THE ISOCHRONOUS MAGNETIC FIELD OPTIMIZATION OF HITFIL CYCLOTRON*

Q.G. Yao#, L.Z. Ma, S.F. Han, X.Y. Zhang, W. Wu, B.L. Guo, H.F. Hao, B. Wang
Institute of Modern Physics, Chinese Academy of Sciences, 730000, Lanzhou, China

Abstract

A new project named HITFiL（Heavy Ion Therapy Facility in Lanzhou）is being constructed. In this project, a 7Mev C125+ cyclotron is selected as the initial injector providing a 10 uA carbon beam. The isochronous magnetic field optimization of the cyclotron is introduced in this paper. Optimization result shows that the deviations between calculation values and theory are smaller than 5Gs. In the design process, the sofware OPERA has been utilized for the field calculation and optimization.

INTRODUCTION

At present, the activities on the development of isochronous cyclotron for the HITFiL are carried out at IMPCAS (Fig.1). This project include cyclotron, synchrotron and four high energy beam lines, which intended for obtaining the carbon beam to treat tumors. The cyclotron magnet has the pole diameter size of 1.68m and provides the maximum magnetic fields 1.8T between sectors. Its main parameter is shown in table1 [1].

Table1: Main parameters of the cyclotron

Maximum energy, [Mev]	7
Beam species	C_{12}^{5+}
Number of sectors	4
Ion source	outer
Hill angle, [^{o}]	56
Valley angle, [^{o}]	34
Maximum average magnetic field,[T]	1.2
Harmonic number	4
Cyclotron frequency,[MHz]	7.755
Magnet aperture, [mm]	50
Injection radius, [mm]	27
Extraction radius, [mm]	750
Extraction beam current, [uA]	10

The main magnet has a round yoke, four pairs of straight-line sectors. The relation of the distance in the "valley" to the distance in the "hill" is equal d_{valley}/d_{hill} =7.2. In this paper, we introduce the main magnet with particular emphasis on the isochronous mangetic field design. It is the important criterion of the designing of the cyclotron magnetic structure.

*Work supported by HITFiL
yaoqinggao@impcas.ac.cn

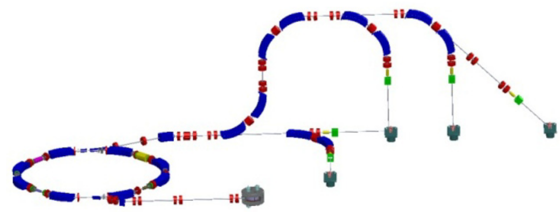


Fig.1 the layout of HITFiL

MAGNETIC FIELD DESIGN

The shape of the magnet yoke is optimized by OPERA-2D and 3D magnetic field calculation [2], Fig.2 shows the 2D cross section along the radial direction of this magnet. As the result of simulation, the straight line sectors with the flat surface are used. The sectors are placed on the magnet pole with the radial displacement with 10mm from the centre of magnet. In addition, for the axial injection of the beam, a cylinder which diameter is 200mm (is used to settle two solenoids) and a cone is designed in the center of magnet. For magnetic field calculation in the valley region, which is obtained with the help of OPERA-2D program [Fig.3]. Total current per each coil is 68734.4 ampere-turens and the current density is about 3.4A/mm2.

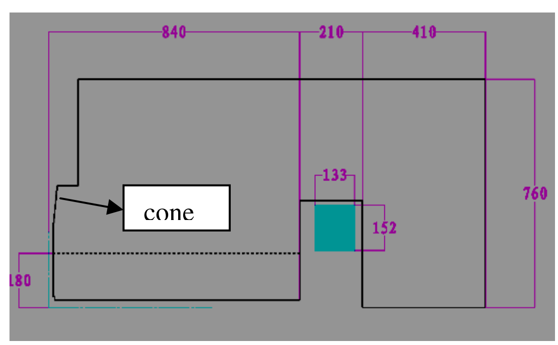


Fig.2：The cross section of cyclotron

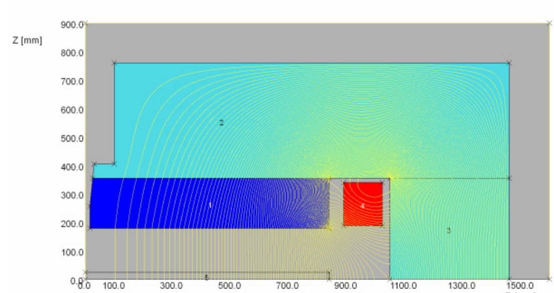


Fig.3 Opera-2D calculation (valley region)

Copyright © 2011 by the respective authors — cc Creative Commons Attribution 3.0 (CC BY 3.0)

The OPERA-3D program was used to calculate the thereee-dimensional field. In the Modeller, the 1/16 model is created according to the symmetry of the magnetic field. Fig.4 shows the geometry of the cyclotron modeled by the OPERA. There are four holes at the valley center which designed for the vacuum and RF systems, they distort the field greatly, a step by step optimization of the magnet geometry is thus needed. Fig.5 shows the radial magnetic field along the "hill" median line at the centre plane, the field seen by accelerating beam is increased in radial direction. We have been able to obtain a reasonable isochronism by some optimization methods.

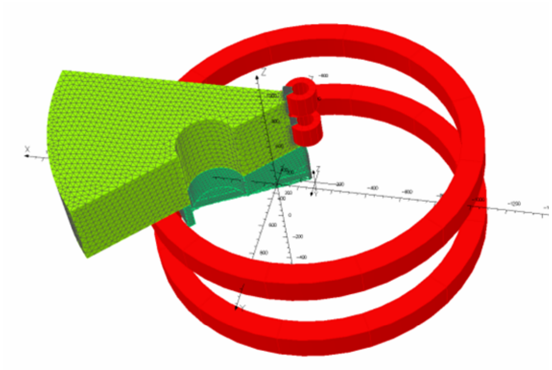


Fig.4 OPERA 3D model (conclude two solenoid).

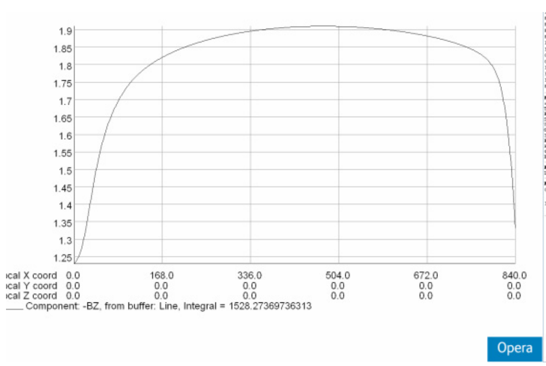


Fig.5 Radial magnetic field distribution

THE ISOCHRONOUS MAGNETIC FIELD OPTIMIZATION

The theoretical isochronous magnetic field $\overline{Bt}$ of carbon is calculated by a fomula as follows:

$$\overline{Bt} = \frac{2\pi mf}{q} \bullet \sqrt{1 - \frac{4\pi^2 \bar{r}^2 f^2}{c^2}}$$

Where $\bar{r}$ is the average radius of orbit, $\frac{m}{q}$ =12/5, f is the cyclotron frequency.

The calculation value $\overline{Bc}$ is obtained by OPERA software. Firstly, to take the mapping magnetic field of cyclotron center plane from post-processor; secondly, to calculate the radius of static balance orbit (fig.6); thirdly, to take the magnetic field in the orbits and calculate their average value.

The aim of magnetic field optimization is to make the $\Delta B = \overline{Br} - \overline{Bc}$ approaches zero as much as possible. There are several shimming methods which optimizing its isocoronous field [3], here we adopted an effective method that is cutting air trim slot and chamfering cover plate of sector. This makes the cyclotron operation simpler, avoiding complicated optimization procedure with trim coils. The optimization method is introduced as follows:

1) Cutting air trim slot: cut a slot along the radial direction (35mm≤R≤782mm) by using several frustum of cones to deal with the sector; it could adjust the magnetic field in large measure and make the error between the calculation value and theory in isochronous field smaller than 30Gs (Fig.7 b) .

2) Chamfering the cover plate(the deep is 5mm): by chamfering the pole plate, it could adjust the magnetic field in a limited range and make the error between the calculation value and theory in isochronous field smaller than 5Gs (Fig.7 c) .

3) Changing the total current: by adjusting the total current, the magnetic field could be optimized as a whole.

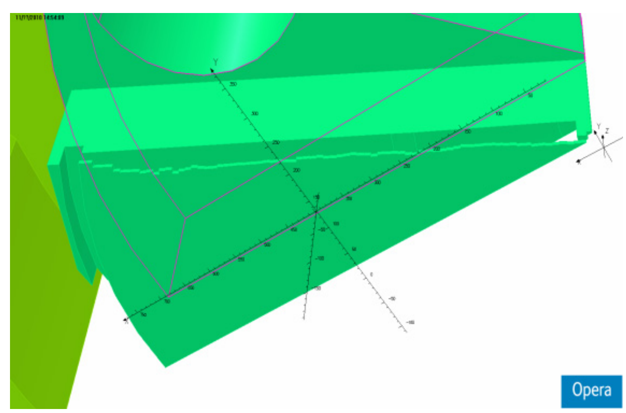
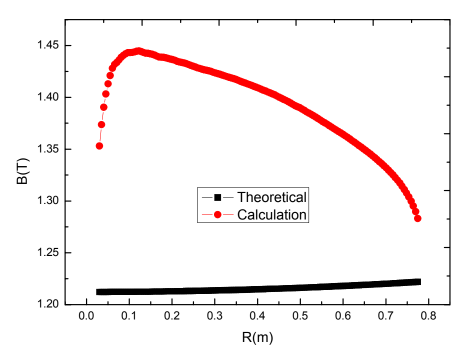
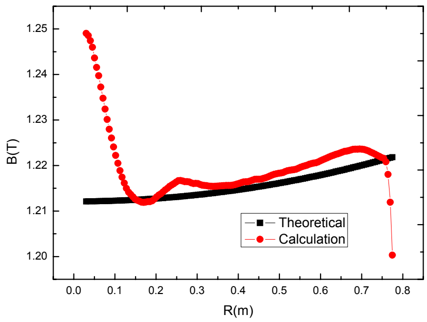


Fig.6 the optimized shape of pole

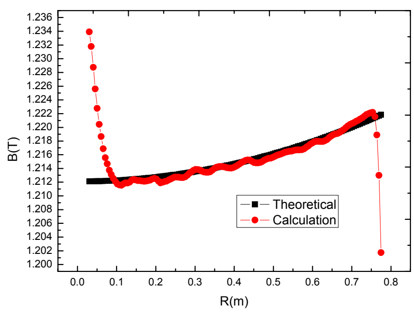


(a) Without any optimization

Copyright © 2011 by the respective authors — cc Creative Commons Attribution 3.0 (CC BY 3.0)



(b) only cutting air trim slot



(c) Cutting air trim slot and chamfering pole plate

Fig.7 Magnetic field optimization procedure

The Fig.6 shows the final optimized pole, the complicated chamfer shape could be seen. The comparison between the calculation and theory is shown in the Fig7, it gives the optimization procedure: the deviation between calculation values and theory is very big before optimization (Fig. 7 a), but after the magnetic field optimiztion, the result shows the deviation does not exceed 5Gs over a large area.

In addition, horizontal and vertical focusing frequencies are also obtained from the equilibrium orbit calculation. Generally we hope the focusing frequency sufficently away from the resonances, especially the vertical focusing frequency. The fig.8 shows the two focusing frequencies, the vertical focusing frequency is below 0.5 except some points in final radius.

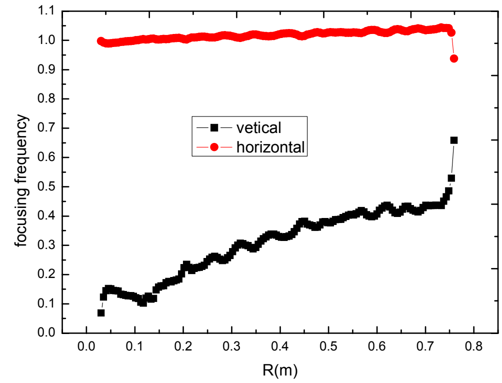


Fig.8 Focusing frequency

Conclusion

Magnetic field calculation of main magnet for a 7Mev C_{12}^{5+} cyclotron have been finished.The purpose of the work is to obtain the resonable isocoronous magnetic field, an effective method has been carried out. By complicated chamfering, the isocoronous magnetic field could satisfy the design requirements.

REFERENCES

[1] HITFiL design parameter handbook
[2] Cobham Technicals Services, www.cobham.com/technicalservices
[3] I.Ivanenko, G.Gulbekian, J.Franko, A. Semchenkov, “The model of DC72 cyclotron magnet. The research of the sector shimming methods for obtaining the working magnetic field for light and heavy ions acceleration.” In: Proceedings of the 8th European Particle Accelerator Conference, 3-7 June 2002, Paris, p.p 2349-2351

Copyright © 2011 by the respective authors — cc Creative Commons Attribution 3.0 (CC BY 3.0)