ISBN: 978-3-95450-205-9 doi:10.18429/JACoW-Cyclotrons2019-MOP030

RF MEASUREMENT OF SKKUCY-10 RF CAVITY FOR IMPEDANCE MATCHING

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Abstract

The 10 MeV cyclotron was designed for next version in Sungkyunkwan University, after the SKKUCY-9 had developed for medical application for PET. The RF cavity, which generates the electric field in cyclotron, was designed based on a half-wavelength resonator and optimized to improve the unloaded quality factor (Q_0). The design specifications of RF cavity were resonance frequency 83.2 MHz, Q_0 5830 and Dee voltage 40 kV with geometrical values resonator length 560 mm, Dee angle 35° and Stem radius 16 mm. The RF cavity of the SKKUCY-10 was fabricated and installed inside the electromagnet, and RF characteristics were measured with a network analyzer. The RF coupling coefficient and characteristic impedance for desired condition were selected at 1.08 and 52 Ω, respectively. The RF coupling coefficient and characteristic impedance were measured 0.8-1.2, 52-49 Ω according to temperature as 15-21°C. The power coupler was checked for optimization of RF coupling coefficient and characteristic impedance, and the results show good agreement with simulated and measured data.

INTRODUCTION

RF cavity generates electric field with resonant frequency in cyclotron and is developed based on coaxial resonator to improve RF power efficiency according to electric field [1]. Cyclotrons aimed at producing radio tracers have been developed as isochronous magnets with azimuthally varying magnetic fields, and fix frequency RF cavities with constant dee voltages [2].

An isochronous cyclotron using fixed frequency has developed to optimize the magnetic field to satisfy the synchronous phase of charged particles by equilibrium-orbit. However, due to the thermal and beam loading effect at cyclotron operation, the RF coupling state and the dee voltage variation can occur inside the RF cavity. To overcome this, the capacitive type fine tuner, the amplitude of the RF amplifier, and the phase control are applied to keep the stable condition of the RF cavity, which are regulation of dee voltage, resonant frequency and RF critical coupling state [3].

The medical AVF cyclotron (named SKKUCY-10) is developing for 10 MeV proton at Sungkyunkwan university, and the RF system based on half-wavelength coaxial resonator was designed to have 83.2 MHz resonant frequency and 50 Ω characteristic impedance [4].

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In this paper, the RF coupling state and characteristic impedance was analyzed with considerations of thermal and beam loading effect. The initial conditions of temperature and beam power were assumed based on the specification of SKKUCY-10, and the RF coupling coefficient and characteristic impedance were calculated by simulation code. In addition, the RF coupling coefficient and characteristic impedance were measured according to environment temperature in RF system, and compared with simulation results.

METHODS AND MATERIALS

The RF cavity, capacitive power coupler and fine tuner structure of the 10 MeV cyclotron are shown in Fig. 1. The power coupler is designed as a 50 Ω, 3.125 inch standard coaxial rigid line, and the inner conductor of the rigid line is coupled by capacitance adjacent to the side of the dee. The fine tuner consists of an electrically grounded plate and movement motor. The plate is coupled by capacitance adjacent to the side of the dee, and the plate diameter was designed to be 50 mm to compensate for wide variations in the RF cavity.

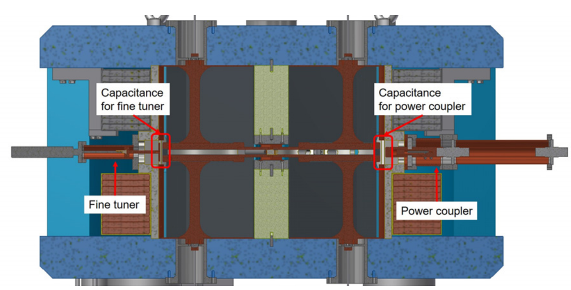

Figure 1: Power coupler and fine tuner for SKKUCY-10.

In the RF system of SKKUCY-10, the power coupler was considered with impedance matching as 50 Ω to satisfy critical coupling state, and the RF specification is shown in Table 1. The fine tuner was designed to have a tuning range of ±0.5 MHz with 83.2 MHz, and the RF coupling coefficient was optimized to 1.03 when the coupler gap distance is 18.7 mm.

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Table 1: RF Specifications

Parameter	Value
Resonance frequency [MHz]	83.2
Coupling coefficient	1.03
Tuning range [MHz]	±0.5
Coupler gap distance [mm]	18.7
Tuner gap distance [mm]	5

In order to understand the thermal effect of the RF cavity, the resistivity of the copper property was changed by temperature in Eq. (1), where T is temperature, β_T is temperature coefficient as $1/(233.54+\mathrm{T})$, $\rho_{T1,2}$ is the specific resistivity at temperature from T_1 to T_2 [5]. The conductivity of the RF cavity, is expressed as the inverse of resistivity, and the change of unloaded quality factor caused by the conductivity can break the matching of β and Z_0.

$$\rho_{T2} = \rho_{T1}(1+\beta_T(T_2-T_1)) \qquad (1)$$

The β with beam loading effect is expressed by equation (2) in the RF cavity, where i is the beam current and r_s is the shunt impedance, p_c is the cavity dissipation power [6].

$$\beta = [\frac{i}{2}\cdot\sqrt{\frac{r_s}{p_c}}+\sqrt{1+\frac{i^2 r_s}{4p_c}}]^2 \qquad (2)$$

The β, and Z_0 of the RF cavity due to thermal effects were simulated by using the Microwave Studio in Computer Simulation Technology [7]. The structure of power coupler for critical coupling state was calculated by changing the gap distance between dee and coupler as shown in Fig. 2.

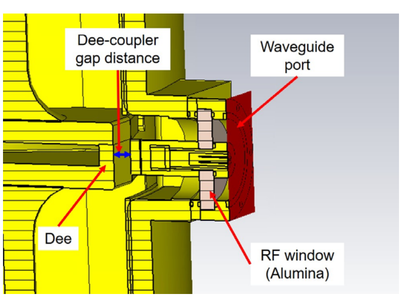

Figure 2: Scheme of power coupler.

RESULTS AND DISCUSSION

The calculation result of RF coupling coefficient (β) caused by beam loading effect is shown in Fig. 3. The β was increased, when the beam current was increased based on equation (2). Our desired beam current 100 μA with β = 1, so β should be optimized to 1.08 for beam loading effect.

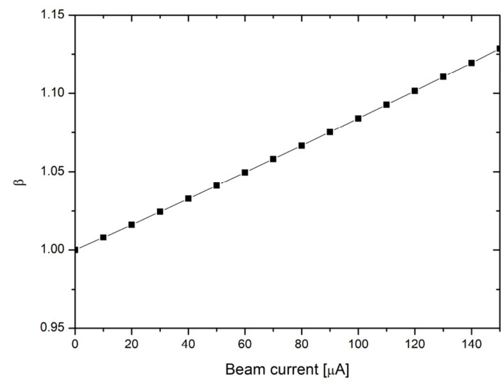

Figure 3: Calculation result of RF coupling coefficient according to beam current.

The results of β and characteristics impedance (Z_0) of RF cavity are shown in Fig. 4, and compared with measured value. For the measurement of β the network analyser was used and scattering parameter was investigated, and Z_0 was measured in smith chart. As the conductivity of copper was decreased with increasing of temperature, the β was decreased based on reduction of unloaded quality factor (Q_0). The Z_0 was decreased, and the coupling state was slightly under-coupled.

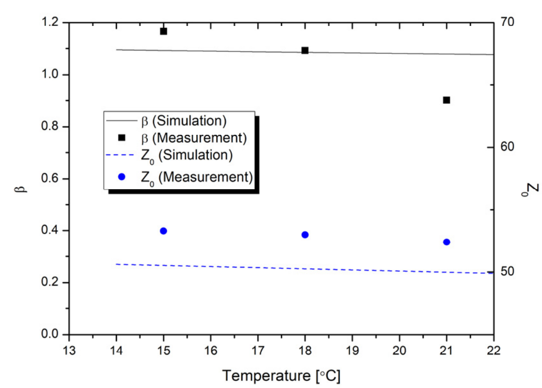

Figure 4: Results of RF coupling coefficient and characteristics impedance according to temperature.

In our RF system, the β was simulated 1.08 ±0.01 for operating condition of 100 μA beam current and ±5 °C. The power coupler and RF cavity was simulated by optimizing the β, and compared with measured value. The gap distance between dee and power coupler was changed for measurement as shown in Fig. 5.

The results of β and Z_0 are shown in Fig. 6, and the simulation results were compared with measurement data. The resonant frequency was kept as constant value 83.2 MHz by moving the tuner plate position at all gap distance of power coupler. When the gap distance between dee and power coupler was increased, the β was decreased and Z_0 was increased.

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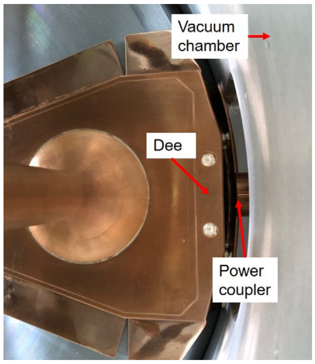

Figure 5: Dee and power coupler in SKKUCY-10 RF cavity.

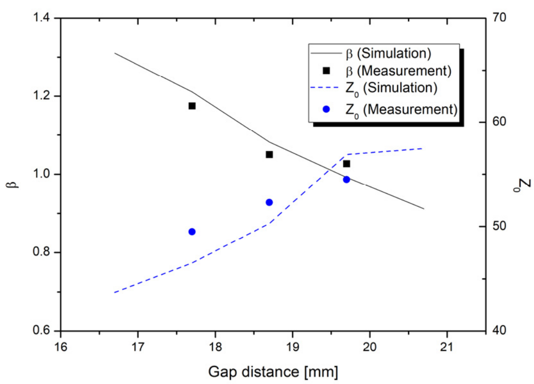

Figure 6: Results of RF coupling coefficient and characteristics impedance by power coupler.

CONCLUSION

The RF coupling coefficient and characteristic impedance were simulated and measured with consideration s of thermal and beam loading effect. The RF system of 10 MeV cyclotron (SKKUCY-10) was analysed with specifications, resonant frequency 83.2 MHz, Q_0 5830 and Dee voltage 40 kV with geometrical values resonator length 560 mm, Dee angle 35° and Stem radius 16 mm. The RF cavity of the SKKUCY-10 was fabricated and installed inside the electromagnet, and RF characteristics were measured with a network analyzer. The RF coupling coefficient and characteristic impedance for desired condition were selected at 1.08 and 52 Ω, respectively. The RF coupling coefficient and characteristic impedance were measured 0.8-1.2, 52-49 Ω according to temperature as 15-21°C. The power coupler was checked for optimization of RF coupling coefficient and characteristic impedance, and the results show good agreement with simulated and measured data.

ACKNOWLEDGEMENTS

This work was supported by the Radiation Technology R&D program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science and ICT (2017M2A2A4A02020347).

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