MÔ PHỎNG HỆ THỐNG RF TRONG MÁY GIA TỐC KOTRON13

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Tóm tắt: Cấu trúc RF (DEE) là một trong những thành phần chính của một cyclotron, được sử dụng để gia tốc hạt. Hệ thống RF là khái niệm tương tự như mạch cộng hưởng LC, trong đó L là cuộn cảm và C là điện dung. Trong tính toán, tần số RF được đặt là 77.3MHz, với hệ số harmonic là 4. Hai dees 39 ° được đặt tại khe có từ trường thấp (valley). Tổng chiều dài của mỗi dee là 50cm. Khoảng cách giữa DEE và liner là 3.4cm. Điện áp áp dụng là 40kV. Hệ thống cộng hưởng RF được mô phỏng với CST MicrowaveStudio (MWS) là một công cụ chuyên dụng để mô phỏng 3D điện từ (EM) nhanh chóng và chính xác cho trường hợp tần số cao.

Từ khóa: *Cyclotron, KIRAMS-13, RF system…*

SIMULATION OF RF SYSTEM ON KOTRON13 CYCLOTRON

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Abstract: RF structures (DEEs) is one of the main components of a cyclotron, used to accelerator particle. The RF system is conceptually similar to the LC resonator circuit, where L is the inductance and C is the capacitance. In the calculation, we set f to be 77.3MHz, which is the fourth harmonic of the revolution frequency of a beam. Two 39° dees are located in two valleys. Total length of each dee is 50cm. The distance between the dee and the liner is 4.4cm. Applied voltage is 40kV. The RF resonator system is simulated with CST MicrowaveStudio (MWS) which is a specialist tool for the fast and accurate 3D Electromagnetic (EM) simulation of high frequency problems.

Key words: *Cyclotron, KIRAMS-13, hệ thống RF…*

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I. INTRODUCTION

KOTRON13 is developed by Korea Institute of Radiological & Medical Sciences (KIRAMS), which is a 13MeV medical cyclotron for Positron Emission Tomography (PET). The RF system of KOTRON13 has vertical cylindrical stems just like other commercial cyclotrons. The power coupling method is capacitive coupling. In this paper, we describe the simulation results of KOTRON13 RF system with MWS.

II. CONTENT

2.1. RF System

KOTRON13 accelerates a negative hydrogen ion and extracts proton. To accelerate the H- beam to 13MeV, vaccum level is maintained under 10^{-6} torr. Material related with the RF system must be manufactured with diamagnetic body to not influence the magnetic field intensity. The RF system needs cooling mechanism because power loss is changed into heat.. The RF specifications are shown in Table 1.

Table 1: RF constituent elements

Resonant Frequency	77.3 MHz
Harmonic Number	4^{th}
Dee Voltage	40 kV
Cavity Shape	Coaxial Type
Resonant Mode	λ/2 fundamental mode
Matching Impedance	50Ω
Material	OFHC copper & Diamagnetic material
Cooling Capacity	30 kW
Pole Gap	12 cm
Dee Angle	39 degree

The RF system has total 2 vertical stems. Before designing this RF system, magnet design was preceded. Almost parameters of whole size are decided from magnet design. Material of RF Cavity is OFHC copper to get electric conductivity better and not affect magnetic field intensity. OFHC copper has good electric conductivity($5.91\times10^{7}\ S/m$) compare with electric conductivity of normal copper ($5.8\times10\ S/m$) [3].

2.2. *RF Design*

Dee angle is 39° which is located both of valleys. Total length of each dee is about 30cm. Cavity is coaxial type which has λ/2 resonant mode:

$$\lambda = \frac{c}{f}$$

Where c is the light velocity and f is frequency of RF system. Supposed resonance frequency of RF system is 77.3 MHz, the wavelength, λ, is 3.88 m

In KOTRON13, the dee capacitance is calculated to be $C_{dee} \approx 42$ pF. The cavity is approximated to be a lossless coaxial line with characteristic impedance Z_0, a capacitance C_{dee} being added at one end and the other end being short. We estimate the length of the coaxial-line part used with the elementary transmission line theory. The impedance looked at a point x into the capacitance side is given by [4]:

$$Z(x) = Z_0 \frac{1 - Z_0 \omega C_{Dee} \tan\left(\frac{x\omega}{c}\right)}{j\left[\tan\left(\frac{x\omega}{c}\right) + Z_0 \omega C_{Dee}\right]}$$

Where c is the light velocity and $\omega = 2\pi f_{rf}$. At $x = L$,the transmission line is shorted and we have $Z(L) = 0$, thus

$$L = \frac{c}{\omega} \tan^{-1}\left(\frac{1}{Z_0 \omega C_{Dee}}\right)$$

The characteristic impedance (50 ohm) of a coaxial line is given by

$$Z_0 = \sqrt{\frac{\mu}{\varepsilon}} \frac{1}{2\pi} \ln\left(\frac{b}{a}\right)$$

Where b is the inner radius of the outer conductor and a is the outer radius of the inner conductor. So ratio of b/a is:

$$ratio = Exp\left[\frac{2\pi}{\sqrt{\frac{\mu_0}{\omega_0}}}.50\right]$$

With ratio is 2.551, Let's assume that b = 0.074 m, a = 0.029 m. Taking the value of 77.3 MHz for f_{rf}, the length of the coaxial part is L = 0.664 m.

2.3. *RF System Simulation*

The RF resonator system is designed with CST MicrowaveStudio (MWS) which is a specialist tool for the fast and accurate 3D EM simulation of high frequency problems. It can show E-field and H-field in the 3-dimensional. The RF system is conceptually similar to the LC resonator circuit, where the resonant frequency is given by [1]:

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

where L is the inductance and C is the capacitance. In the calculation, we set f to be 77.3 MHz, which is the fourth harmonic of the revolution frequency of a beam. Two 39° dees are located in two valleys. Total length of each dee is approximately 50cm. The distance between the dee and the liner is 4.4 cm. The MWS model of the RF dee and the resonator is illustrated in Fig.1.

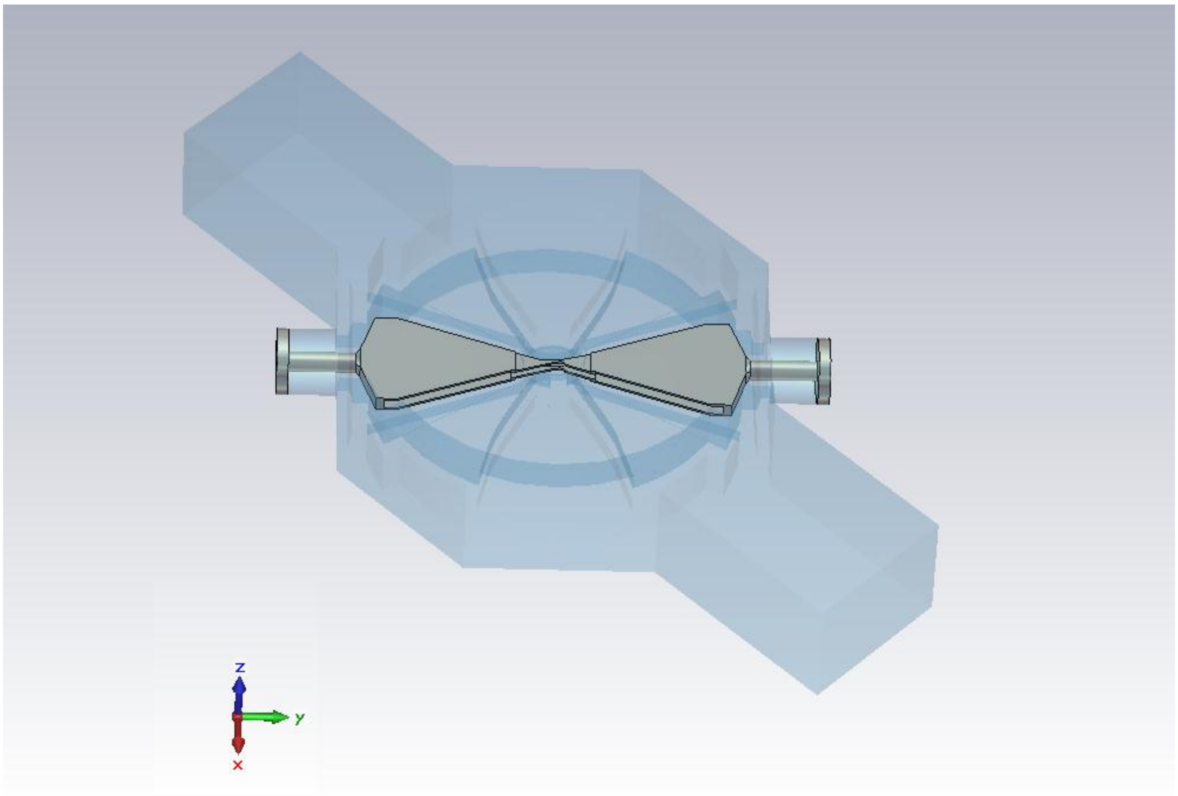

Figure.1: MWS model of RF system

Vector distribution of electric field is shown in Fig. 2 & 3. Since electric field is formed vertically to dee edges, it is adequate to accelerate ion beam.

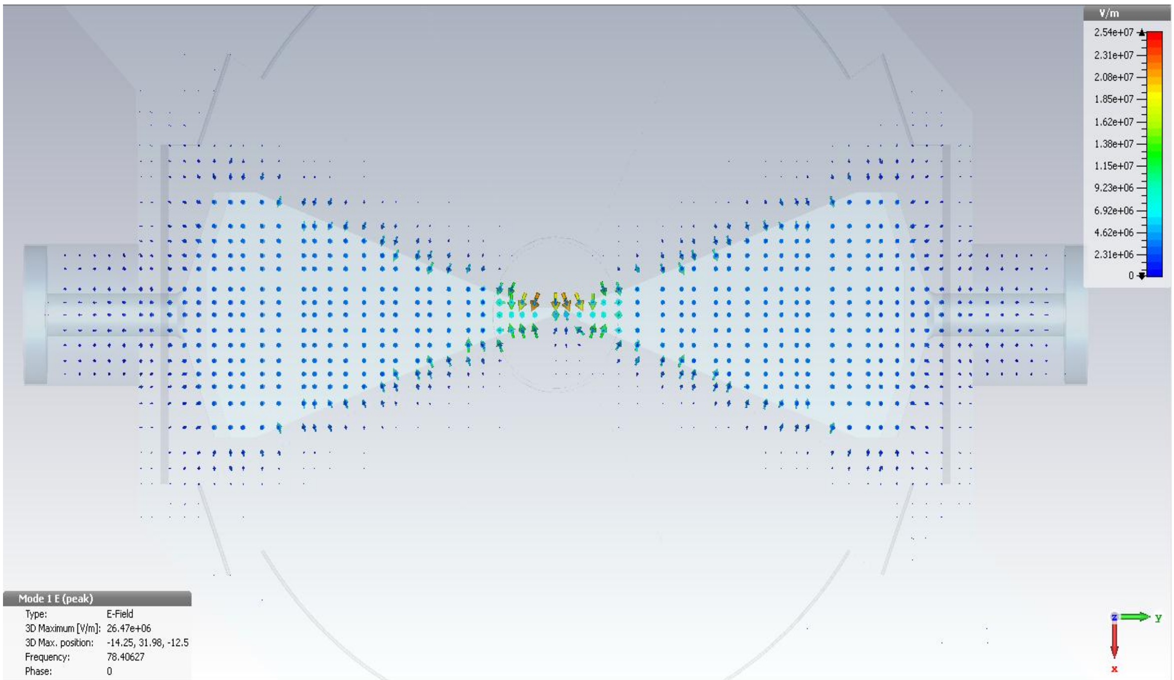

Figure.2: Vector distribution of electric field with phase is 0^o

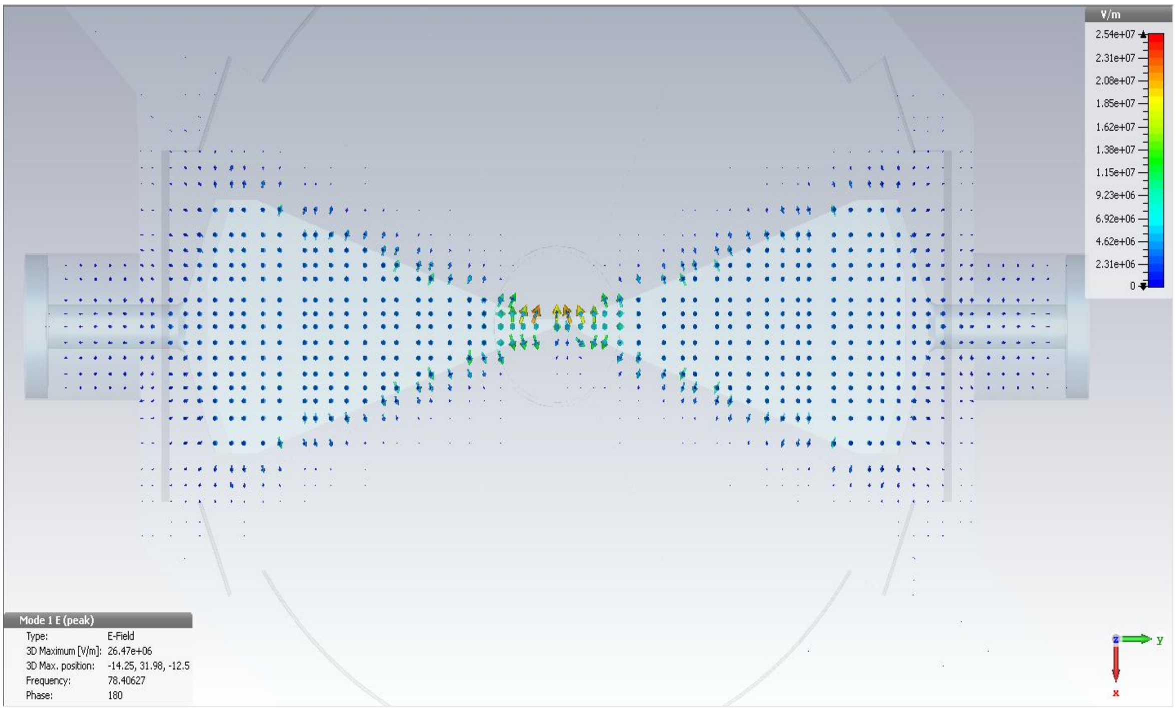

Figure.2: Vector distribution of electric field with phase is 180^o

The resonant frequency is 78.4MHz calculated with MWS. Difference between simulation and calculation is due to omit some parts such as RF fine tuners and simplify inner structure.

3. CONCLUSION

This paper has explained the features of 13 MeV injector cyclotron RF cavities, we could acquire the optimal Q value and resonant frequency after iterated simulation many times. Designed cavity has proper RF frequency and Q value. Marginal error of RF frequency will control by RF tuner next process.

4. REFERENCES

[1] THEORETICAL CALCULATIONS AND MEASUREMENTS OF THE DEE VOLTAGE IN THE RUTGERS 12 INCH CYCLOTRON , Timothy W. Koeth Rutgers University, Piscataway NJ 08854, September, 2005;

[2] A DESIGN OF RF SYSTEM FOR KIRAMS-13, In Su Jung, Yu Seuk Kim, Bong Hwan Hong, Proceedings of the Korean Nuclear Society Spring Meeting Gyeongju, Korea, 2004;

[3] DESIGN OF RF SYSTEM FOR COMPACT AVF CYCLOTRON, J.H. Oh, B.N. Lee, H.W. Kim, J.S. Chai; Proceedings of CYCLOTRONS 2010, Lanzhou, China;

[4] DESIGN OF THE RF SYSTEM FOR A 30MEV CYCLOTRON In Su Jung, Dong Hyun An, Bong Hwan Hong, Proceedings of EPAC 2006, Edinburgh, Scotland.