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THE MAGNETIC FIELD DESIGN OF CYCLOTRON AT IMP

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Abstract

A cyclotron magnet is studied at Institute of Modern Physics, Chinese Academy of Sciences (IMP, CAS), and the whole system include one main magnet and other magnetic gradient correctors, which is used to accelerate the Kr^{26+} beam. The structure of superconducting coils and room-temperature iron core are adopted for the main magnet. This paper describes the magnetic field design of the cyclotron, and several shimming methods are used to meet the isochronous magnetic field of Kr^{26+} beam, including pole face shimming method and side shimming method. The final optimization results show that the error between simulation and theory value is small. In addition, the magnet structure is also described.

INTRODUCTION

At present, the activities on the development of isochronous cyclotron are carried out at IMPCAS (Fig. 1). This project includes cyclotron and several beam lines, which intended for obtaining the Kr^{26+} beam to produce nuclear track membrane. The cyclotron magnet has the pole diameter size of 1.64 m and provides the maximum magnetic fields 2.8 T between sectors. Its main parameter is shown in Table 1.

Table1: Main Parameters of the Cyclotron

Parameter	Value
Maximum energy [MeV]	10
Beam species	$^{86}Kr^{26+}$
Number of sectors	4
Ion source	outer
Hill angle [°]	56
Valley angle [°]	34
Max. average Mag. field [T]	2
Harmonic number	4
Magnet aperture [mm]	50-80

The main magnet has a round yoke, four pairs of straight-line sectors. In this paper, we introduce the main magnet with particular emphasis on the isochronous mangetic field design. In addition, we would ensure the cyclotron magnet structure of accordance with the magnetic field calculation.

MAGNETIC FIELD DESIGN AND OPTIMIZATION

The shape of the magnet yoke is optimized by OPERA- 3D magnetic field calculation [1], The OPERA-3D program was used to calculate the three-dimensional field. In the Modeller, the 1/16 model is created according to the symmetry of the magnetic field. Figure 1 shows the geometry of the cyclotron model by the OPERA. Consider with the vacuum and RF systems, there are four holes at the valley centre was designed. Figure 2 shows the radial magnetic field along the “hill” median line at the centre plane. We have been able to obtain a reasonable isochronous magnetic field by some optimization methods.

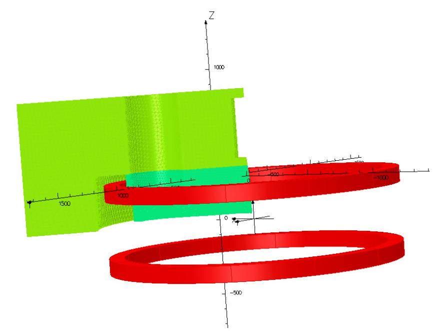

Figure 1: OPERA 3D model.

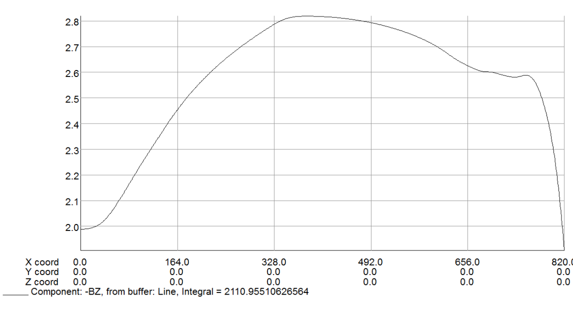

Figure 2: Radial magnetic field distribution.

By successive approximation, cylinder side is optimized as the final shape. In addition, to avoid the rapidly decreasing field in the center region and at the final radius, two special shimming shapes are adopted in these two areas. The optimization structure of sector is shown in Fig. 3. The comparison between the calculation and theory is shown in the Fig. 4, the result shows the deviation does not exceed 10 Gauss 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 away from the resonances, especially the vertical focusing frequency. Figure 5 shows the two focusing frequencies, the vertical focusing frequency is below 0.5 except some points in final radius [2].

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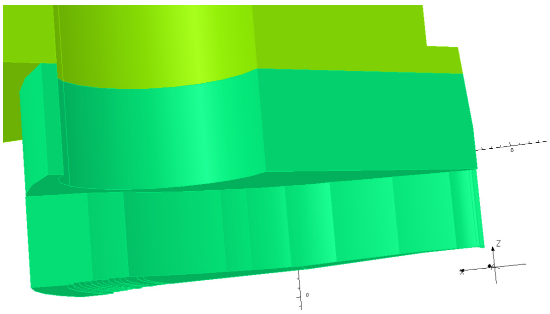

Figure 3: The optimized shape of pole.

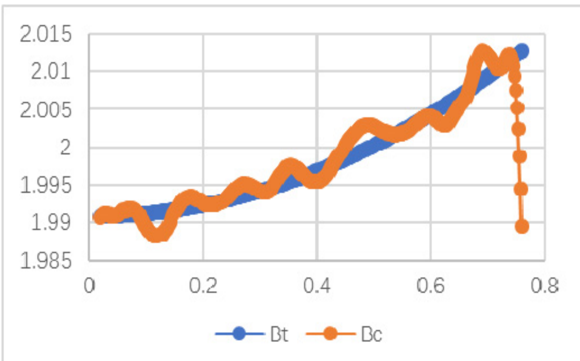

Figure 4: Comparison between calculation and theory values.

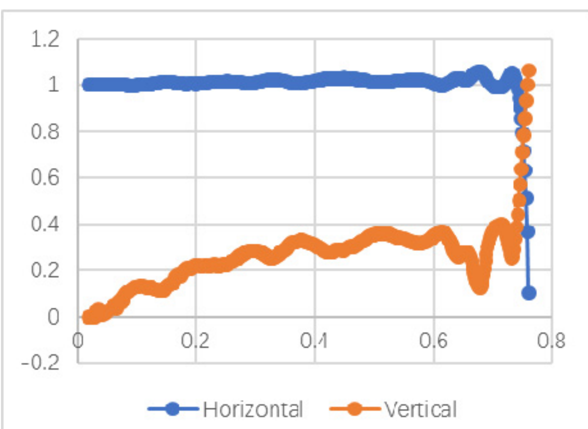

Figure 5: Focusing frequency.

When the optimization of isochronous magnetic field has been finished, the extraction elements need to be designed. Extraction elements such as electrical septum and gradient correctors would be used to extract the Kr beams.

MAGNET STRUCTURE

For the main magnet system, we adopt the structure of superconducting coils and room-temperature iron core. Figure 6 gives the sectional dimension of cyclotron. The outer diameter of cyclotron is 2.98 m, the height is 1.72 m.

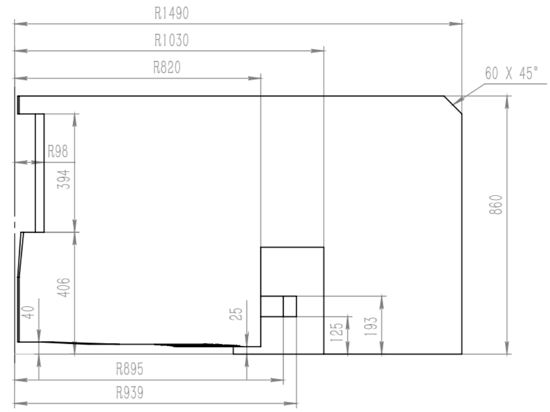

Figure 6: Sectional dimension.

Low carbon steel, electrical pure iron DT4 for the pole and No. 10 Steel for the yoke is the main material of the magnet. The weight of iron core is about 72 t. DT4 is annealed and forged, to improve the material magnetic properties. In the shimming optimization process, the real B-H curves of the magnet material must be taken into account, because different materials, especially the sector material, influence the isochronous field.

Accordance with the basic magnetic field calculation, the total current is 306000 A. The size of coil conductor wires is 1.565×1.040 mm, the critical current@4.2 K is 1200 A (2 T), the ratio of Cu/non-Cu is 5. RRR (273 K/10 K) is 100. Table 2 shows the main parameters of coil system. The superconducting coil is about 0.3 t and the cryogenic system is about 4.7 t.

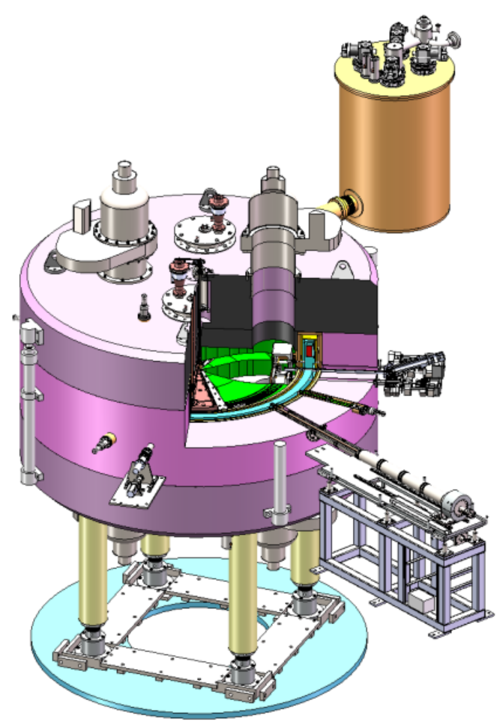

Figure 7: The preliminary structure of cyclotron.

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Table 2: Main Parameters of the Coil System

Item	Value
Number of coils	2
Inner radius of coils	895 mm
Outer radius of coils	939 mm
Height of coils	68 mm
Distance between two coils	250 mm
Design current	243 A
Number of turns	1258
Number of layers	34
Number of per layer	37
Load line	32%

The cryogenic system of superconducting cyclotron consists of two coil windings, two coil cases, thermal shield, outer vacuum vessel, valve box, four two-stage GM cryocoolers which are installed for re-condensing the evaporated helium gas, two single-stage GM cryocoolers which are used for thermal shield cooling, a pair of high temperature superconducting (HTS) current leads, and other auxiliary devices (see Fig. 7). The cryostat for the two sets of superconducting coil windings are separated into upper and lower parts. The circulation of helium between the re-condensing vessel and each coil case is performed by the natural convection.

CONCLUSION

Magnetic field calculation of main magnet for a 10 MeV Kr^{26+} 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. The next step is the optimization of extraction system and cryogenic system.

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