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DESIGN OF HIGH SENSITIVE MAGNET AND BEAM DYNAMICS FOR AMS CYCLOTRON

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Abstract

To produce a Carbon 14 for Accelerator Mass Spectrometry (AMS), AMS Cyclotron magnet was designed. For AMS system, Cyclotron magnet has been required high mass resolution. In order to realize high mass resolution, the phase error is designed within ±10 and the mass resolution was 5000. Cyclotron electromagnet was designed with a mass resolution of 5000, a harmonic number of 10, a center magnetic field of 0.5332 T, a maximum energy of 200 keV, a minimum turn separation of 1.2 mm. and a size of 1580 mm × 800 mm. We used CST particle studio and Cyclone for beam dynamics simulation of this cyclotron magnet. This paper describes AMS cyclotron magnet and beam dynamics design.

INTRODUCTION

Design of high sensitive magnet and beam dynamics study of AMS Cyclotron magnet was started in 2017 May at Sungkyunkwan University. The main purpose of AMS Cyclotron is accelerator mass spectrometry for medical purpose. Accelerated Carbon-14 beam can be used for mass spectrometry [1, 2].

This paper presents a design of high sensitive magnet and beam dynamics for AMS cyclotron. A magnet of AMS cyclotron is made of DT-4 steel with 10^{th} harmonics. The main parameters of magnet are decided by 200 keV Carbon-14 beam. These main parameters are relation with size of magnet, power consumption, beam parameters. The accelerators for AMS system require high mass resolution.

DESIGN AND SYSTEM DESCRIPTION

The design process of cyclotron magnet is shown in Fig. 1. The main design parameter is decided at initial calculation. The maximum beam energy, dimension of cyclotron magnet size is the part of main design parameters. From the initial calculation, maximum energy of Carbon-14 beam is decided from the magnetic rigidity. The extraction radius set as 453.6 mm and central magnetic field is set to 0.5332 T so RF frequency is 5.8 MHz when the 10^{th} harmonic is used. The approximate 3D modelling of the electromagnet was performed based on calculated main design parameters. The magnetic field of the 3D model of the electromagnet is analysed using TOSCA. After that, the phase error is calculated using the CYCLONE code and the reference field is designed using the phase error

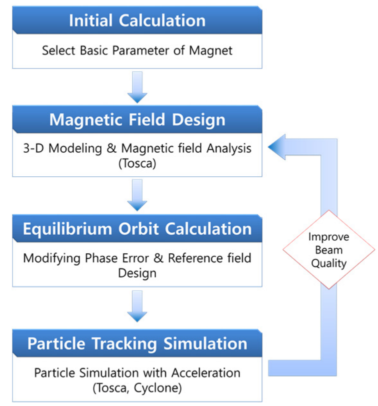

Figure 1: Cyclotron design process.

The designed magnetic field result from TOSCA were imported into CYCLONE. CYCLONE code calculates equilibrium orbit, phase error, single particle trajectory, tunes of designed magnetic field. The magnetic field error between reference field and designed field has calculated by using

$$\frac{\Delta B(r)}{B(r)} = \gamma^2(r)\frac{\Delta f_p(r)}{f_p(r)}. \quad (1)$$

The magnetic field was modified by magnetic field error from Eq. (1) [3]. The magnetic field error between reference field and designed field should be less than 10 Gauss for get high quality of Carbon-14 beam (Fig. 2).

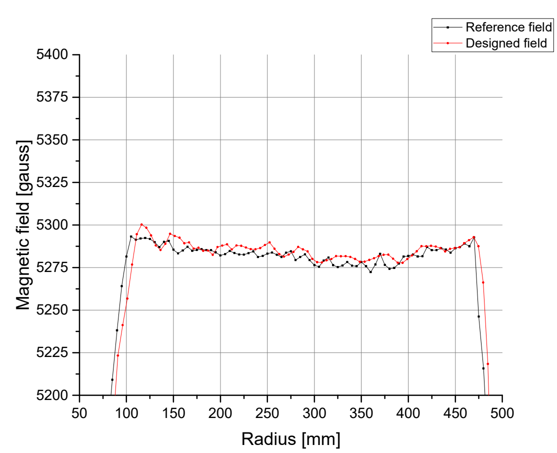

Figure 2: Magnetic field design.

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The 3D drawing of AMS cyclotron magnet is shown as Fig. 3. This magnet has been adopted to design of low valley which can reduce the power consumption of magnet. The cyclotron ion source is injected vertically and a small hole in the center of the cyclotron was made for this purpose. A hole for the vacuum pump was also made in the center of the valley. The magnetic field design is based on basic design parameter and calculated by Opera 3D (TOSCA) [4]. The coil of AMS cyclotron specification is shown as Table 1 and the magnet specification is shown in Table 2. The power consumption of magnet coil was set as 2.75 kW. The power consumption has been modified by coil design.

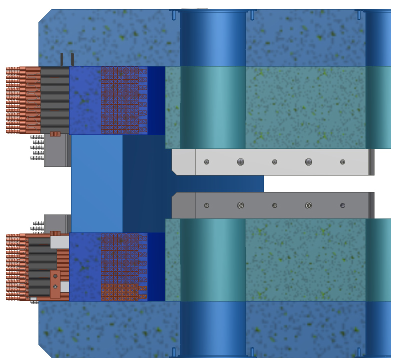

Figure 3: AMS magnet side view.

Table 1: AMS Cyclotron Coil Specification

Parameter	Value
Square	9 mm
Hole	4.5 Phi
Coil Turn	160
A-T	13700
Current	85 A
Voltage	32 V
Power	2.75 kW

RESULTS AND DISCUSSIONS

Figure 4 shows designed magnetic field and reference field. vertical tune is around 0.4, radial tune is around 1.01. Estimated RF Dee voltage is 300 V.

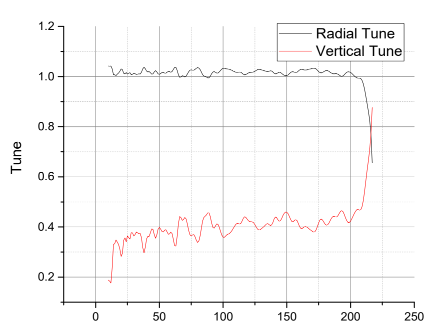

Figure 4: Tunes of magnetic field.

The reference particle is start with 20 keV and accelerated up to 200 keV. The location of RF cavity was set as the valley. Accelerating voltage was 5.8 MHz with the 10th harmonics. The beam trajectory is shown in Fig. 5.

Table 2: AMS Cyclotron Magnet Specification

Parameter	Value
Maximum energy	200 keV
Beam species	Carbon-14 negative
Ion source	Cs sputtering
Number of sectors	4
Hill angle	60°
Valley angle	40°
Pole radius	0.510 m
Extraction radius	0.453 m
Hill / Valley gap	0.25
Harmonic number	10
Radio frequency	5.8 MHz
Radial tune	~ 1.01
Vertical tune	0.4
B-field (min., max.)	0.137, 0.687 T

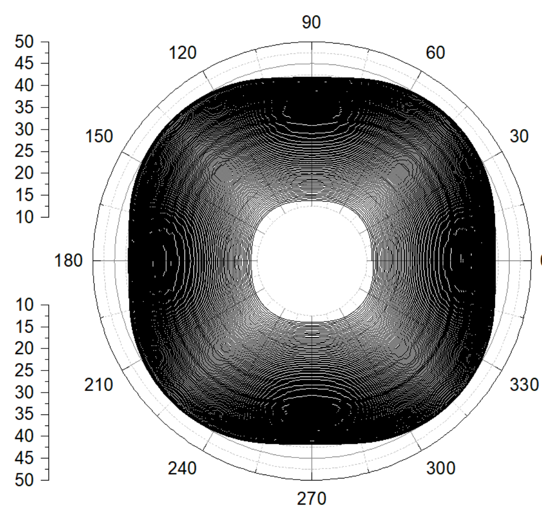

Figure 5: Single particle trajectory of Carbon-14.

The distribution of magnetic field on the z = 0 plane of the magnet is form 0.137 T to 0.687 T. A Carbon-14 beam is produced for an ion source and is injected on the cyclotron in the vertical direction. It is bent 90º through the inflector and starts acceleration at a radius of 138 mm. The Carbon-14 beam is accelerated to a Dee voltage of 300 V and rotates a total of 160 turns to 200 keV. Cyclotron for AMS require high mass resolution, which is calculated as

$$\frac{M}{\Delta M} = \frac{f}{\Delta f} \approx \pi h N. \qquad (2)$$

This cyclotron has 10^{th} harmonics and 160 turns, the mass resolution is about 5000 according to Eq. (2) [5].

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The space where the Carbon-14 beam is accelerated is 315 mm (138 mm to 453 mm). The Carbon-14 beam rotates 160 turns in a space of 315 mm, the turn separation is optimized and the turn separation is shown in Fig. 6. Through magnetic field optimization, the minimum turn separation was optimized to 1.2 mm.

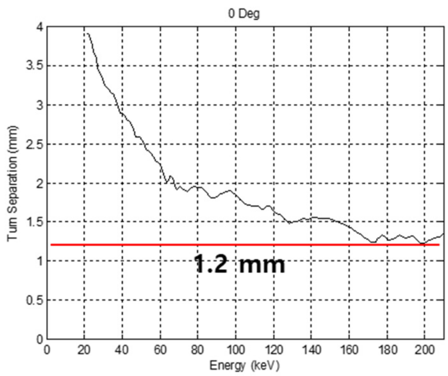

Figure 6: Turn separation of Carbon-14 beam.

CONCLUSION

In this study, Design of High Sensitive Magnet and Beam Dynamics for AMS cyclotron was done. The cyclotron for AMS with 200 keV Carbon-14 beam was designed and its mass resolution was 5000. To develop cyclotron for AMS system, magnetic field design for 200 keV Carbon-14 beam was performed and magnetic field optimization was performed within 10 Gauss. The optimized magnetic field was analysed using cyclone code. This cyclotron was manufactured by Korean company. The AMS cyclotron is being shimming with the goal of starting in 2020.

ACKNOWLEDGMENT

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