rf) resonators having a wide frequency range from 18 to 38.2 MHz to suit the condition of the RRC operation. To realize a few mm turn separation at the extraction region, a high acceleration voltage of a few MV/turn is crucial especially for the final stage booster SRC which has a strong magnetic field generated by superconducting sector magnets.

For example, in the case of the acceleration of the $^{16}O^{7+}$ ion up to the maximum energy of 400 MeV/u at the rf frequency of 38.2 MHz with a harmonic number h=6, an acceleration voltage of 2.4 MV/turn is needed to obtain a turn separation larger than 4 mm. Such a high voltage acceleration is also helpful to depress the longitudinal emittance growth of high intensity beams because the space charge effect can be depressed by a high voltage acceleration. Installation of a flattop system by the third harmonic deceleration method is also planned.

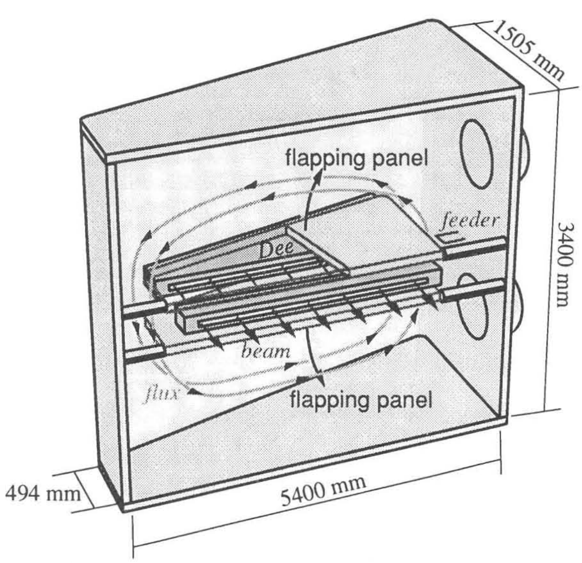


FIG. 1. RCNP-RC type Acceleration resonator.

II. STRUCTURE OF THE ACCELERATION RESONATORS

The present design of the acceleration rf resonator is a single-gap type whose structure is basically same as that of RCNP ring cyclotron (RCNP-RC) [3]. The single-gap type resonator is suitable for the narrow valley section of

TABLE I. Characteristics of the acceleration and flattop resonators for SRC and IRC.

parameters	SRC accel.	IRC accel.	SRC/IRC flattop
No. of unit	3	2	1
frequency [MHz]	18 ∼ 38.2		54 ∼ 114.6
length [mm]	4200	3800	3550
height [mm]	2700	3500	3000
width [mm]	600∼ 1200	717∼ 1594	35
gap [mm]	250	250	100
aperture [mm×mm]	60 ×2330	60 ×1680	60 ×2180
tuner	flapping panel		shorting plate
tuner stroke	0° ∼ 90°		1100 mm
feeder	inductive	inductive	inductive
Max. V_p [MV/gap]	0.6	0.6	0.2
Max. Power* [kW/cav]	90	50	30

* estimated by using a shunt-impedance from the MAFIA calculation.

the 6-sector ring cyclotron because its size is quite compact compared with the double-gap type resonator. The RCNP-RC type acceleration resonator has two main advantages. Firstly, the shunt impedance and Q-value are large so that a wall power loss is small. Secondly, the structure does not require to use a sliding contact which ocasionally causes a operational trouble. These advantages are vital for high power resonators.

A schematic view of the acceleration resonator is shown in Fig. 1. It has a large acceleration gap and two tuning panels. The resonant frequency is tuned by flapping the tuning panels. The resonances with the lowest and highest resonant frequencies are obtained when the panel angle is horizontal (0°) and vertical (90°), respectively. The lowest resonant frequency efficiently becomes lower by enlarging the width of the cavity. Schematic drawing of the acceleration resonators are shown in Fig. 2-(a) and -(b). Modifying the dimensions of the RCNP-RC resonator, the frequency range of the present design range successfully covers the range required.

A schematic drawing of the present design of the flattop resonator is shown in Fig. 2-(c). The resonant frequency is changed by sliding the shorting plates. The flattop resonater works on the third harmonic of the acceleration resonator so that its frequency range is set to be from 54 MHz to 114.6 MHz. The deceleration voltage is 11 % of the acceleration voltage per turn.

The main parameters and dimensions of the acceleration and flattop resonators for SRC and IRC are summarized in Table. I.

III. RF CHARACTERISTICS OF THE RESONATORS FROM MAFIA CALCULATION

Design study of the rf resonators for the new booster cyclotrons has been made by using a three dimensional RF calculation code, MAFIA [4]. A brief summary of the rf characteristics of the resonators with the tuning panel angles of 0° and 90° are shown in Table. II. As shown in Table. II, the resonant frequency, shunt-impedance (Rs), and Q-value (Q) become larger when the tuning panel angle becomes larger. From the RCNP data [3] Rs and Q are roughly proportional to the resonant frequency. The maximum powers for the IRC and the SRC resonators are estimated to be 90 kW/cavity and 50 kW/cavity with a peak voltage of 0.6 MV/gap, respectively, at the highest operational frequency of 38.2 MHz.

TABLE II. Calculated shunt-impedance and Q-value.

param	SRC accel.		IRC accel.		flattop	
	0°	90°	0°	90°	1210 mm	110 mm
f_o [MHz]	17.3 (17.8)	38.4 (39.0)	16.7	38.4	53.7	118.4
Rs [MΩ]	0.52	2.12	0.65	3.83	0.87	0.72
Q	27000	37000	28000	53000	30000	28000

( ) obtained from the measurement with 1/10 scaled model.

In the acceleration resonators, the current density at the root of the tuning panel is quite large, where a flexible

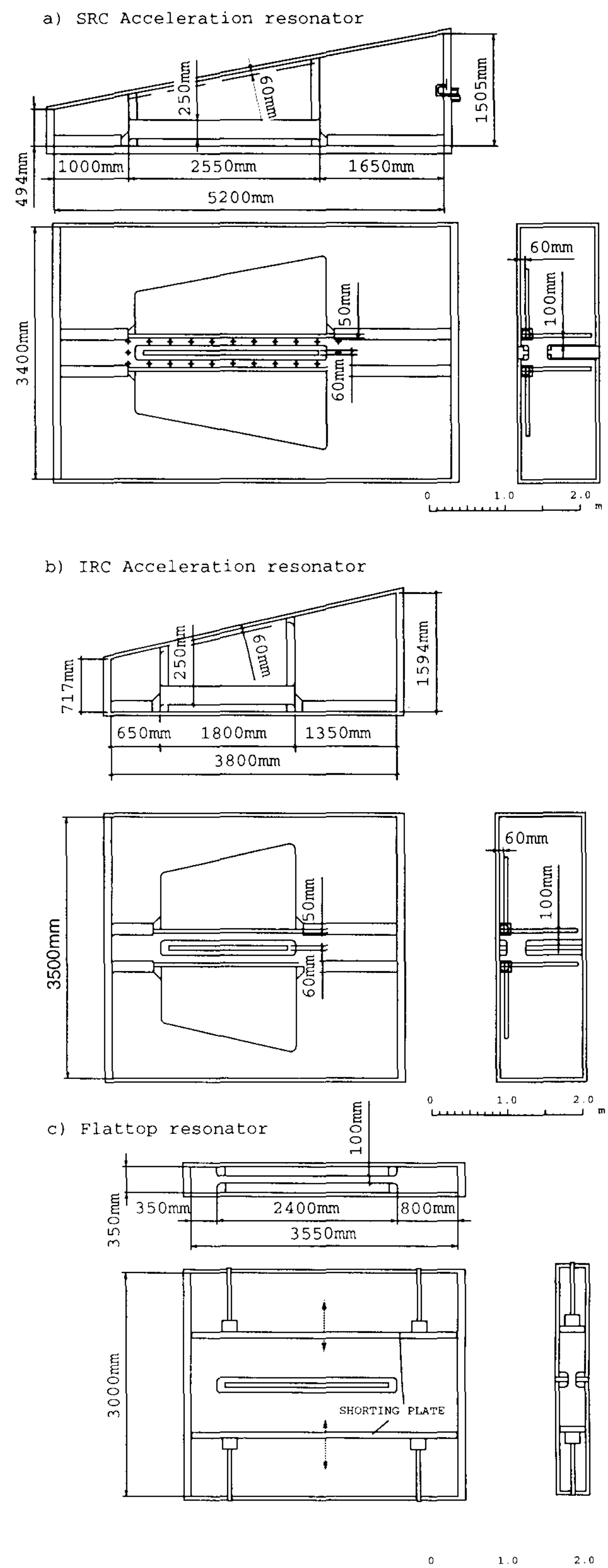
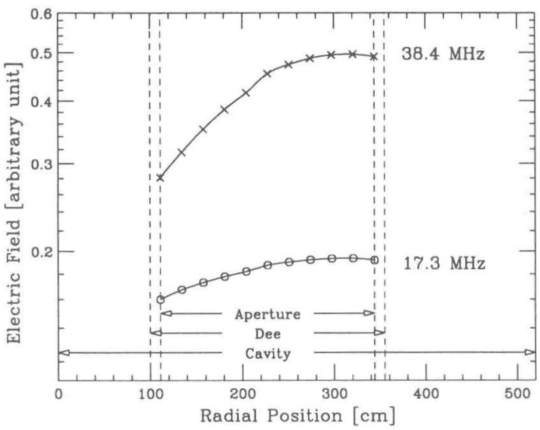


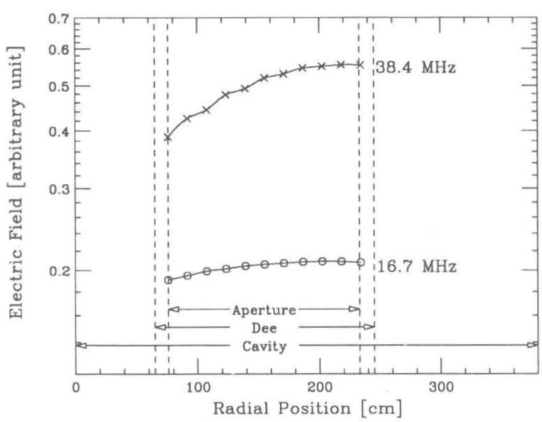
FIG. 2. Schematic drawings of the resonators.

panel is installed to make electric contact between the tuning panel and the cavity wall. The current density at the flexible panel should be less than 60 A/cm due to the cooling problem. From the MAFIA calculation for the SRC resonator, the maximum current density at the tuning panel angles of 0° and 90° are 7.5 A/cm and 3.7 A/cm at the gap voltage of 100 kV, respectively. The maximum acceleration voltage will be restricted by the current density at the flexible panel.

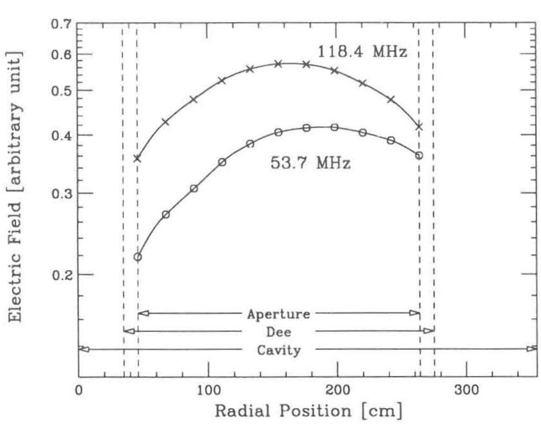
The electric field distributions along the gap center for the acceleration and flattop resonators are shown in Fig. 3. While the electric field of the acceleration resonator has a maximum at around the extraction region, the electric field of the flattop resonator has a maximum at around the middle of the Dee electrode.



a) acceleration resonator for the SRC



b) acceleration resonator for the IRC



c) flattop resonator

FIG. 3. Electric field distribution along the gap center.

IV. 1/10 SCALED MODEL STUDY OF THE SRC ACCELERATION RESONATOR

A 1/10 scaled model of the SRC acceleration resonator which is shown in Fig. 4 was constructed with wood boards covered with an aluminum foil with a thickness of 15 μm. The resonant frequencies are measured by using a network analyzer for the tuning panel angle of 0° to 90° with a step of 15°. We estimated the error due to a misalignment of the tuning panels and/or a deformation of the cavity less than ± 5.0 MHz which corresponds to ± 500 kHz for 1/1 scaled cavity. As shown in Fig. 5, the resonant frequency is approximately proportional to the angle of the tuning panel angle. The resonant frequencies at the angle of 0° and 90° are well reproduced by the MAFIA calculation with an accuracy of a few percent(see Table II).

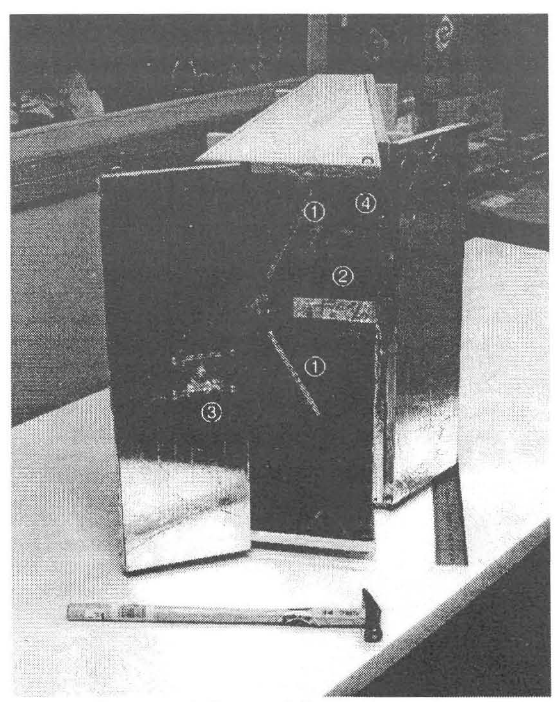


FIG. 4. Picture of the model resonator for the SRC.
1. FLAPPING PANEL, 2. DEE, 3. FEEDER, 4. PICKUP

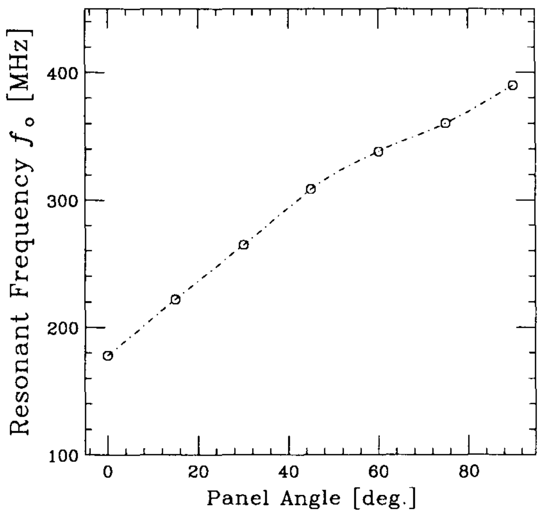


FIG. 5. Measurement of the resontant frequency.

V. CONCLUSIONS AND FUTURE PLAN

It is concluded that the RCNP-RC type acceleration resonator is applicable to the new booster ring cyclotrons in RIBF. The 1/10 scaled model test demonstrates the reliability of the MAFIA calculation for this structure. The details of the dimension will be decided from the result of the calculation. Further investigation on the feasibility of our rf system will be made by using a 1/5 scaled model which is planned to be constructed.

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[1] Y. Yano *et al.*, Proc. 14th Int. Conf. on Cyclotrons and their Applications (Cape Town 1995), p. 590 : Y. Yano *et al.*, "Overview of the RIKEN RI Beam Factory", this proceedings.

[2] A. Goto *et al.*, "The K2500 Superconducting Ring Cyclotron of the RIKEN RI Beam Factory - Overview and status -", this proceedings.

[3] T. Saito *et al.*, Proc. 12th Int. Conf. on Cyclotrons and their Applications (Berlin 1989), p. 201.

[4] The MAFIA collaboration, User's Guide MAFIA Version 3.2, CST GmbH, Lauteschägerstraße 38, D-64289, Darmstadt, Germany.