DESIGN OF RF CAVITY FOR COMPACT 9 MEV CYCLOTRON

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Abstract

The number of PET facility is rapidly increasing worldwide. To get the PET image, circular accelerator such as cyclotron is needed. Compact 9 MeV H- cyclotron which has a diameter of 1.25m is being designed at Sungkyunkwan University starting from July 2010 for getting F-18. It is expected to be constructed by next year. In this paper, RF system of 9 MeV cyclotron including the design processes and detail analysis of the result is reported. RF system mainly describes RF cavity design.

INTRODUCTION

A Compact 9 MeV cyclotron is being designed for producing short-life isotope, such as F-18 for Positron Emission Tomography (PET). For getting F-18 with 9 MeV cyclotron, high beam current is not needed (less than 100 μA is required). In addition, in order to obtain a good quality of the beam, we need a precise calculation of electric field and magnetic field. This paper shows the main design process of RF cavity. Computer simulation code such as CST microwave studio (CST MWS) was used for electric field and magnetic field calculation. [1] Also basic 3D modelling was performed by 3D Computer Aided Design program CATIA P3 V5 R18. [2]

RF SYSTEM

We chose the RF system of main cyclotron as the double gap cavities. Normally, double gap cavities are utilized in lower energy cyclotrons whereas single gap is used in higher energy [3]. Capacitive part is formed by the gap between the dee and outer conductor. And inductive one is made by the vertical stem. [4] By changing the size and length of the stem, we can get the proper resonant frequency. However, the optimal geometry of stem design is not easy. The diagram of 9 MeV RF cavity is seen on Fig. 1, which was drawn by 3D computer aided program. Vertical and side viewpoints are seen on this Fig. Table 1 shows 9 MeV cyclotron RF system specifications. Total length of dees, magnetic gap (2.1cm), and stem reaches $\lambda/2$ and dee radius is 27.8cm. 4^{th} harmonic mode has been adopted, and length of dee gap corresponds to the hill gap.

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Table 1: 9 MeV Cyclotron RF System Specifications

Parameters	**Values**
Energy	9 MeV
Pole radius	0.35m
Extraction radius	0.31m
Hill / Valley gap	0.021 / 0.38m
Number of cavities	2
Dee angle	25 degrees
Dee voltage	50 kV
Harmonic mode	4
Resonant frequency	84.92 MHz

Design Concept

The basic geometry of RF cavity is seen on Fig. 1. Rough geometry of the cavity is delta type as a normal cavity. As the voltage increases along the radius, the size of stem also needs to be bigger to handle high power. Pole radius of this 9 MeV cyclotron is 35cm and, and dee voltage on this cyclotron is almost constant along the radius. Stem geometry should be carefully considered especially in the area of dee and stem edges because power consumption is concentrated in the coupling region. In addition, too much increase of the stem size can reduce Q factor. In case of the dee voltage, we chose a reasonable voltage, which does not have an influence on discharge effect in the central region. With all concepts in mind, Cavities with a stem is conventional scheme for RF cavity design but its simplicity and structural stability makes it used in this 9 MeV cyclotron.

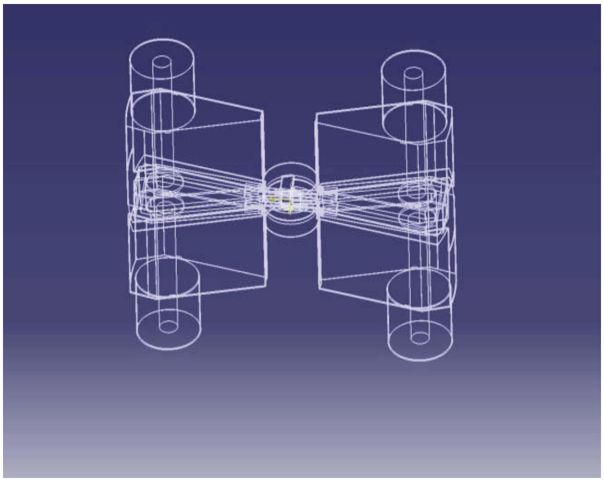

Fig. 1: Wireframe of RF cavity basic model

Cavity Design Process

Acceleration gap is kept to be constant. Internal stem length is 3 cm in radius. In addition, by adjusting the ratio of outer conductor and inner conductor we can obtain the characteristic impedance. Computer simulations have been conducted based on CST microwave studio (MWS). For the cavity material, we have used OFC C11000 (which has a electric conductivity of $5.91\text{x}10^8 \text{S/m}$). However CST does not provide lossy materials with conductor, so we used a perfect electric conductor instead of OFC. We have simulated with different stem size, length. In addition, in order to accommodate the limited space for valley we reduced the angle of dee to 25 degrees since hill angle is 60 degrees. Furthermore, the thickness of the conductor was also considered.

Table 2: RF cavity simulation results

Parameters	Value
Resonance frequency	85.44 MHz
Quality value	5250

Cavity design has been done on the following processes. First, basic parameters were calculated to design basic geometry of RF cavity by 3D CAD, and then it was exported to computer simulation program to calculate electric field and magnetic field of the RF cavity. Second, since resonant frequency is geometry dependent, basic cavity structures such as thickness of dee, stem length, and etc. were changed to get expected RF frequency. Acceleration voltage is obtained by calculating electric field along the dee radius. After conducting several iterations of modelling, we obtained optimal values of RF cavity. The resonance frequency is 85.44 MHz, which corresponds to the 4^{th} harmonic mode. Resonance frequency difference between simulation and expected values can be adjusted by fine tuner. [5] Q value calculated by MWS CST is 5250, which can be also calculated by following formula, where f_r is resonant frequency. [6] Two parameters are shown on table 2.

$$Q = 2\pi f_r \frac{\text{Energy Stored}}{\text{Power Loss}} \qquad (1)$$

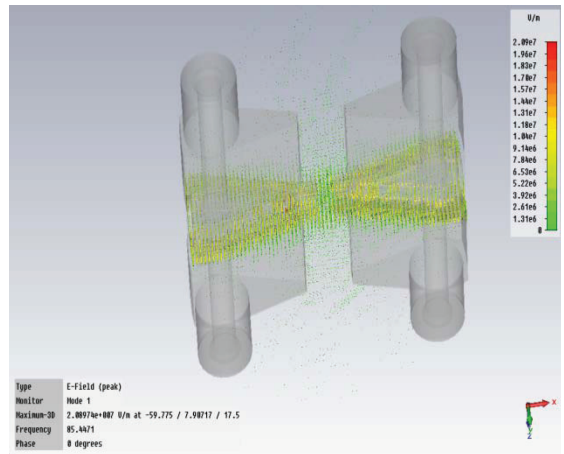

Fig. 2: Electric field distribution

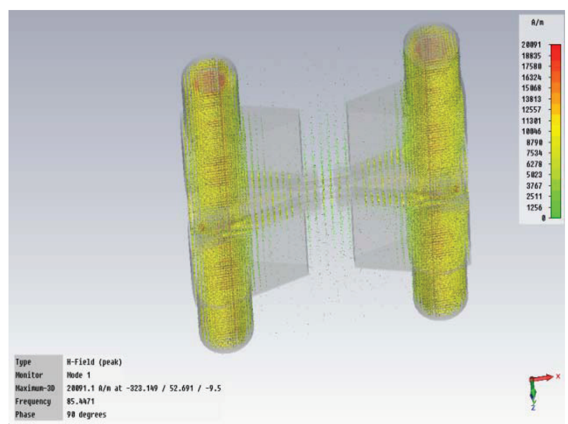

Fig. 3: Magnetic field distribution

The E-field and H-field distribution can be seen on Fig. 2 and Fig. 3. With this figure, we can see that E field is concentrated on the acceleration gap. In addition, H field is perpendicular to the E field concentrated on each stem. Geometry of RF cavity can be seen on Fig. 4. The central region model is composed of two dees, the puller, and beam channel. This cyclotron adopts Penning Ion Source (PIG) and the beam comes out of this internal source goes into the guide. [7] The central region is connected to dee and dee itself is joined with RF cavity.

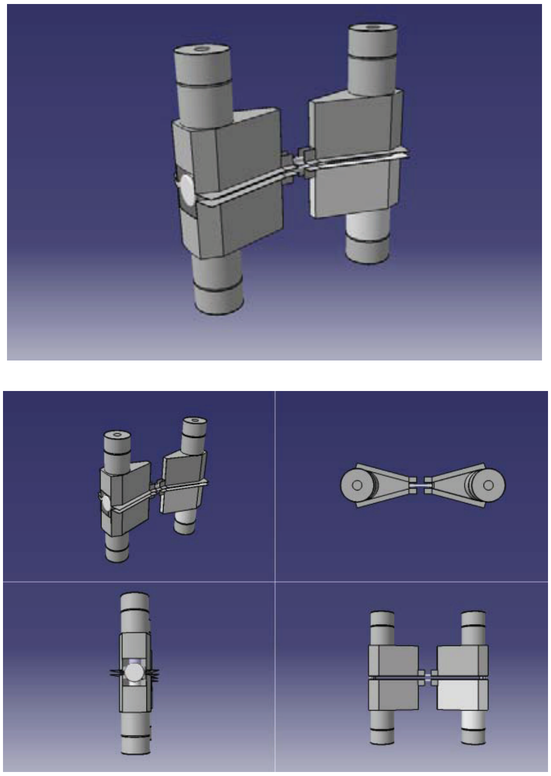

Fig. 4: RF Cavity Design using CATIA V5

SUMMARY

We have looked at the features of cyclotron focusing on RF system. After changing the geometries of stems and dees, we could obtain the optimal Q value and resonant frequency of RF cavities. Completed design of RF system of 9 MeV cyclotron is expected to be finished by 2012.

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