PRELIMINARY STRUCTURE DESIGN OF THE MAIN MAGNET FOR THE 100MEV CYCLOTRON

Chengjie Chu, Junqing Zhong, Tianjue Zhang, Zhiguo Yin,
Jiansheng Xing, Jianjun Yang Shigang Hou,
China Institute of Atomic Energy
P.O.Box 275-3, Beijing 102413, China

Abstract

This paper presents the preliminary design of the 100MeV compact cyclotron main magnet for the BRIF Project in CIAE. Several structures of the main magnet, the electromagnetic force calculation and the deformation of the magnet will be described.

INTRODUCTION

A 100MeV H^- isochronous cyclotron is being designed in CIAE. This isochronous machine will provide 75MeV-100MeV, 200µA-500µA proton beam for various applications with a fixed magnetic field and a fixed RF frequency. The magnet is 2.64m in height and 6.4m in diameter. The structure of the main body is shown in Fig.1

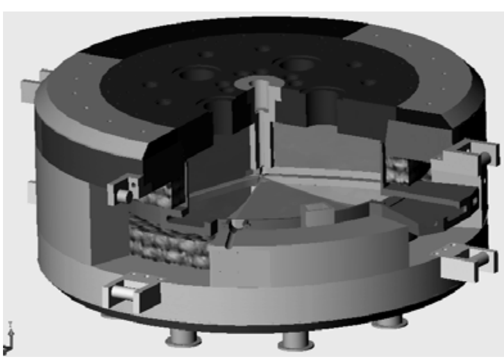


Figure 1. Magnetic structure of CIAE-100

The main magnet deformation is one of the most important factors to influence the magnetic field stability. Magnetic field force, magnet gravity and air pressure, could change the magnet pole gap both in shape and in dimensions, which will influence the field distribution in the accelerating gap and accordingly the motion of the beam current. This paper focuses on the mechanical structure and the deformation of the magnet.

MAIN MAGNET STRUCTURE

At the stage of physical design, there are several possible ways to construct the main magnet system. For the lid and magnetic pole, they all can be designed as one piece or a combined structure.

The structure of one piece lid is shown in Fig.2. The advantage of this kind of lid is that its rigidity is quite good and it can easily guarantee the precision when processed. The disadvantage is that its dimension and weight are relatively large so that the roughcast is hard to manufacture. Additional to this, its transportation and hoisting become more difficult.

The combined structure of lid is shown in Fig.3. The advantage is that its dimensions and weight for each piece are relatively small, and it is easy to guarantee the quality of the roughcast. Besides, there will be no difficulty to deal with the transportation and hoisting. The disadvantage is that the precision requirement for each piece is hard to meet and it will bring much "imperfection" because bolts are used for jointing.

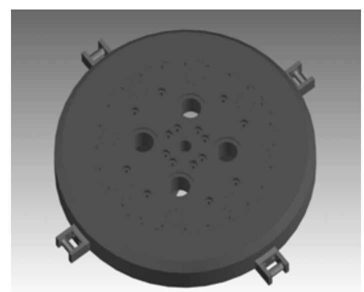


Figure 2. The structure of the one piece lid

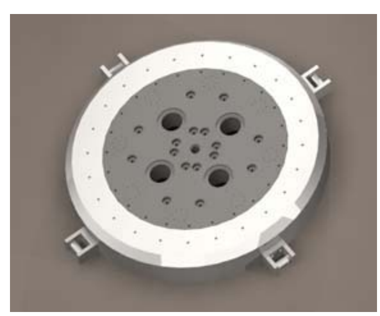


Figure 3. The structure of the combined lid

The structure of the magnetic pole in one piece is shown in Fig.4. It is connected to the lid through bolts. Its advantage is that the integral precision is easy to meet. However, the dimensions and weight for each piece is relatively large and it will be difficult in assembling if the magnetic pole needs to be modified.

The structure of the combined magnetic pole is shown in Fig.5. It is connected to the lid through bolts. Its advantage is that the dimension and weight for each piece is relatively small. In case the magnetic pole needs to be modified, it needs only dismount the thin magnetic pole. Despite the advantage, using bolts for joining two parts together will bring much "imperfection" near the median plane, which will result in the variation of the relevant magnetic field. In that case, precision control is required.

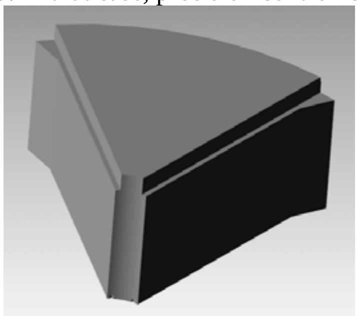


Figure 4. The structure of the one piece magnetic pole

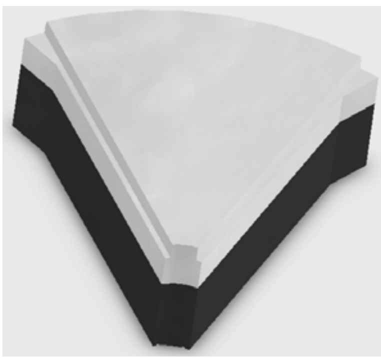


Figure 5. The structure of the combined magnetic pole

The combination of the two basic structures and their variation lead to different structures of the main magnet. They are shown in Fig.6 respectively.

NUMERICAL CALCULATION OF MAGNETIC FIELD FORCE IN MAXWELL STRESS TENSOR METHOD

In physical design of the CYCIAE-100 cyclotron main magnet, we got a fairly satisfactory result of the magnetic field distribution in FEA method. The main magnet structure is shown in Fig. 7, including 4 sector poles with 1920mm in radius, 4 yokes with 3100mm at outer radius and 2400mm at inner radius. Hill gap is 40mm. The total weight of the main magnet is about 475 tons, and the weight of the magnet poles is 84 tons. The magnetic field distribution in the median plane of the gap is shown in Fig. 7. The average field in hill region and valley region is 1.3T and 0.1T respectively.

In Maxwell method, the boundary surface is divided into pieces and the local stress on each piece is calculated according to the magnetic field data, then all the local stresses are accumulated to get the total force of the volume.

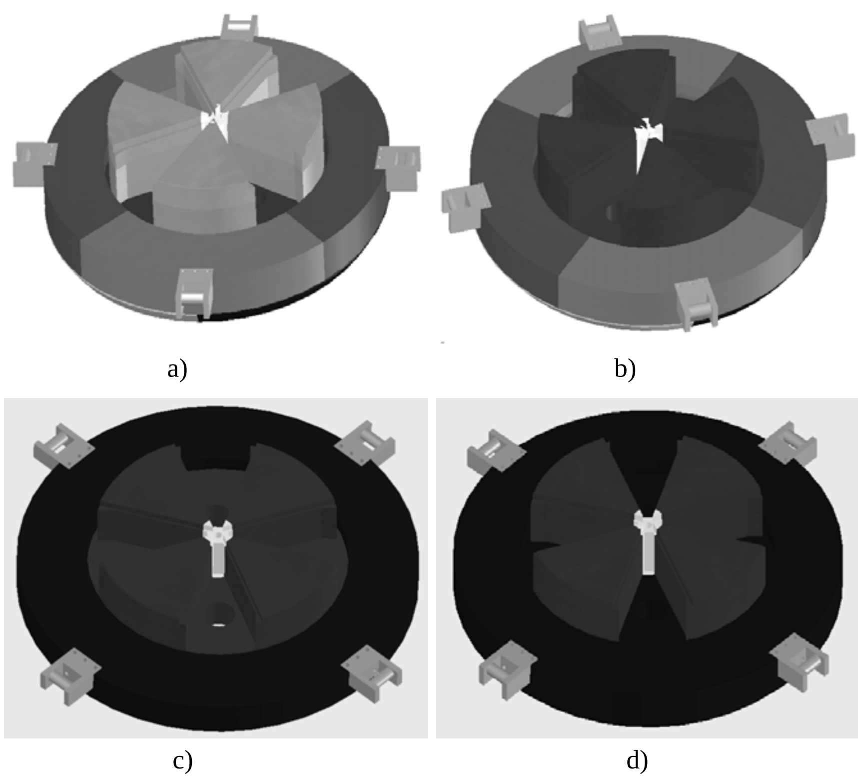
Magnetic force is the volume integration of the magnetic force density vector.

After getting the magnetic force on one pole (shown in Table 1.) through programming, we obtained the magnetic force on the 1/2 main magnet.

Table 1: Magnetic force on one sector

Fx /N	37968.6550
Fy /N	37968.6550
Fz /N	-201679.8474

As is shown above, the vertical magnetic force on one



a) b) c) d)

Figure.6 Several different structures of the main magnet sector is 201680 N, 20.58 tons. So, the magnetic force on the 1/2 main magnet is 82.32 tons.

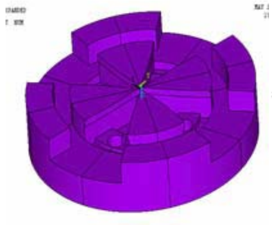


Figure 7. 100MeV Cyclotron 1/2 Frame

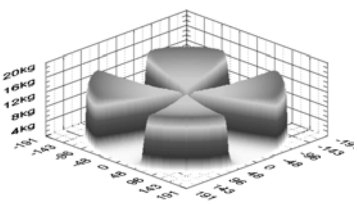


Figure 8. B distribution in the median plane

CALCULATION OF THE MAIN MAGNET DEFORMATION IN WORKING CONDITION

As a result of multi-influence of the magnetic field force, the magnet gravity and the air pressure, the CYCIAE-100 cyclotron main magnet will be deformed, which, therefore, will influence the field distribution in the median plane and the motion of the particles. It is essential to study more on the deformation and its influence on magnetic field.

As the main magnet is symmetric, we only need to build a 90 degree model to simulate the deformation, as is shown in Fig.9. The Young's modulus, Poisson's ratio and density of material are $2*10^{10}$ Pa, 0.3 and 7800kg/m^3 respectively. Acceleration of gravity is 9.8m/s^2, and air pressure is 101285 Pa. The model has been meshed by hexahedron. The total number of the elements is 250,000.

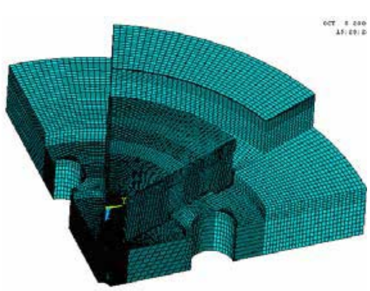


Figure 9. The 90 degree model of the main magnet

On the pole surface, the vertical displacement at points in different angle and radius is shown in Fig.10.

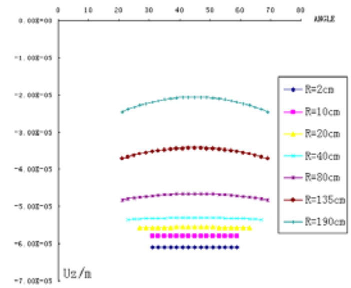


Figure 10. The vertical displacement at points in different angle and radius

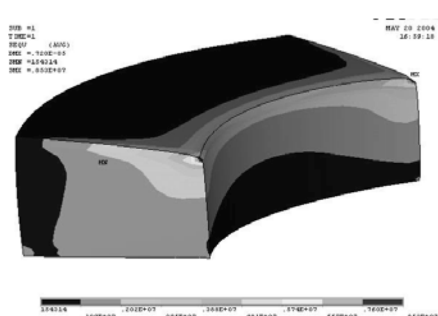
Above calculation could lead to the following conclusions:

- The smaller the radius is, the larger the vertical displacement. In working condition ˘ the maximum vertical displacement is 0.0609mm at the smallest radius and the minimum is 0.02049mm at the largest radius.
- Vertical displacement is symmetrical about the symmetric plane of the sector magnet. The displacement becomes larger from center to border and the trend is more obvious as radius increases, as shown in Fig.10 above. For instance, the displacement is almost the same at radius of 2cm. At radius of 80cm, displacement at the middle point is 0.04653mm and at border is 0.04821mm, the latter is 1.036 times of the former. At radius 190cm, displacement at the middle point is 0.02049mm and at border is 0.02454mm, the latter is 1.198 times of the former.
- At the top of the inner part of the yoke, structural stress and strain are both large, as is shown in Fig.11. As a result, there might yield in some place. The other region is relatively small.

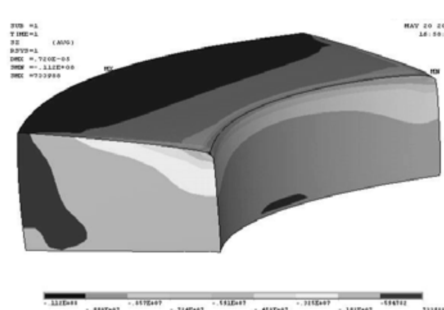
REFERENCES

[1] W.Beeckman, et al.,The C235 IBA-SHI Protontherapy Cyclotron for the NPTC Project Mangetic System Design and Construction,Proceedings of the 14th International Conference,South Africa,1995,p218-221.

[2]Tianjue Zhang, et al., Research Activities Related to Low Energy Accelerators in CIAE, APAC' 2001.



a) Vertical stress distribution on yoke



b) Von Mises stress distribution on yoke

Figure.11 ANSYS output stress