DESIGN STUDY OF COMPACT CYCLOTRON FOR INJECTION K=100 SSC*

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Abstract

The Compact cyclotron was designed for injection of K=100 Separated-Sector-Cyclotron (SSC) [1]. It has four magnet sectors with pancake type and maximum magnetic field is 1.92T. The magnet adopting 4 harmonics has three kinds of holes for beam injection, vacuum pumps and RF systems. The pole diameter was chosen about 80 cm with 50kV dee-voltage and 40˚dee-angles. The Injection system of this accelerator consists of a double gap buncher, Solenoid-Qaudrupole-Qaudrupole (SQQ) and a spiral inflector. It will provide a 4~8 MeV, ~1 mA of proton beams and 2~4 MeV, ~0.5mA of deuteron ion beam. In this paper we will describe the conceptual design of this machine including the design of Ion-source, Injection system, Magnet and RF system.

INTRODUCTION

In this research, we designed a cyclotron which can produce beam more than 1mA with relatively small energy, 8MeV. General specifications of this cyclotron are shown at Table 1. The particle of negative hydrogen is accelerated, in the end of the procedure it generates proton beam through a carbon stripper. The H- ion created from ion source runs into the injection system and is accelerated to 8MeV at the middle plane of upper and lower magnet poles. After this acceleration it is ejected to outside by drawn system. For the higher beam current the multicusp ion source of volume type is used and the injection system make DC beam have pulse type to have same phase with RF system. The magnet is designed to produce isochronous magnetic field by shimming and RF system is considered for easily occurring a resonance near 74.3MHz.These process supported by MicroWaveStudio(MWS)[2] andOPERA-3D TOSCA[3].

ION SOURCE

The high intensity and improved TRIUMF type DC Volume-Cusp H^- ion source is used for source of beam. It consists of three major parts: body assembly, lens assembly and vacuum box assembly. Lenses are plasma lens (first electrode) and extraction lens (second electrode) with magnet filter to remove the extracted electron and re-enter beam. Vacuum box is the third electrode and it consists of steering magnet for plasma confinement.

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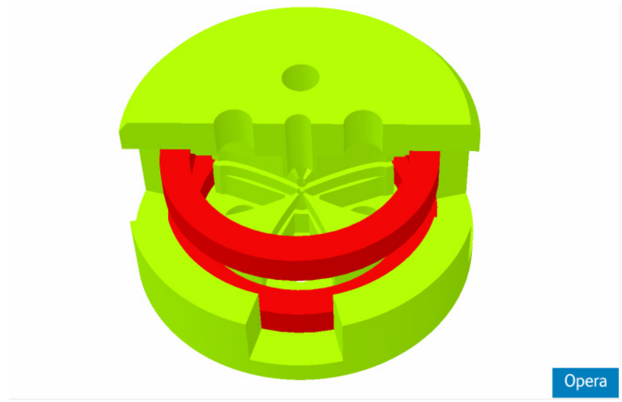


Figure 1:Model of magnet system and main coils.

Table 1: Specifications of 8MeV Cyclotron

Parameters		Values
Ionsource	Multi-cusp DC Type	
	Max. Extracted Beam Current	15mA
	Max. Arc Volt.	150V
	Type of Extracted Ion	H-, D-
Injector System	Buncher Max. E-potential	200 V
	Solenoid-Q doublet OP. power	35kW
	Inflectorelectrode potential	±10 kV
Magnet	Pole/Extraction Radius	0.4m / 0.35m
	Diameter	0.8 m
	Hill Angle	48˚
	Center field	1.15T
	Max./min B field	0.3T / 1.95T
RF System	Frequency/ Harmonics Number	74.3MHz/4th
	Dee Number/Dee angles	2 /40˚
	Dee Voltage/Q-value	50kV/5981

The 15mA H^- beam is extracted with a measured emittance of about 0.860 mm mrad. Beam kinetic energy is about 20 to 30 keV because of bias supply voltage (28 keV).

Filament current is about from 230A to 340A for the ionizing. The ion source is filled with hydrogen gas. When the filament current flows, the thermal electron is extracted from filament. This extracted thermal electron is accelerated to the cusp-body. In this situation thermal electrons are collided with cusp-body's hydrogen and generate H^- ions because of 150V arc voltage. The Ion-source is identical to TRIUMF one. [4]

INJECTION SYSTEM

Designed injection system consists of Double gap buncher, faraday cup, Solenoid-Q doublet lens andspiral inflector.The Beam pass along the way in the same order as above and the faraday cup plays ion particle detector.[5]

Buncher

The aim of Buncher is bunching of negative hydrogen from ion-source.It is composed of RF signal generator, RF amplifier, RF matching circuit, double gap buncher andfrequency tuner.Maximum electric potential at the centre pole is 200 V. Distance between gap is 18.7mm which is calculated by $(\beta \cdot \lambda)/2$.When the DC negative hydrogen beam incident into buncher, the energy distribution of ions is formed by double gap and then it becomes a kind of bunch shape with condensation and rarefaction of ion at specific distance by the difference of energy.

Solenoid-Q doublet

Solenoid-Q doublet is located at the centre hole of upper magnet yoke.Solenoid lens is used to convert the rapid magnetic field variation to gradual one. Spiral inflector acceptsreasonable beam size and transverse distribution by Q-doublet lens. The Maximum beam size in SQQ occurs at the centre of solenoid along the axial direction.

Spiral Inflector

To inject the pulsed beam which given in the magnetic field along the SQQ located at the upperyoke of magnet in horizontal orbit plane, we use spiral inflector. It is the main factor that minimizing distortion and loss of quantity with safe arrival in the middle plane including proper matching when the beam change its orbit.[6] Designed spiral inflector has 20 cm E-field radius and k'=0. Injected energy at the entrance of inflector is 24 keV.

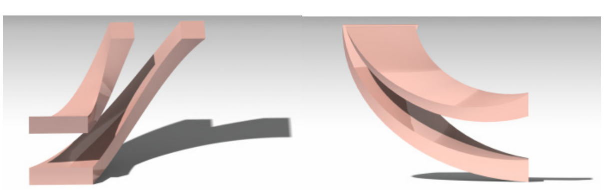


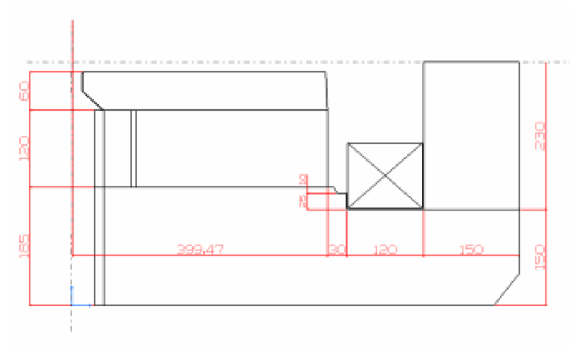
Figure 2: Spiral Inflector design using 3D CAD

MAGNET

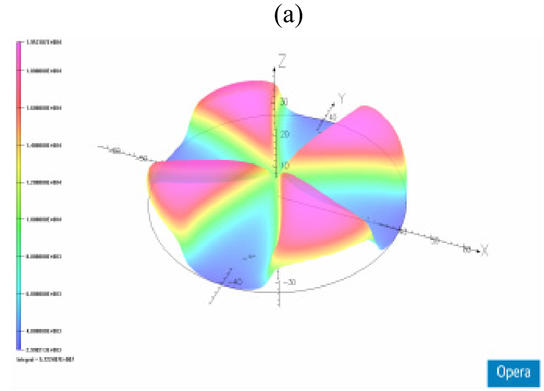
Magnet using normal conductor with 4 sectors was designed for the radius of whole magnet and pole is 0.7m and 0.4m, respectively. The upper and bottom yokes have a two holes at each valley so that totally 4 holes are there and those are used for vacuum and RF system. The value of maximum field on the mid-plane is 1.95T while central region has 1.15T.

Fig.3 shows a longitudinal drawing and magnetic field characteristics of magnet of 8 MeV Cyclotron. To produce isochronous field, three stageswere weredone in this study. At First we define parameters such the kinds of like harmonic number and RF frequency. And then gamma value, magnetic rigidity at maximum beam energy and extraction radius was calculated. After the mathematical work, 3D CAD drawing with CATIA P3 v5 r18[6] and field simulation with OPERA-3D TOSCA were done.

In the central region the magnetic field decreases slightly with increasing radius and to make isochronous field shimming process and the method that changing hill-valley ratio along the azimuthal direction were used.[7]The average magnetic fields and radial and axial beam tunes of magnet were shown in Fig.4.

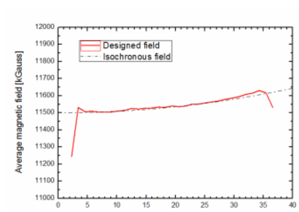


(a)



(b)

Figure 3: A longitudinal drawing (a) and Magnetic field characteristics (b) of 8 MeV cyclotron.



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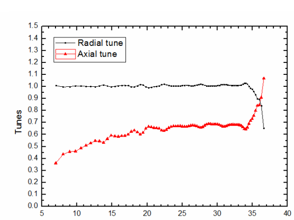
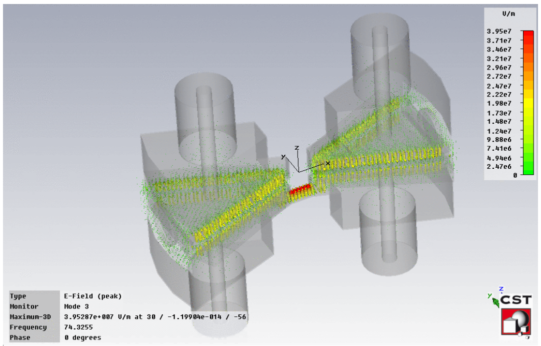


(b)

Figure 4: Average magnetic field of magnet with idle isochronous field (a) and radial and axial beam tunes of



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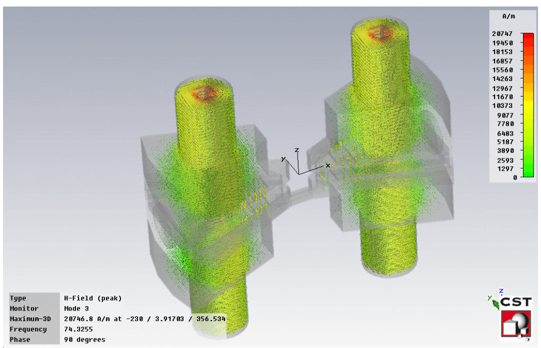

(b)

Figure 6: Electric field distribution (a) and Magnetic field distribution (b) of 8 MeV cyclotron magnet.

RF SYSTEM

H- particles exposed to middle plane through inflector run into an acceleration by Dee-voltage of 50KeV. These particles get there energy from resonance of 70MHz cavity frequency and are emitted with 8MeV energy from final extraction stage.

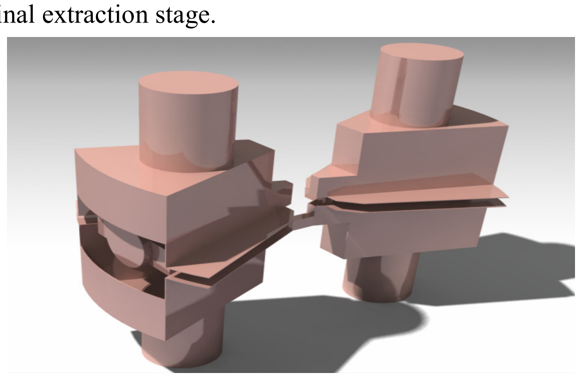

Figure 5: Cavity design using 3D CAD

A resonator mode of λ/2 is used in designed RF system. The sum of length of two Dees and four stems is roughly 2.15m which almost correspond with the half of wavelength of 70MHz. There was an adjustment through stem because of lack of space with magnet. The material for RF cavity is OFHC having better electrical conductivity ($5.91\times\frac{10^7 s}{m}$) than normal cupper.

Once the diameter was decided to 4 cm by repeating process using CST-MWS code, the Q value of RF resonator with same code was 5981.

CONCLUSION

We designed ion source, injection system, magnet and RF system of cyclotron as injector for K=100 SSC. To guarantee 1mA beam current, ion source produces a beam with more than 10mA and that supposed to be reached in orbit plane through spiral inflector. The magnet and RF system are designed for extraction of particles accelerated by 8MeV.

Based on this design, we will compose extraction and transporting system according to main cyclotron. This K=100 cyclotron will be able to accelerate particles up to 74.3MeV with the designed 8MeV cyclotron.

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