DESIGN OF RADIO FREQUENCY SYSTEM FOR THE RIKEN SEPARATED SECTOR CYCLOTRON

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The radio-frequency(RF) system of the RIKEN SSC(K=540) is required to work in a frequency range of 20 to 45 MHz and to generate the maximum acceleration voltage 250 kV. A new movable box type variable frequency resonator is designed for that purpose. This resonator is a compact half wave length coaxial type ((2.1 m(H) × 3.5 m(W) × 1.6 m(D)). The delta shaped dee whose radial length is 2.7 m is supported in median plane by vertical stems from the both sides. The resonant frequency is varied by moving the boxes surrounding the stems. The performance of this resonator is studied on a one-fourth scale model. The maximum power loss is estimated to be 250 kW for the required dee voltages and the radially increasing voltage distributions are obtained. The RF power is fed into the resonator through a 50 Ω coaxial feeder line(~ 1.8 m length) which is coupled with the resonator in good impedance matching by means of a variable capacitive coupler. The final amplifier is of grounded grid configuration; load resistance matching is made by a variable capacitor inserted in series at its output port. The final amplifier and its components are studied on full sized models. The result shows the movable box type resonator and power amplifier satisfy the design aim.

Introduction

General features of the SSC have been already described[1]. In Table 1, the basic parameters of the RF system are summarized.

Table 1 Basic parameters of the RF system.

Number of resonators	2
RF frequency	20 ~ 45 MHz
Harmonic number	5,9,10,11
RF peak voltage	250 kV
Frequency stability	10^{-8}
Voltage stability	10^{-4}
Phase stability	< 1°
Mean injection radius	89.3 cm
Mean extraction radius	356 cm
Dee angle	23.5°
Output power of each RF amplifier	300 kW

A new movable box type variable frequency resonator was designed for the SSC[2]. In this resonator, both the inductance and capacitance are varied by moving the boxes surrounding the stems. The boxes are in contact with the outer conductor and not with the stems. Therefore, the height of the resonator and travelling length of the box become much shorter than those of a conventional movable shorting plate type resonators[3]. Furthermore, the current densities at the sliding short fingers become much lower because the current density on the outer conductor is much smaller than that on the stem. The power loss of the resonator presented in Ref. 2 was reasonable as expected , but the voltage distribution along the accelerating gap has the minimum at around 1/4 way from the injection point. Therefore the resonator is modified to have a radially increasing voltage distribution[4]; the slanting stems are exchanged to straight stems, the heights of the chamber and movable boxes are shortened, and the stem positions on the dee are moved toward the outer radius.

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Each of two resonators is powered by a separate RF amplifier capable of delivering 300 kW in a frequency range of 17 to 45 MHz*. A design of amplifier using a RCA4648 tetrode in a grounded cathode circuit has been completed[2]. However, recently we can get a new tube, SIEMENS RS2042SK, whose maximum plate dissipation is 300 kW. This tube is inexpensive and is expected to be delivered quickly compared with RCA 4648. Hence, we re-design an amplifier system using the new tube, RS2042SK[5].

One Fourth Scale Model Resonator

Figure 1 shows a photograph of the final model resonator, whose main parts are made of copper plate. The movable boxes and capacitive fine tuner are in contact with the outer coductor by sliding contact fingers. The 50Ω feeder line is passed through the center of the tuner facing the dee end. In Figs. 2 and 3, the tuning characteristic, Q-value(Q), and shunt impedance(R_S) of the actual resonator deduced from the model test are shown together with the calculations. The tuning characteristic, and frequency dependences of Q and R_S are well reproduced by the calculation but the differences between the absolute values of the calculations and measurements are not so small in Q and R_S. We think such disagreements are that the structure of the resonator is too complex for one dimensional transmission line approximation and resistances of many contacts are not taken into account. The capacitance C_f(See Fig. 6) satisfying impedance matching deduced from the shunt impedance are also shown in Fig. 3. The matching is obtained by changing C_f from 1 pF for 45 MHz to 5 pF for 20 MHz.

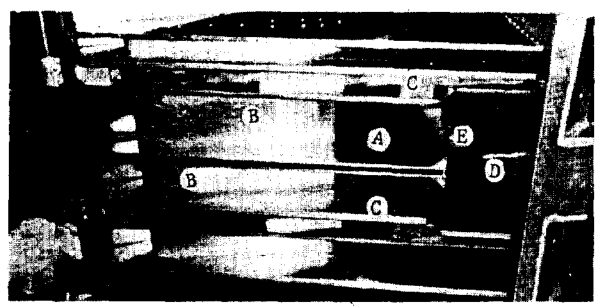

Fig. 1 Picture of one fourth scale model of the movable box type resonator(525 mm(h) × 875 mm(W) × 440 mm(d)). A: dee, B: stem, C: movable box, D: capacitive frequency tuner, E: coupler.

Relative distributions of RF electric field along the dee gap were measured by perturbation method using a perturbator of dielectric material to avoid the effect of RF magnetic field at the dee gap. The results are shown in Fig. 4, where the dee voltages are normalized at the beam injection radius. The radially increasing voltage distribution are obtained. The dee voltages at the injection and extraction radii for the input power of 250 kW are calculated from the shunt

* The lowest frequency of the RF-system was changed from 17 MHz to to 20 MHz. However, the resonant frequency of the new resonator can be lowered to 17 MHz though the gap between the movable box and dee becomes shorter than 30 mm. Therefore the frequency range of the amplifier is set at 17 MHz.

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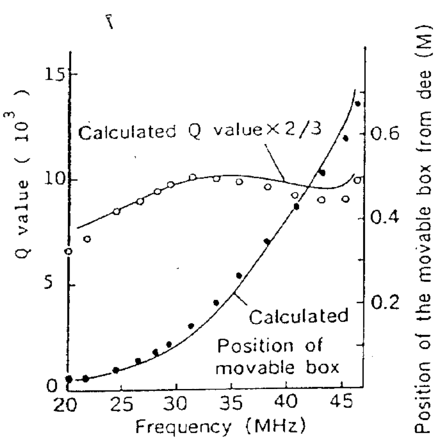

Fig. 2 Q-values and resonant frequency of the actual resonator estimated by the experimental results.

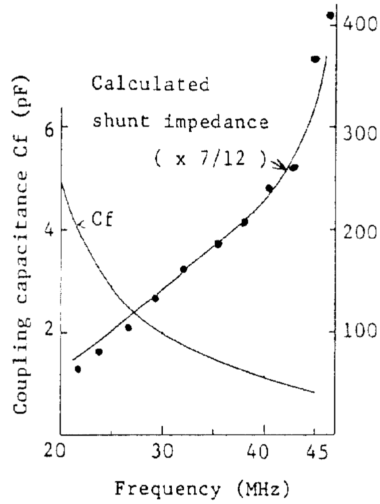

Fig. 3 Shunt impedance of the actual resonator and coupling capacitance C_f for the impedance matching.

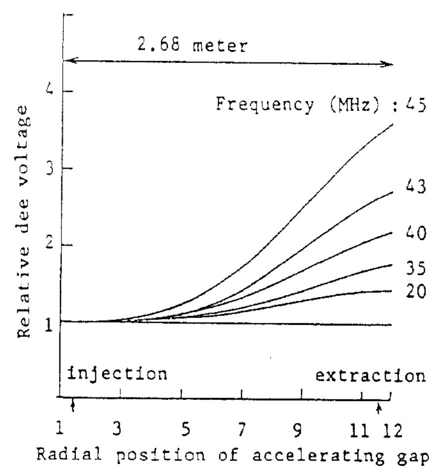

Fig. 4 Relative distributions of RF electric field along the dee gap.

impedances and the radial voltage distributions. They are presented in another report of this conference[6]. The input power of 250 kW is enough to generate the dee voltage required for beam acceleration. The maximum current density at the sliding contact finger is estimated to be about 20 A/cm for the input power of 250 kW. Higher resonant modes of the resonator and frequency changes by the trimmer and coupler were also measured. No difficulty was found for the resonator to satisfies the requirements[4].

Design of Actual Resonator

In Fig. 5, a cross sectional view of the actual resonator is shown. The vacuum chamber is divided into two compartments by a wall having many holes for evacuation. The main part is the RF resonator and the other is a space for the fine tuner and coupler positioning mechanism and a vacuum system. The stem, dee, and outer wall are made of copper-clad stainless steel which has many cooling channels engraved on the surface of stainless steel under the copper overlay. A cryo-panel for evacuation is installed inside the stem. The movable box and fine tuner are constructed from stainless steel frames and copper sheet covers. The movable box is supported by three rods which accommodate the pipings for cooling water and pneumatic pressure. Sliding contact fingers made of silver rods are pressed to the outer conductor by pneumatic pressure. The main cryo-pump and turbo-molecular pump are mounted on the outer wall of the compartment for the mechanism. All the system are installed on a platform car and can be moved 2 m from the valley space between the magnets leaving the side walls to allow the resonator accessible for maintenance.

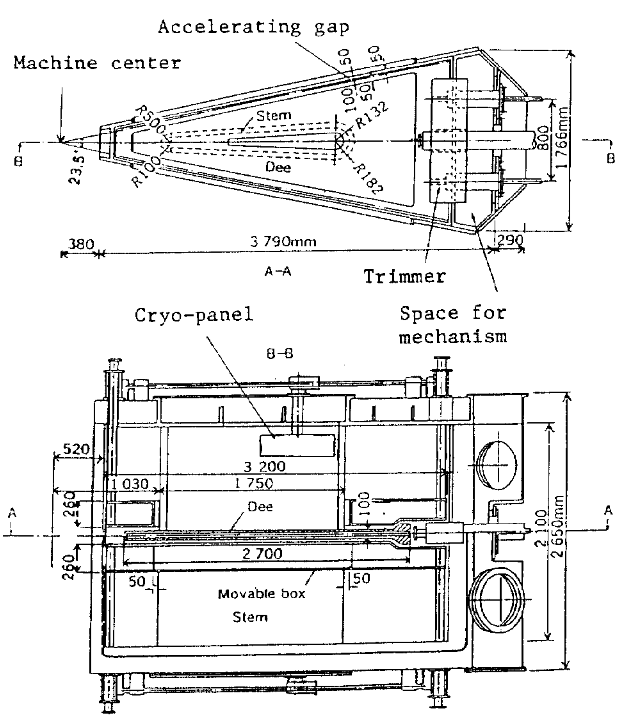

Fig. 5 Cross sectional view of the actual resonator.

Power Amplifier

Structure of the final amplifier and its components were investigated on full sized models with a real RS2042SK tube. The inter-electrode capacitances of the tube were measured to design the amplifier. The results are the following(pF): $C_{A,G2}$=114, $C_{A,G1}$=5.7, $C_{A,K}$=1.1 , $C_{G1,G2}$=451 , $C_{G2,K}$=37.5, $C_{G1,K}$=315. Figure 6 shows a schematic drawing of the final and driver amplifiers and Fig. 7 an equivalent circuit of the plate assumed. The RS2042SK is used in grounded grid configuration. The plate circuit is the same as that designed for the 4648[2]. The tuning element is an adjustable $\lambda/4$ coaxial stub whose stroke is 1.2 m. The model of the plate circuit is represented in Ref. 6. Load resistance matching for the tube is made by a variable capacitor(C_S). The impedance matching condition was investigated on the model whose output port was terminated by an equivalent dummy load of 50 ohm. The experimental result was in good agreement with the calculations. The load impedance of the tube can be varied in a sufficiently wide range by adjusting the capacitance C_S and the range of C_S was from 60 to 120 pF to keep the load resistance 200 Ω in the frequency range. The DC blocking capacitor is a cylindrical capacitor (35 cm(h) × 35 cm (Φ): 2350 pF) whose insulator is made of Kapton film (125 μm × 16 turns). No parasitic oscillation mode due to the blocking capacitor was detected at frequencies from 17 to 150 MHz. The maximum power consumption of the capacitor is estimated to be about 1 kW from the maximum reactive power of 110 kVA and the dissipation factor of Kapton($\tan\delta$=0.01). The screen(0.09 μF) and control grid(0.115 μF) bypass capacitors are parallel plate

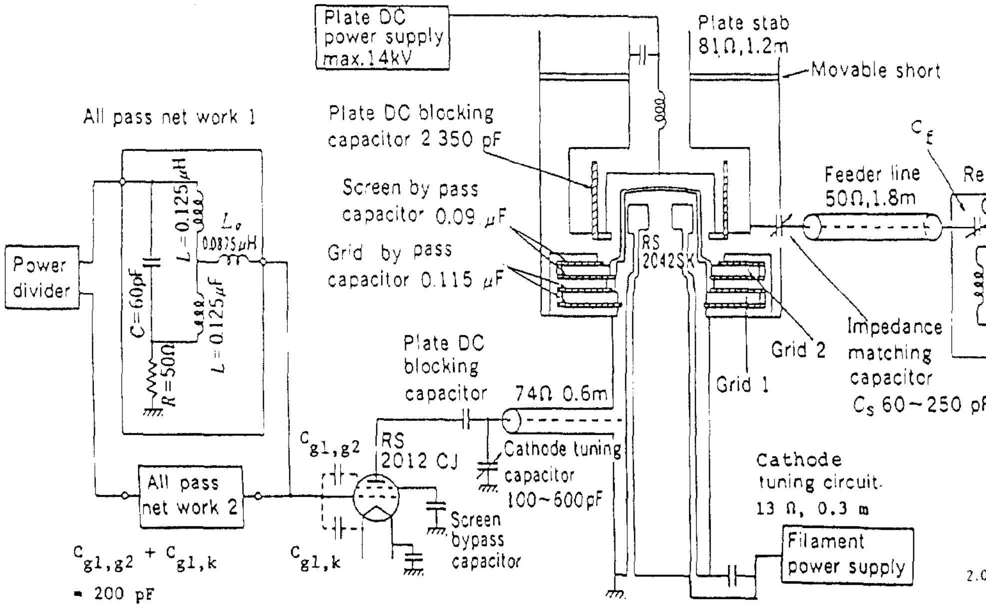

Fig. 6 Schematic drawing of the final and driver amplifiers.

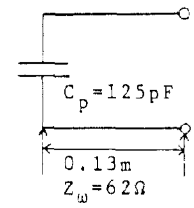

Fig. 7 Equivalent circuit of the plate of RS2042SK.

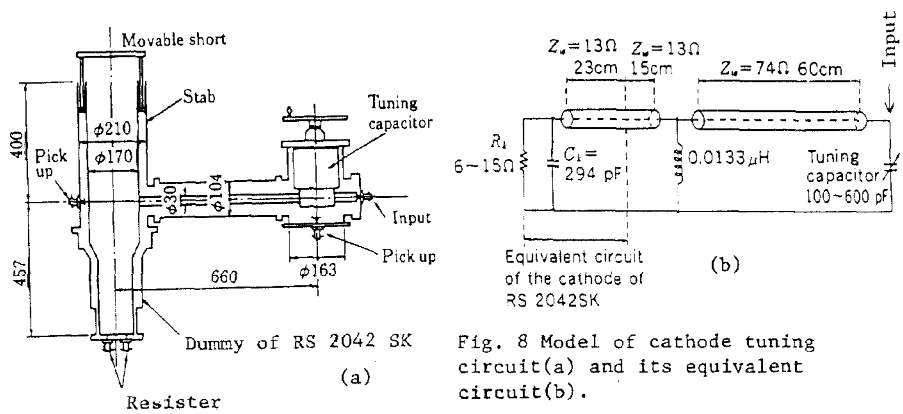

Fig. 8 Model of cathode tuning circuit(a) and its equivalent circuit(b).

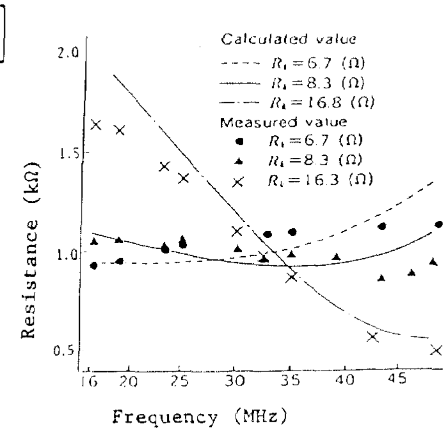

Fig. 9 Input resistance of the cathode tuning circuit. Parameters are cathode resistance.

capacitors whose electrode (520 mm Φ) are insulated by 50 μm Kapton films from the upper and lower ground surfaces. The voltage transmission ratios from the plate to the grids and cathode showed almost flat frequency responses in a frequency range of 30 to 48 MHz. The ratios are about 6×10^{-5} for the control grid, 1.2×10^{-3} for the screen grid, and 3×10^{-3} for the cathode. The inter-electrode capacitances of $C_{A,G1}$ and $C_{A,K}$ presented above were deduced from the ratios. A screen bypass capacitor made on the same method has been working well in the amplifier of RILAC for about three years[7].

The cathode circuit consists of a variable tuning capacitor and a fixed λ/4 coaxial stub, through which the filament current is supplied from a power source at ground potential. Figure 8 shows the model of the cathode circuit and its equivalent circuit, where the input impedance of the final tube is simulated by a coaxial line and a resistor. The circuit was tuned for the frequency range by the tuning capacitor (90 pF at 45 MHz ~ 550 pF at 17 MHz). The input impedances measured are shown in Fig. 9 together with the result of the calculation. The calculations and measurements are in fairly good agreements. The cathode input resistance varies from about 6 to 15 Ω depending on the cathode RF and grid DC voltages. The driver tube RS2012CJ can deliver the power of 15 kW for load resistances from 500 to 1500 Ω. The input impedance of the cathode circuit takes a value between 500 Ω and 1600 Ω for the frequency range even if the cathode resistance changes. The input circuit of the driver tube consists of a pair of all pass networks similar to the one developed by Mosko[8]. A model of the network worked well in the frequency range.

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