DESIGN STUDY ON MAGNET AND RF SYSTEMS OF A 5 MeV H^- CYCLOTRON

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Abstract

The development of a 5 MeV H^- cyclotron, KIRAMS-5 has been started by KIRAMS (Korea Institute of Radiological & Medical Sciences). The final goal of this work is to extract the 2 mA of 5 MeV proton beam for the neutron generation. The H^- beam is injected from an external ion source and is extracted with the stripping foil to obtain the protons. The magnet has the pillbox type yoke and is made up of four sectors with deep valley. The RF system consists of two dees and vertical type resonators. In this paper, the prototype models of the magnet and RF systems are presented. Also, the design parameters and simulation results of them are described.

INTRODUCTION

Nowadays, neutron applications are used in many fields; medicine, industry, physics, etc. Either the accelerator or the reactor is used to obtain the neutrons. The accelerator-based neutron source is more attractive than the reactor-based neutron source with installation space, cost, and access system[1].

The development of a low energy and high current cyclotron has been started to generate the neutrons at KIRAMS. The cyclotron is composed of the external ion source, the injection system with an inflector, the magnet, the RF system, the vacuum system, the extraction system, and the target. The final beam energy was chosen to be 5 MeV of protons for the beryllium target[2]. The beam current is expected to be over 2 mA. To obtain the beam current, an external multicusp ion source that can produce about 15 mA of H^- will be used[3]. The magnet is composed of four sectors, injection hole, and pumping holes at the valleys. The RF system consists of two dees with vertical stems and cavities. The RF power is transmitted through the capacitive coupler. The study for the injection system and central region has been worked out simultaneously[4].

This paper contains the design study of the magnet and RF systems of KIRAMS-5. The design parameters and simulation results of the magnet and RF prototype models are presented following sections.

DESIGN PARAMETERS

In the aspects of the magnet and the RF systems, there are several things to consider obtaining a few mA of beams; the space charge effect, the focusing, the turn separation of the orbits, and so on. Because the magnet and RF systems are correlated, the design work is very iterative. The cyclotron is basically composed of four sectors of magnet and two dees of RF systems. To guarantee over 1.4 cm for the turn separation at the last orbit[5], the constant magnetic field at the magnet center, B_0 and RF dee voltage were chosen to be 0.8 T and 100 kV, respectively. The beam is injected from the spiral inflector with 50 keV of energy at 3.03 cm of radius[4]. The maximum energy gain per turn is 399 keV when the angle of acceleration gap is 43 °. The total number of turns to reach 5 MeV is therefore approximately 13. The RF-frequency corresponding to the B_0 is 48.83 MHz with the 4^{th} harmonics. To increase the axial focusing force, the deep valley structure has been employed[6]. This structure also can give the space to the RF cavity and simple structure of vacuum system. The extraction radius is about 39.7 cm. The radius of the sector is 45 cm considering the magnetic fringe field at the end of the sector. The hill angle is about 40 ° and increases with the radius to make the isochronous magnetic field. The hill gap is 4 cm ,and the valley gap is 52 cm that is the same with the distance between the upper and lower return yoke. For the injection system, one hole is located at the center. Four holes are located at each valley. The two of them are used for vacuum pumps and the rest are used for the RF cavities vertically. The RF power will be capacitively fed into the resonator via a disk mounted at the end of the dee. The general specifications are summarized in Table 1.

MAGNET DESIGN

The OPERA-3d TOSCA solver[7] was used to calculate the magnetic field and to make the isochronous magnetic field. The magnetic fields at 5 MeV are 1.2 T and 0.16 T at the hill and valley centers, respectively. The average magnetic field is about 0.8 T. The total ampere-turns of the exciting coil is about 40600 A-turns and the current density is 165.8 A/cm^2. Because the cyclotron has low energy and a few tens of beam rotations, the side shim of a hill for the isochronous magnetic field is not so complex. The designed model is illustrated in Fig. 1.

After the magnetic field calculation, the radial and axial tunes, frequency error, integrated phase shift, and average magnetic field were calculated by the equilibrium orbit (EO) program that was written by Gordon[8]. Fig. 2 shows the calculated average magnetic field and the radii of the equilibrium orbits with the radius. All the EO calculations were computed from 50 keV of energy. The turn separation

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Table 1: General specifications of a 5 MeV cyclotron

Parameters	**Values**
Accelerating particle	H^-
Injection energy	50 keV
Final energy	5 MeV
Beam intensity	2 mA
Magnet	
Number of sectors	4
Extraction radius	39.7 cm
Hill angle	40 °
Hill gap	4 cm
Valley gap	52 cm
Average field	0.8 T
RF	
Radio-frequency	48.83 MHz
Harmonic number	4
Number of dees	2
Dee angle	43 °
Dee voltage	100 kV
RF power	60 kW

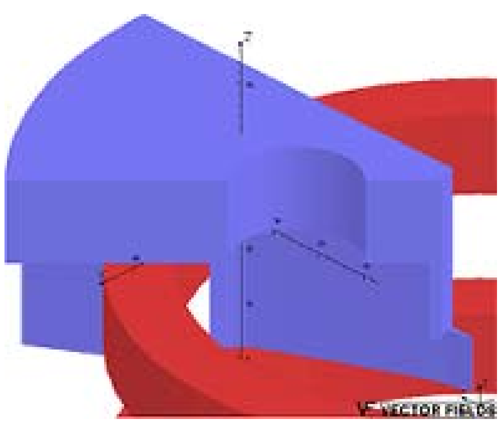

Figure 1: 1/8 designed model of the magnet.

at the last orbit is about 1.6 cm.

Fig. 3 presents the frequency error between the designed field and isochronous field. The frequency error Ω is defined by

$$\Omega(E) = \frac{\omega_0}{\omega} - 1 \quad (1)$$

where E is the energy and ω_0 and ω are a fixed frequency and revolution frequency of a particle, respectively. Fig. 4 presents the integrated phase shift. The phase excursion during the acceleration is within $\pm\, 2°$. This is very reasonable to reduce the beam loss. The radial and axial betatron oscillation frequencies are plotted in Fig. 5. Fig. 6 presents the path of the operating points and the dangerous resonances. This figure shows that the beam is stable during the acceleration.

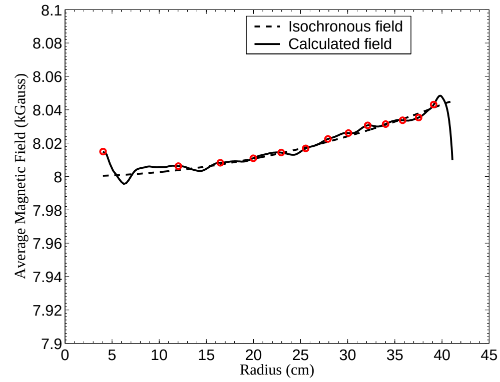

Figure 2: Average magnetic field with the radius at median plane.

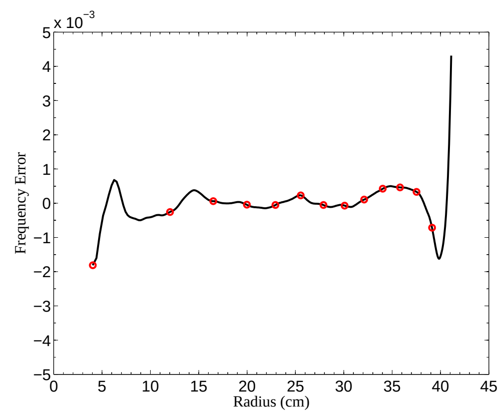

Figure 3: Frequency error with the radius.

RF SYSTEM DESIGN

Because of the low magnetic field, the RF frequency with the 4^{th} harmonics is relatively low to other general cyclotrons. This makes the stem length of the cavity 80 cm that is from the mid-plane. The RF dee and resonator system were designed with MWS Eigen mode solver[9]. The MWS model of the RF system is illustrated in Fig. 7. The simulated resonant frequency and Q value are 50.43 MHz

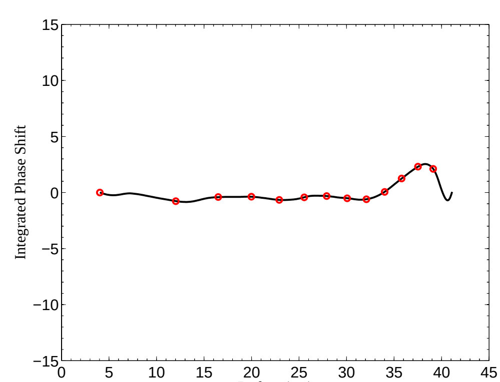

Figure 4: Integrated phase shift with the radius.

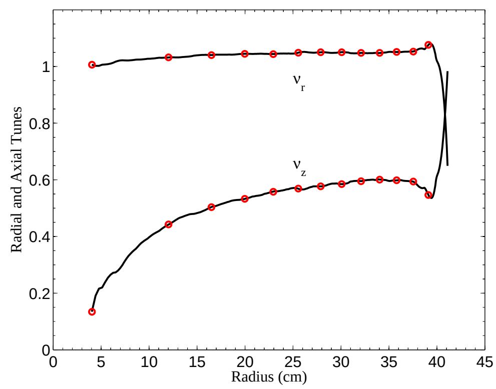

Figure 5: Radial and axial tunes with the radius.

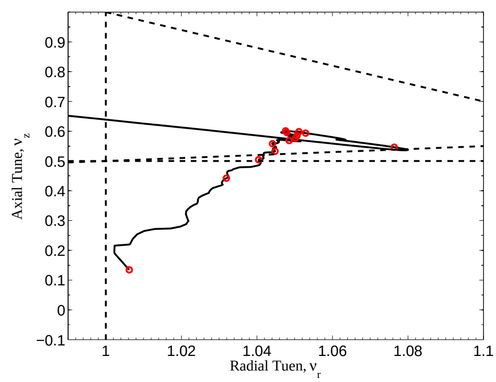

Figure 6: The operating points diagram during the acceleration and the dangerous resonances.

and 5583.8, respectively. There is some difference between the required and simulated frequencies. This is because of the simple modeling in the central region and the other parts. Fig. 8 shows the simulated electric field distribution of the RF system when the resonance frequency is 50.43 MHz.

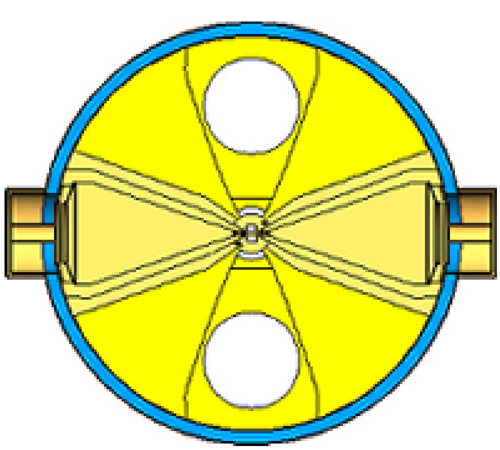

Figure 7: Cross-sectional view of the dees in the mid-plane.

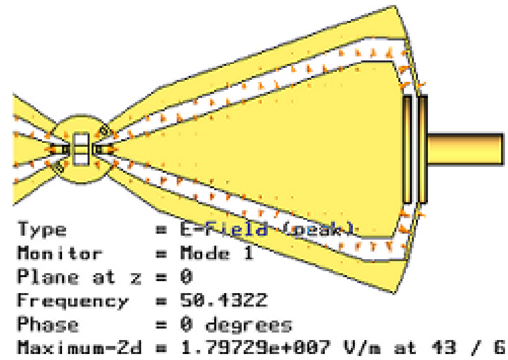

Figure 8: The electric field distribution in the mid-plane.

CONCLUSION

The design study of the 5 MeV H^- cyclotron for neutron generation is being in progress at KIRAMS. In this paper, the prototype model of the magnet and RF system was suggested. The design of the magnet was done by using TOSCA and EO programs. The design of the RF resonator system also was carried out with the MWS program. More detail study on designing the systems is in progress.

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