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DESIGN OF 5.8 MHz RF ELECTRODE FOR AMS CYCLOTRON

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Abstract

Accelerator Mass Spectrometry (AMS) is a powerful method for separating isotopes, and electrostatic tandem accelerators are widely used for AMS. Sungkyunkwan University is developing AMS that can be used in a smaller space based on cyclotron. Unlike conventional cyclotrons used in PET or proton therapy, cyclotron-based AMS provides high turn number and high resolution. In this study, we proposed a cavity with a frequency of 5.8 MHz and an accelerating voltage of 300 V to accelerate the particles in the cyclotron. The proposed cavity was designed as an electrode and verified by CST Microwave studio.

INTRODUCTION

AMS has been developing rapidly since the 1980s. As a new application of accelerators, AMS has been widely applied in archeology, earth and planetary science, materials and environmental sciences. Especially AMS has a bright future in biomedical applications.

In general, the accelerator used in the AMS system is an electrostatic accelerator Tandem. This is because tandem accelerators are electrostatically accelerated and can be applied to a wide variety of particles, regardless of their weight.

Cyclotrons can be used to separate particles on their own. so cyclotron is suitable for use in AMS systems. This can benefit greatly from the size and cost of AMS systems compared to tandem accelerators. However, cyclotrons can only be used for specifically targeted particles and have a major weakness in resolution and sample acquisition which are key variables in AMS systems.

Sungkyunkwan University has developed a cyclotron-based AMS system targeting carbon which is the most widely used particle in AMS systems. The cyclotrons were developed with a focus on particle classification which is a key variable of AMS rather than acceleration efficiency which is an important variable of the accelerator. In order to improve the resolution, a design with a high turn number and a high Harmonic number was carried out and artificial intelligence was applied to have high accuracy at a low sample acquisition number. The final specifications are as follows.

In this study, we describe a cavity in the cyclotron's components that accelerates particles. The cavity is designed and impedance matched through the RF circuit, verified by CST MICROWAVE STUDIO.

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DESIGN FEATURE

The resolution of cyclotron is as follows:

$$\text{Resolution} = \pi h n$$

Where h is the harmonic number and n is the number of turns. According to the equation, the higher the harmonic number and the number of turns the greater the resolution. Cyclotrons induce the movement of particles through the magnetic field of the electromagnet and accelerate the particles through the electric field of the cavity. Because it affects each other, the electromagnet and the cavity are designed to have one side design first, and the other side design according to the design side first.

In this study, the design of the electromagnet was carried out and the cavity was designed according to the design of the electromagnet. The requirements are shown in Table 1.

Table 1: Specification of AMS Cyclotron

Specification	Value	Unit
E	200	keV
R_{in} / R_{ext}	138 / 453.6	mm
Mass Resolution	5000	
Turn number	159	
Dee voltage	300	V
Frequency	5.8	MHz
E_{in}	25	keV
Dee angle	20	°
Number of Dees	2	

By default, the size of the cavity is proportional to the wavelength of the frequency. The larger the band of frequencies used, the shorter the wavelength of the frequency. So the size of the cavity is usually smaller. At 5.8 MHz, the wavelength is approximately 51724 mm. The types of cavities commonly used in cyclotrons are λ/4 and λ/2 resonators. In this case, 12931 mm for the λ/4 type and 25862 mm for the λ/2 type are required. The acceleration section of the particle required in Table 1 is very different from 138 mm to 453.6 mm.

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The frequency follows the formula:

$$f = \frac{1}{2\pi\sqrt{LC}}$$

L means inductance component and C means capacitance component. According to the equation, the frequency can be adjusted by adding an inductance component and a capacitance component to the cavity.

In general cyclotron, high power is used to increase acceleration efficiency. In this case, power cannot be tolerated at the device level of inductance or capacitance. Create L and C structurally to adjust the frequency.

In this study, AMS cyclotron is focusing on high-resolution rather than acceleration efficiency. So, Acceleration voltage is very low as 300 V. In addition to the cavity, the RF circuit box is designed for impedance matching and frequency tuning such as shown in Fig. 1.

By using CST, the field data in Fig. 2 can be obtained.

Computer simulation results show that the acceleration voltage 145840 V is generated when the power of 6656 W is consumed. Power consumption and generated voltage are generated in proportion to the square. Using this, it can be seen that the power required to generate 300 V requires about 0.03 W. Because of the very small power dissipation, you can see that impedance matching and frequency matching are possible at the device level.

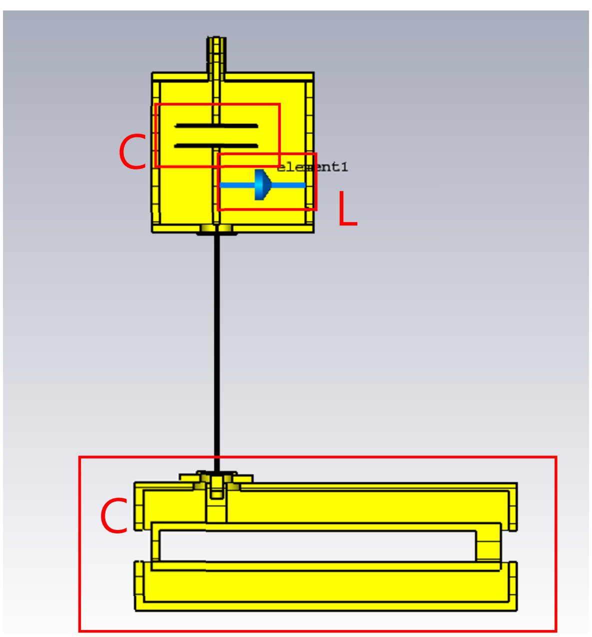

Figure 1: RF cavity.

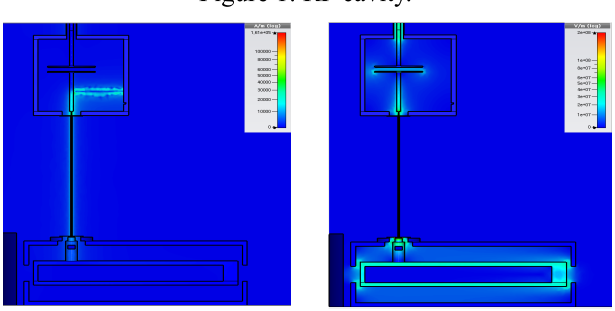

Figure 2: H-field and E-field created in the cavity.

Impedance matching and frequency matching were performed by adjusting L and C of the external RF circuit box, and the results are shown in Figs. 3 and 4.

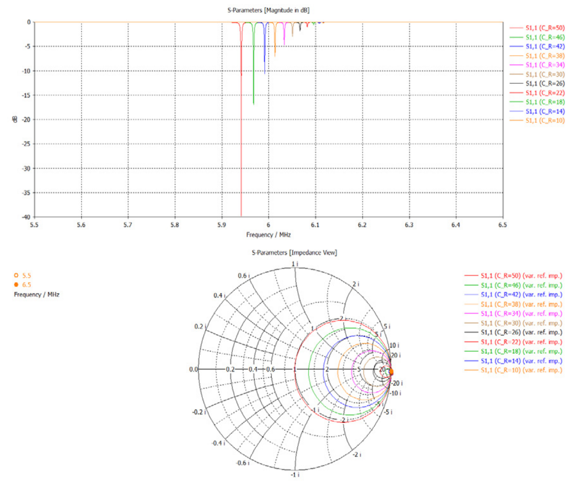

Figure 3: matching with variable capacitance.

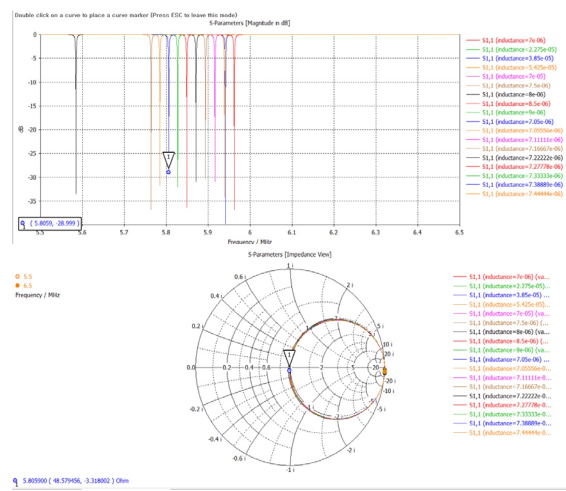

Figure 4: Matching with variable inductance.

Figure 3 shows the change in frequency and impedance with capacitance. Impedance matching changes significantly compared to the change in frequency as shown in Fig. 3. However, there is almost no change in impedance matching compared to the frequency change in Fig. 4, which shows the change in frequency and impedance with inductance. Therefore, the design was carried out by adjusting the inductance to adjust the frequency near 5.8 MHz and then adjusting the capacitance to match the impedance and frequency. Finally, an RF cavity with impedance 50 Ω and frequency 5.8 MHz was designed.

DISCUSSION

In the currently designed RF cavity, Dee is in the air with only a physical design in progress. Engineering design, such as fixing between liner and Dee with dielectric material, is necessary and additional changes should be considered.

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