BEAM OPTICS AND MAGNET DESIGN OF HELIUM ION FFAG ACCELERATOR

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Abstract

In recent years, Fixed Field Alternating Gradient (FFAG) accelerator is becoming a highlight in particle accelerator R&D area. In this paper, the periodic focusing structure model of Helium ion (He^+) FFAG accelerator is being studied to at a lower cost provide He^+ beam with higher beam current than conventional circular accelerator, which could be more useful for the study of the impact of Helium embitterment on fusion reactor envelope material. A large-aperture magnet for He^+ FFAG accelerator is designed by POISSON program and 3D magnetic field simulation code OPERA. The linear and nonlinear beam dynamics is studied through tracking the particle in the magnetic field generated by OPERA-TOSCA.

INTRODUCTION

The macroscopic property of some material will be debased severely, when high density of Helium ion (He^+) is introduced into metallic material, since He^+ is easily captured, gathered and precipitated by reason of fairly low solubility of Helium in metal, coming into being Helium bubbles. This phenomenon is known as Helium embrittlement [1-3] for which the research is one of key researches in the field of nuclear science and technology. The motive for carrying out conceptual study of He^+ FFAG accelerator is to design and construct a small FFAG accelerator in the context of permissive condition, providing He^+ for the study of helium embrittlement.

The initial concept of FFAG accelerator was independently and simultaneously invented by T. Ohkawa in Japan, K. R. Symon in the US and A. A. Kolomensky in the USSR [4], after the principle of the alternating gradient focusing was put forward. FFAG accelerator has some characteristics that are the varying closed orbit, high repetition frequency, large energy acceptance and large dynamic aperture, high density and high output power.

In this paper, the periodic focusing structure model of He^+ FFAG accelerator, scaling FFAG with a triplet focusing lattice (DFD combination) and eight super periods, is proposed in the first chapter. In addition, injection and extraction is simply considered, and as a preliminary planning, He^+ beam with average current 100 μA and average beam power of 1 kW at the top energy of 10 MeV will be extracted in 1 millisecond. In the second chapter, a combined magnet for He^+ FFAG accelerator is designed and optimized by POISSON program and 3D magnetic field simulation code OPERA.

BEAM OPTICS DESIGN OF HELIUM ION FFAG ACCELERATOR

FFAG accelerator with the constant field index is considered to be scaling FFAG in general. The relation between magnetic flux density and magnet geometry radius is given by following formula [5],

$$B_y(r) = B_0\left(\frac{r}{r_0}\right)^k \tag{1}$$

Here, B_0 refers to magnetic flux density for $r = r_0$ in injection momentum, r is the radius from geometric center of the machine, and k is called field index.

In the study of He^+ FFAG, a triplet focusing lattice (DFD combination) is adopted for each cell structure in main ring consisting of 8 cycles and one accelerating cavity. Table 1 summarizes some main parameters of He^+ FFAG accelerator. Fig. 1 gives lattice functions at the injection energy of 0.8 MeV.

Table1: Helium Ion FFAG accelerator main Parameters

Parameters	Design goal
Energy, MeV	0.8 ~ 10
Number of cell	8
Magnet type	Radial section DFD
Field Index k	4.15
Bending angle, deg	F/2 : 30.15 D : 7.65
Average Orbit radius, m	2.458
Average Straight section, m	0.791
Betatron tunes	Horizontal : 2.824 Vertical : 1.254
Max Magnetic field, T	1.300
Repetition Rate, kHz	1
revolution frequency, MHz	0.467 ~ 1.289
Injection Peak Current, mA	20
Injection Beam Emit. rms norm	$0.1\ \pi \cdot \mathrm{mm} \cdot \mathrm{mrad}$
Half Horizontal Beam Size, cm	3.1
Half Vertical Beam Size, cm	2.9

2.45 GHz microwave ion source was preliminarily taken into account as injector, providing He^+ beam with beam current of 20 mA, and the root mean square (rms) emittance also relatively small, about $0.1\ \pi \cdot \mathrm{mm} \cdot \mathrm{mrad}$. He^+ beam with the current 100 μA was initially extracted,

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[#] Graduate student, huanli@mail.ustc.edu.cn which yields the required average beam power of 1 kW at the top energy of 10 MeV.

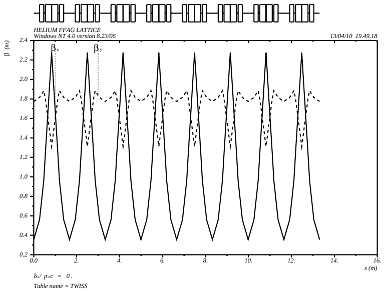

Figure 1: Lattice functions calculated with MAD for Helium Ion FFAG.

MAGNET DESIGN OF HELIUM ION FFAG ACCELERATOR

The triplet combination focusing magnet was designed with help of POISSON program and three-dimensional magnetic field simulation code OPERA-TOSCA. In the magnet type, magnetic field with gradient, satisfying the formula (1), is generated and optimized by adjusting gap distances and coil currents of main iron, to make theory design value of magnetic flux density, field index and the ratio, the ratio of *BL* integral of focusing magnet iron to that of defocusing magnet iron, on magnet median plane, which are given by [6]

$$B_F L(r) = \int_{B_y(r)>0} B_y(r) r d\theta \qquad (2)$$

$$B_D L(r) = \int_{B_y(r)<0} B_y(r) r d\theta \qquad (3)$$

$$F/D = B_F L(r)/B_D L(r) \qquad (4)$$

Table 2 summarizes He^+ FFAG accelerator magnet theory design value. Fig. 2 and Fig. 3 show a cross section view of F magnet, an H-shape magnet designed through 2D POISSON program, and field index changing in radial direction and on median plane. As can be seen from Fig. 3, field index almost remain constant in effective radius within 3.5%.

Table2: He^+ FFAG accelerator magnet main parameters

Parameters	Design goal
Number of cell	8
Bend Magnet type	H type
Opening angle, deg	F/2 : 7.533 D : 5.200
Magnet Aperture, cm	H: 80.000 × V: 9.700
$B_F L$ at r = 2.4579 m , T · m	0.530
$B_D L$ at r = 2.4579 m , T · m	0.135
F/D ratio	3.926

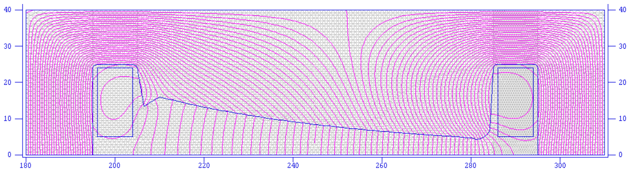

Figure 2: A cross section view of F magnet

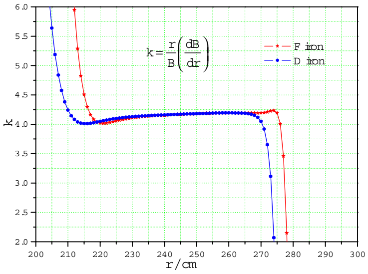

Figure 3: field index changing with radial direction on median plane of F iron and D iron in POISSON program

In accordance with the POISSON design results, 3D magnet model is designed by OPERA-TOSCA. A magnet arrangement in a cell and magnetic flux density on median plane are respectively showed in Fig. 4 and Fig. 5.

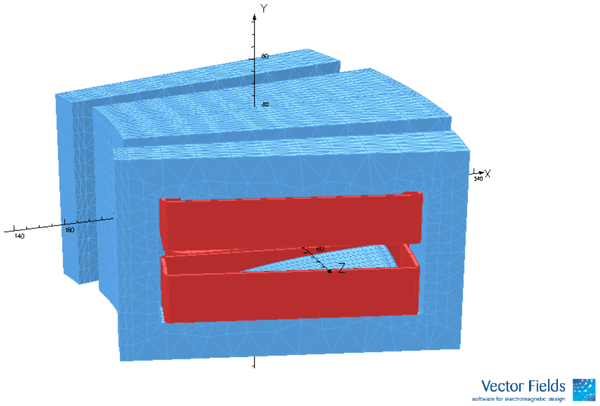

Figure 4: A 3D model view of He^+ FFAG magnet

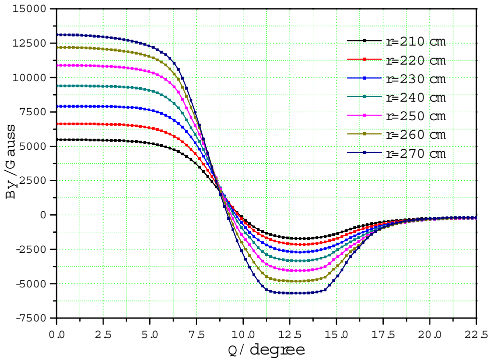

Figure 5: magnetic flux density changing as a function of θ on median plane

However, the complicated fringe effect, magnetic dispersion of the field and field disturbance are caused by the varying gap and big aperture, to study which more jobs are needed, without mature theory of knowledge to be adopted.

SUMMARY

The lattice for He^+ FFAG accelerator is designed respectively via MAD and numerical computation. He^+ FFAG magnet has been designed and optimized by POISSON and OPERA-TOSCA, still more jobs needing to study fringe effect and field disturbance caused by big magnet gap and aperture. Particle tracking for He^+ FFAG by runge-kutta is exercised later on in accordance with magnetic field generated by OPERA-TOSCA, to finish a complete physical design of He^+ FFAG accelerator.

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