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Magnet design and construction preparation for CYCIAE-100 at CIAE ☆

Tianjue Zhang *, Chengjie Chu, Junqing Zhong, Jianjun Yang, Jiansheng Xing, Yunlong Lu, Sumin Wei, Rongfan Chen, Zhenguo Li, Mingwu Fan

China Institute of Atomic Energy, P.O.Box 275(3), Beijing 102413, PR China

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Abstract

A 100 MeV H-compact cyclotron is being designed in China Institute of Atomic Energy (CIAE). It will provide a 75–100 MeV, 200–500 μA proton beam for various applications, including serving as a driving accelerator for RIB generation. In this paper, the basic magnet structure, 3D numerical simulation, magnetic material, mechanical design, deformation, imperfection field. will be described in detail respectively. In addition the preparation for construction will be discussed.

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Keywords: Cyclotron; Magnet; FEM simulation; Deformation; Imperfection field

1. Introduction

The RIB driving accelerator CYCIAE-100, a 100 MeV H^- compact cyclotron is being designed and constructed at CIAE. This four sectors isochronous cyclotron will provide a 75–100 MeV, 200–500 μA proton beam for various applications. It is a fixed magnetic field, fixed RF frequency machine. Two cavities installed completely into the valleys of the magnet will accelerate beam four times per turn. The magnet is 2.13 m in height and 6.16 m in diameter, the radius of the pole is 2.0 m. The maximum field in the hill sector is 1.35 T. The general view of CYCIAE-100 is shown in Fig. 1. Recently, the basic geometry and its field distribution design were fixed and many engineering aspects were in progress, including the mechanical structure design and construction preparation.

2. Field requirement from beam dynamics

For the original design, because of the installation of RF cavity liner was not taken into account, the hill gap needs to be increased by ∼1 cm (from 5 cm to 6 cm in central region and from 4 cm to ∼5 cm in outer region) compared with the original design [1]. Several adjusted geometries of the main magnet are investigated numerically by our magnet design group and the new magnetic field distribution is provided for beam dynamics study in both acceleration and central region. Obviously, many key parameters of the magnet, such as the profile of hill gap, shimming bar and, central plug, have to be re-designed while the excitation current is adjusted to reach the need of beam dynamics.

If one assumes that the stability of RF frequency is of 1.00×10^{-6}, and permits a ±30° phase shift, the precision requirement of the isochronism can be estimated as 1.03×10^{-4}, because the total turn number is about 390 in this 4th harmonics machine. The limits from the beam dynamics study on the imperfection of the harmonic field from the beam dynamics study are listed in Table 1.

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* Corresponding author. Tel./fax: +86 10 69357341.
E-mail address: tjzhang@iris.ciae.ac.cn (T. Zhang).

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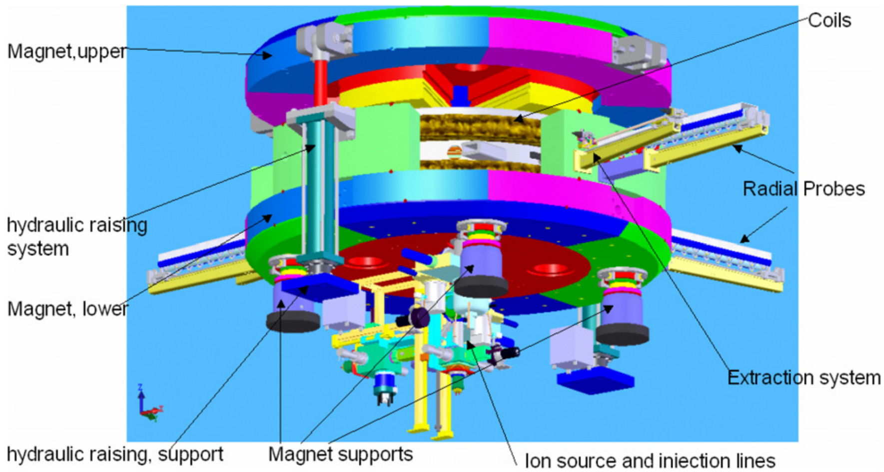


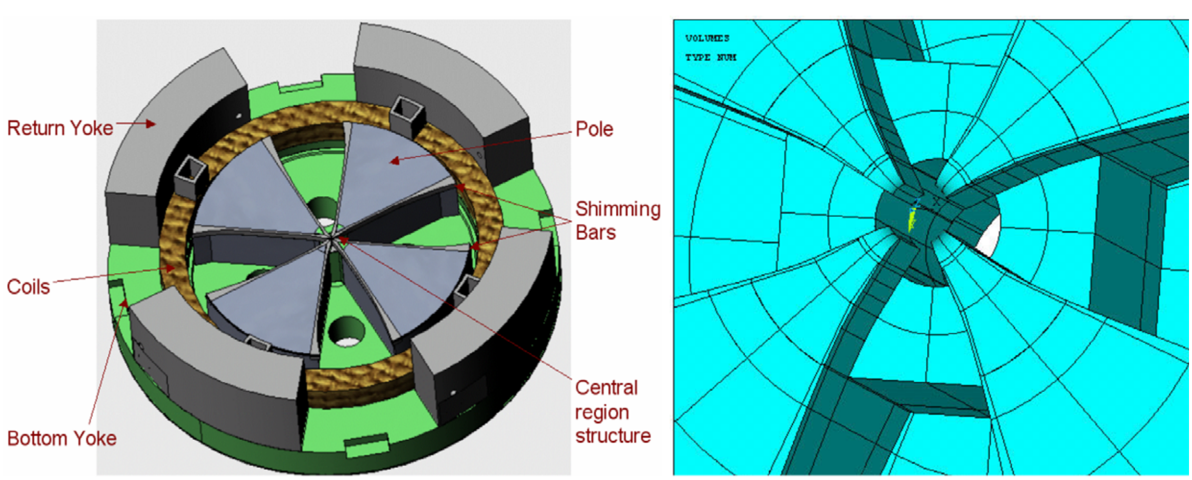
Fig. 1. The general view of CYCIAE-100.

Table 1
The requirement of imperfection harmonic fields

Resonance	Driving term	Field error (G)
$\nu_r = 1$	B_{z1}	2
$2\nu_r = 2$	B_{z2}	40
$2\nu_r = 2$	$\partial B_{z2}/\partial r$	**6**
$2\nu_z = 1$	$\partial B_{z1}/\partial r$	5
$\nu_r = 2\nu_z$	$\frac{\partial \bar{B}_z}{\partial r}, \frac{\partial^2 \bar{B}_z}{\partial^2 r}$	

3. Magnet design and field computation

The Basic geometry of the magnet is shown in Fig. 2. It is a compact, four straight sector magnet. Since the hill gap is increased, the fringe field extends further. As a result, the excitation current and the elliptical surface of hill profile have to be adjusted to get the isochronous field and control the tune diagram. In the meantime the shims at both sides of the poles are reduced to ensure the flutter and produce the isochronous field. Special attention is given to avoid the Walkinshaw resonance in the design of magnet. Compared with the hill gap of the original design, which is 1 cm smaller, the new design has almost the same beam dynamic behavior except that the beam losses by Lorentz stripping are increased from 0.31% to 0.36% of total beam current. The magnet design is based on the 3D FEM simulation [2,3]. The amount of adjustment at any sensitive area of the magnet is relatively small, for a magnet of 6.16 m in dimension and over 400 T in weight, 0.5 mm or even less change in dimension is quite difficult to deal with in the numerical simulation. A special meshing grid is used to improve the precision of the computing data. During the optimization, the following parameters are investigated in great detail and their effects balanced: (1) angle and height of pole, (2) radius of pole (beam loss by em dissociation), (3) displacement of pole with respect to the machine center, (4) profile of hill gap, (5) thickness of top/bottom yoke (field, force and deformation), (6) sizes and positions of opening on the top/bottom yoke for vacuum, trim/center-



(a) The bottom half (b) The Central region structure

Fig. 2. The basic geometry of the magnet. (a) The bottom half; (b) The central region structure.