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THE DESIGN AND CALCULATION ON THE INJECTION AND CENTRAL REGION FOR CYCIAE-50

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Abstract

A 50 MeV cyclotron is being built at China Institute of Atomic Energy (CYCIAE-50). CYCIAE-50 is a compact H^- cyclotron with the proton beam energy of 30 MeV to 50 MeV and the beam current of 10 μA. A multi-cusp H^- ion source with the beam current of 5 mA will be used for this machine. The design on the injection and central region of CYAIAE-50 has been finished. The way of matching the beam from ion source to central region and the design of central region will be present in this paper. In addition, some significant problems in central region will be discussed, including radial alignment, axial focusing, longitudinal focusing, etc.

INTRODUCTION

A compact H^- cyclotron, CYCIAE-50, is being constructed for Space Science and Applied Research (CSSAR). H^- beams are injected through a spiral deflector with the energy of 30 keV, and extracted by a stripping foil in the range 30 - 50 MeV with the current of 10 μA. There are four straight pole sectors in CYCIAE-50 and the magnetic field in central region is 0.9 T. Forth harmonic acceleration is adopted with two 50 kV, 65.5 MHz cavities in the valleys.

A 30 keV, 5 mA external H^- multi-cusp ion source is adopted, which is the same as the case of CYCIAE-100 [1]. The injection system is very simple design. The H^- beam from the ion source enters the spiral inflector in the center region only through a solenoid. The ion source and the injection beamline are being manufactured. The design procedure and results of central region, spiral inflector and injection line are displayed in this paper.

CENTRAL REGION DESIGN

The following problems should be concerned for the central region designs:

- Central region must fit the structures of RF cavities and shimming bars.
- Beams should pass through electrodes from their center line.
- Good axial focussing and radial centering.

CYCLONE is a particle tracking code especially fitting the calculation in central region. The magnet field is got from finite element method program [2] and the 3D electric potential map can be obtained from code of RELAX3D [3]. When we design central region, we usually adjust electrode structure and sometimes shimming bars if necessary.

The process of central region design is shown as follows:

- According to the magnetic field, RF cavities, shimming bars and injection energy, the central region will be designed, partly referring to the design of cyclotrons at CIAE [4-8].
- Finding the reference particle in accelerating region by orbit tracking, who needs the least turn to be accelerated to 50 MeV and has the least amplitude of radial oscillation.
- Tracking reference particle backwards to injection point, by which optimizing electrode structure.
- Tracking multiparticle from injection to extraction and optimizing electrode structure until getting a good beam dynamical result.

The Electrode structure, electric field distribution and particles' trajectory in central region are shown in Fig. 1. Central rays within ±20° phase width is tracked, whose phase history is shown in Fig. 2 and radial misalignment is shown in Fig. 3. It needs 272 turns for the reference particle from 30 keV to 50 MeV and less than 279 turns for particles within ±20° phase width. As shown in Fig. 2, the 40° phase width is compressed to 25° in central region. The amplitudes of radial oscillation around static equilibrium orbit (SEO) are less than 1.5 mm.

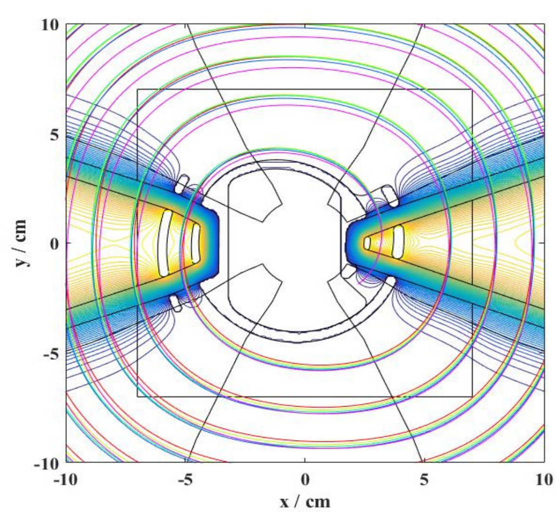

Figure 1: Electrode structure, electric field and particles' trajectory in central region.

The vertical focussing includes magnetic focussing and electric focussing. Vertical electric focussing plays an important role at low energy, which depends on electrode structure and the phase of particles [9].

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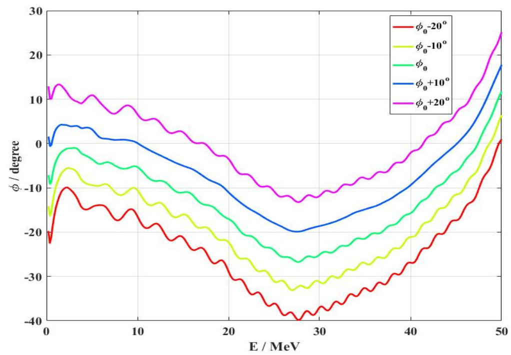

Figure 2: Phase history of central rays within ±20° phase width.

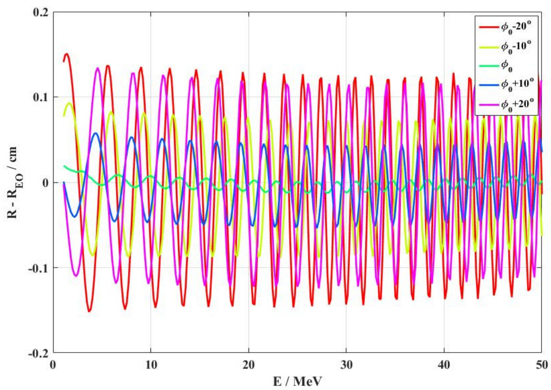

Figure 3: Radial misalignment of central rays within ±20° phase width.

Figure 4 gives the results of tracking particles with different phase and axial coordinates. The top one is particles start at $z = 1$ mm and the bottom one is particles start at $p_z = 1$ mm. We can see that positive phases leads a bigger v_z in central region.

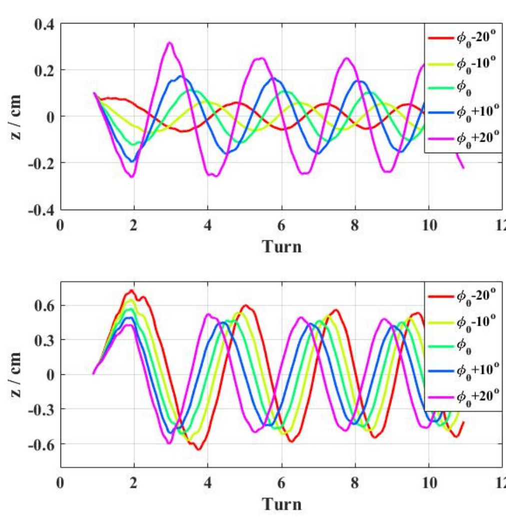

Figure 4: Axial motion of particles with different starting RF phase. (The top one for the starting particles at $z = 1$ mm and the bottom one for the starting particles at $p_z = 1$ mm).

INFLECTOR DESIGN

After finishing central region design, the orbit of reference particle is obtained. Inflector design needs the coordinates of inflector's central particle closely to the reference particle at the exit of spiral inflector. The simulation was done by program CASINO [10] and INFLECTOR [11]. Table 1 shows some main parameters of inflector. Figure 5 shows the surface of inflector electrodes and the trajectory of central particle.

Table 1: Main Parameters of Inflector

Parameter(unit)	Value	Unit
Injection energy	30	keV
Electric bend radius	32	mm
Tilt parameter	-0.75	
Electrode spacing	8	mm
Electrode width	16	mm
Voltage	12.60	kV
Matching point θ	313.23	°
Matching point R	2.81	cm
Matching point P_R	0.61	cm

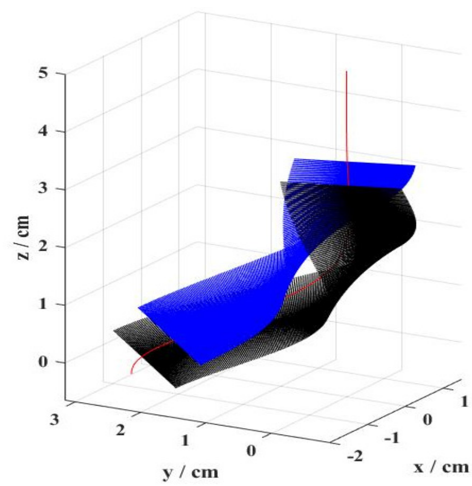

Figure 5: The surface of inflector electrodes and the trajectory of central particle.

INJECTION LINE DESIGN

As shown in Fig. 6, the injection line is about 1.4 m, which consists of ion source, vacuum chamber, x-y steering, solenoid and spiral inflector. The DC beam is injected from the ion source which is upper the magnet of the cyclotron. The solenoid has a effective length of 35 cm with a field of 1.9 kG. The transfer matrix of spiral inflector is calculated by orbit tracking. The ion source provides a 5 mA beam, whose normalized emittance is 0.4 π·mm·mrad [12]. A more than 10^{-4} Pa vacuum makes the 95% neutralization achieved [13]. The parameters of the ion source and injection beamline are shown in Table 2 and the beam size (FWHM) is shown in Table 3.

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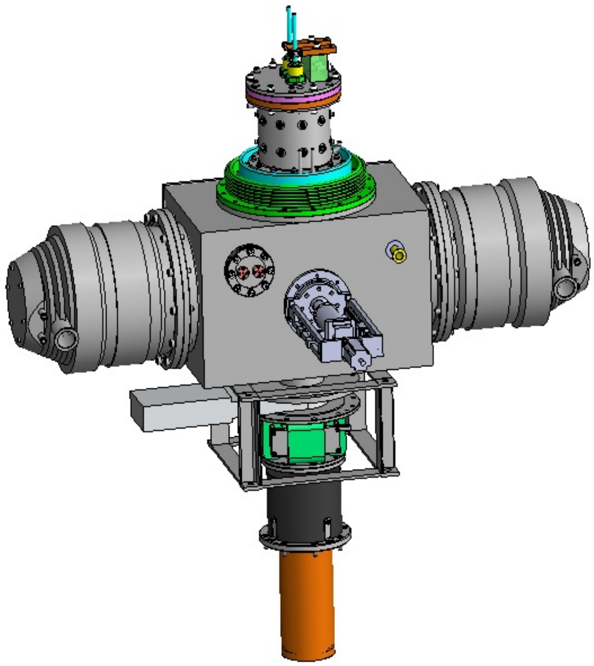

Figure 6: Injection line of CYCIAE-50.

Table 2: The Parameters of the Ion Source and Injection Beamline

Parameter	**Value**	**Unit**
Beam energy	30	keV
Normalized emittance	0.4	π·mm·mrad
Beam current	5	mA
Inflector voltage	±10	kV
Injection beamline	~1.4	m
Inflector gap	8	mm

Table 3: Beam Parameters in the CYCIAE-50 Beam Line

Position	x **[mm]**	x' **[mrad]**	y **[mm]**	y' **[mrad]**
Exit of ion source	4.0	22.0	4.0	22.0
Entrance of inflector	1.0	50.9	1.0	50.9
Exit of inflector	2.4	55.7	1.2	41.6

CONCLUSION

All the calculation and simulation on the injection system has been finished for CYCIAE-50. The central region design results are described in detail in this paper. From the calculation, the beam is well centered and more than 40° RF phase width can be accepted. Spiral inflector is designed to match the injection point and reference particle in central region. The beam line from ion source to central region is matched with a 5 mA, 0.4 π·mm·mrad H^- beam. The main parts of the cyclotron such as the main magnet are being manufactured now. The final structure of the central region will be fixed after finishing the magnet filed measurement and shimming. Beam commissioning is expected to be done at the end of the next year.

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