ALUMINIUM RF CAVITY FOR THE RCNP RING CYCLOTRON

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Abstract

An aluminium RF cavity was constructed for the RCNP ring cyclotron. The cavity is variable frequency (20∿33 MHz) H_{101} mode resonator. The voltage distriubtions along the acceleration gap of the cavity produce phase compression ratio of around 3. An RF power amplifier to excite the cavity has also been developed.

1. Introduction

A single gap RF cavity is being studied for the RCNP ring cyclotron project. At first a variable frequency H_{101} mode RF cavity was developed with 1/10 scale models. The RF cavity is equipped with a movable tuner plate to cover the proposed frequency range.[1,2] More detailed investigations were made with a full scale model.[3]

Recently, a high energy version of the proposal of a ring cyclotron has been made.[4] Fig. 1 shows the layout of the ring cyclotron. A 1/10 scale model study of the cavity for the new version was done. Detailed structures were determined on the basis of the model study. The charactristics of the RF system are given in table 1. The cavity produces phase compression ratio of around 3. Aluminium alloy has been adopted for material of the cavity. Some advantages of aluminium alloys are as follows.

1) low magnetic susceptibility,
2) radioactivity decreases rapidly after irradiation of neutron,
3) high conductivity of electricity and heat.

Table 1.
Characteristics of the RF system.

RF frequency	20∿33 MHz
Harmonic No.	4,6,8,12
Phase compression ratio	∿3
RF peak voltage	500 kV
RF power	200 kW/cavity
No. of cavities	2

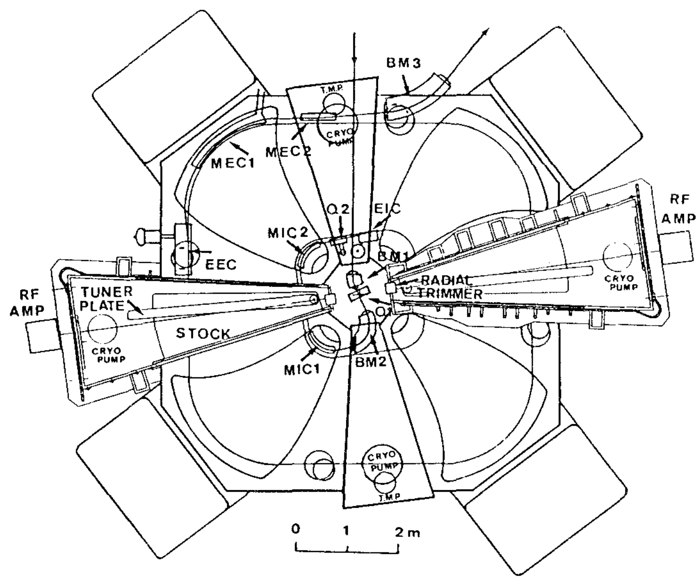

Fig. 1. Layout of the ring cycltoron.

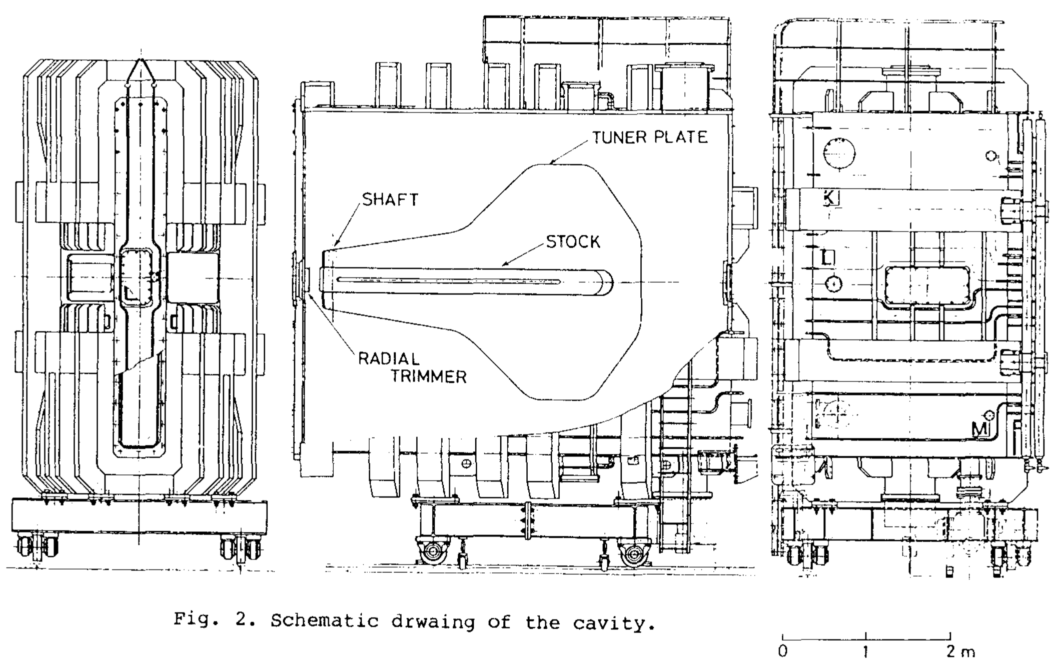

Fig. 2. Schematic drwaing of the cavity.

2. Acceleration Cavity

2.1. RF characteristics

The final RF characterisitcs were investigated on the 1/10 scale model study. Some modifications were adopted to correct the frequency range and voltage distributions. The schematic drawing of the cavity is shown in fig. 2. The cavity has a tuner plate which rotate on a stock, and a radial trimmer to vary voltage distributions as shown in figs. 1 and 2. A range of the resonance frequency is 20 to 33 MHz.

The measurements of the relative electric field strength in the gap of the 1/10 scale model were performed with a perturbation method. The measrued voltage distributions along acceleration gap are shown in fig. 3 for two resonant frequencies. The voltage distribuitons show radially increasing distributions and no frequency dependence. These voltage distriubitons produce phase compression ratio of around 3.[5,6] The voltage distributions are able to be varied with the radial trimmer.

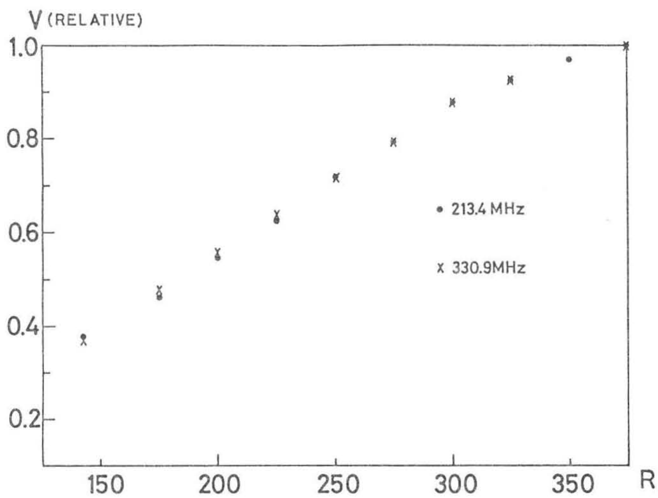

Fig. 3. Voltage distributions along the acceleration gap.

Because of low conductivity of aluminium compairing with that of copper, the RF power loss is larger than that of copper by 30 %. The maximum power loss is about 200 kW (33MHz, 500 kV).

2.2 Mechanical description

Fig. 4 shows the photograph of the cavity. The cavity walls are made of 50 mm thick pure aluminium (A1070), and welded each other. The cavity is reinforced by ribs made of anticorrosion aluminium alloy (A5052). The cavity walls will be cooled with demineralized water. An external shape of the cavity is designed to fit a space between the sector magnets of the cyclotron. The maximum mechanical distortion of the cavity is small when the cavity is under vacuum. The mechanical structure itself is rigid enough and needs no additional support.

The sotck, the tuner plate and an anti stock electrode are made of oxigen free copper. Fig. 5 shows the tuner plate. The copper of the stock and the tuner plate is sustained by stainless steel and aluminium structures. The acceleration gaps at the injection and extraction radii are 100 mm and 250 mm, respectively. Water cooling tubes are soldered inside the tuner plate and the stock. The tuner plate is moved with a rack and pinion system. The rack is set on the stock. The pinion is driven by a stepping motor which is set inside the tuner plate. Cooling water of the tuner plate and power of the stepping motor are supplied throuh a shaft shown in fig. 2. Electrical contact between the stock and the cavity wall is performed by using Be-Cu finger contacts. Copper-clad aluminium plates are welded at the contact surface of the cavity wall.

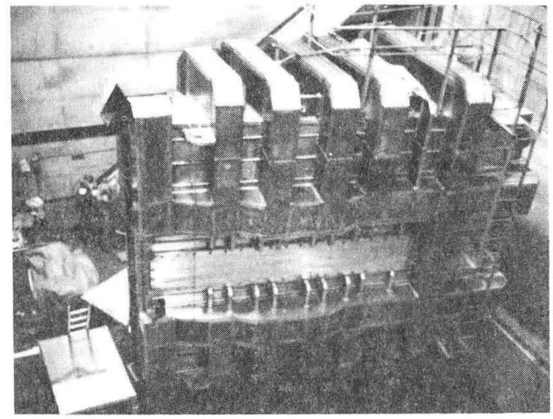

Fig. 4. Photograph of the cavity.

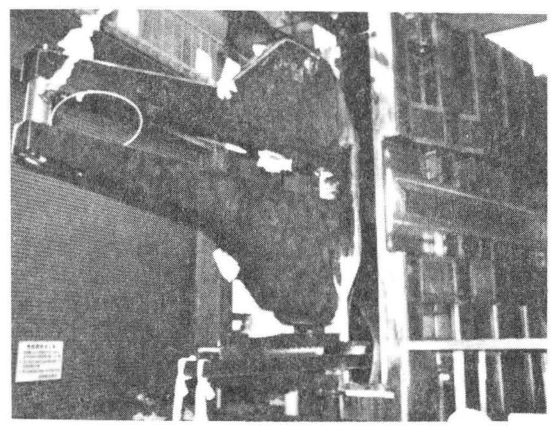

Fig. 5. Photograph of the tuner plate being assembled.

3. RF Power Amplifier

An RF amplifier was developed to excite the cavity up to 500 kV as shown in fig. 6. A tetrode (RCA 4648) is used for the amplifier. Maximum output power of the amplifier is to be 200 kW. The full-scale model of the cavity is used as the load of a prototype RF amplifier.[5] The maximum RF output of the amplifier is limited to 10 kW becasue of the low DC power (6 kV, 5A) of the anode power supply.

3.1 Input circuit

Fig. 7 shows the tuning system designed for the input circuit of the RF power amplifier. The input circuit consists of a quater wave-length coaxial line with a sliding short. The sliding short is formed by an assembly of DC blocking condenser for grid bias. A grid capacitance (C_g) of the tube is 1200 pF. The input circuit is damped by 50Ω terminating resistance. The equivalent circuit of the grid tuning system is shown in fig. 8.

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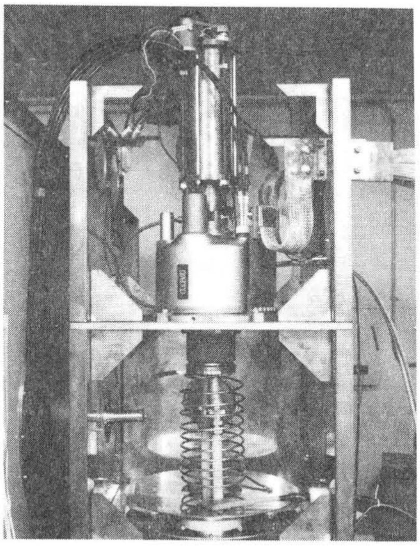

Fig. 6. Photograph of the RF amplifier.

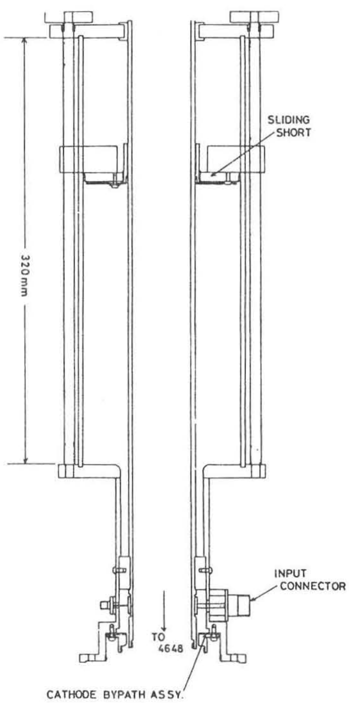

Fig. 7. Grid tuning system.

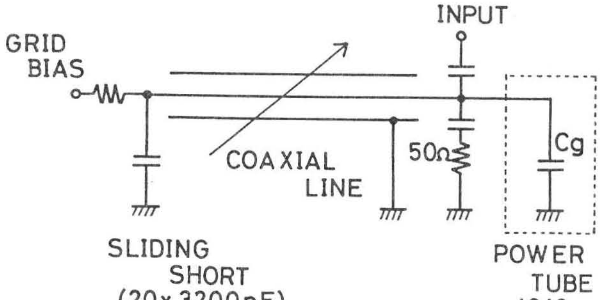

Fig. 8. Equivalent circuit of the grid tuning system.

3.2 Coupling circuit between the power tube and the cavity

An output capacitance of the power tube is 85PF, and a self inductance of a coupling loop is ∿0.5μ H. A coupling circuit was designed to cancel the effects of these reactances. Figs. 9 and 10 shows the schematic illustration and equivalent circuit for output circuit of the amplifier. The characterstics of the H_{101} mode resonance are expressed in lumped constants. The impedance matching at the anode of the power tube is performed by the variable coupling capacitor and variable mutual inductance of the coupling loop. Typical parameters of the circuit are given in table 2.

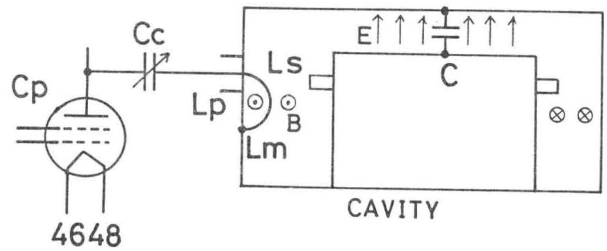

Fig. 9. Schematic illustration of the output circuit of the RF system.

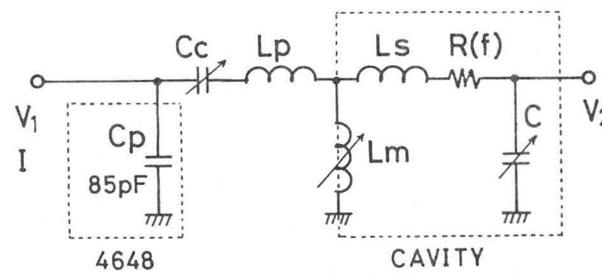

Fig.10. Equivalent circuit of the output circuit of the RF system.

Table 2. Parameters of the output circuit.

f (MHz)	20.0	25.0	32.0
Cc (pF)	126.68	81.053	49.473
Lp (μH)	0.5	0.5	0.5
Lm (μH)	0.0055133	0.0046279	0.0039286
Ls (μH)	0.16	0.16	0.16
R (mΩ)	1.20	1.32	1.56
C (pF)	395.68496	253.23187	154.55263
Zin (=V1/I)	400Ω, 0.0°	400Ω, 0.0°	400Ω, 0.0°
Ztrn (=V2/I)	11.6kΩ, 0.0°	13.8kΩ, 0.0°	16.3kΩ, 0.0°
V2/V1	29.0, 0.0°	34.6, 0.0°	40.7, 0.0°
Q	18000	19000	20000

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3.3 Power test

A coupling circuit for the full-scale model cavity was designed and made on the basis of the analysis. This coupling assembly was designed to be able to transfer RF power up to 10 kW. The coupling condenser (Cc) is cylindrical tefron condenser. A water cooled vacuum variable capacitor is prepared for a full power test. Fig. 11 shows the impedance of the cavity measured from the anode of 4648. The impedance at the anode is adjusted to 425 Ω, 0.0° at 30 MHz. Phase difference between anode voltage and acceleration voltage is 0.0°. The model cavity was excited by the amplifier successfully, up to 100 kV (peak value) at 30 and 22 MHz. This voltage (100 kV) corresponds to the breakdown voltage of the gap in atmosphere. Fig. 12 is the photograp of the atmospheric discharge at the acceleration gap. The full power test (500 kV, 200 kW) of the RF system is being carried out.

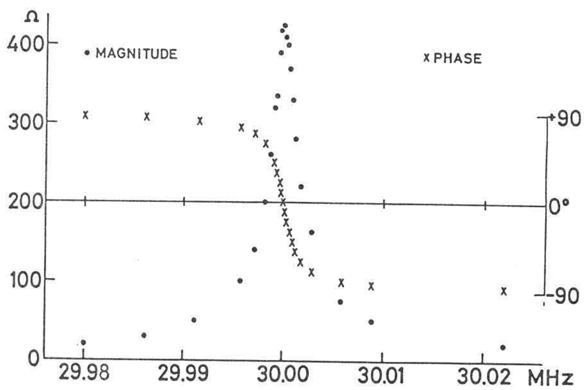

Fig.11. Impedance of the cavity around the resonance frequency measrued from the anode of 4648.

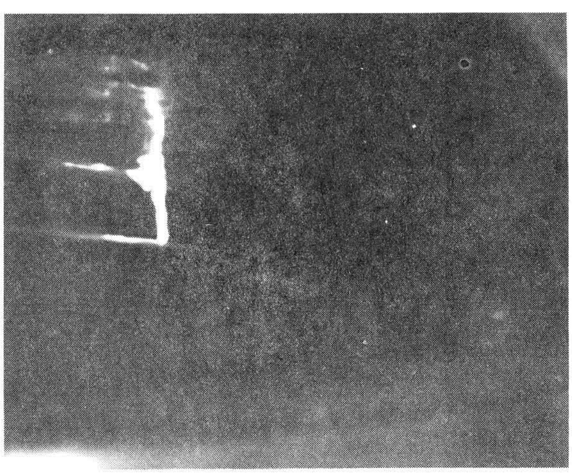

Fig.12. Photograph of the atmospheric discharge at the acceleration gap of the model cavity.

4. Vacuum system

The total volume of the cavity is about 25 m^3 with a surface of about 130 m^2 (75 m^2 Al-surface, the rest is copper). Elastomer seals with a total length of about 50 m are used. The weld defect was checked by ultrasonic and X-ray inspections. The aluminium surface was polished with 240 mesh buff, degreased with acetone and rinsed with a neutral detergent.

Preliminary evacuation test of the cavity chamber without the tuner plate and the stock was done. The achieved vacuum was 1×10^{-4} Pa with a 10 in. diffusion pump. Degassing rate of the aluminium surface after 20 hours evacuation was estimated to be 1×10^{-3} Pa·ℓ/m^2s.

The cavity will be evacuated down to 1 10^{-5}Pa by a 22 in. cryogenic pump and a 10 in. diffusion pump.

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