H- CUSP SOURCE, INJECTION LINE AND CENTRAL REGION FOR 100 MeV COMPACT CYCLOTRON AT CIAE[1]

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Abstract

A 100 MeV H- cyclotron is being designed in China Institute of Atomic Energy(CIAE) now. It will provide a 75 MeV - 100 MeV, 200 µA - 500 µA proton beam for various applications, including serving as a driving accelerator for RIB generation. Due to the limit of acceptance by the cyclotron central region, a new H- cusp source was developed at CIAE. More than 10 mA of H- beam with a measured emittance of 0.65 pi mm mrad are obtained at a voltage of 28 kV from an extraction hole of 11 mm in diameter. In this paper, the design aspect of the axial transportation line for high intensity beam injection, the inflector and central region will be also described respectively.

INTRODUCTION

As a part of the project BRIF, Beijing Radioactive Ion-beam Facility[1], a 100 MeV compact cyclotron was designed to provide 75 MeV ~ 100 MeV, 200 µA ~ 500 µA proton beams for various applications, including serving as a driving accelerator for RIB generation. A compact magnet and H^- acceleration with stripping extraction was opted so as to make the machine smaller and cheaper. It is a fix field, four sectors cyclotron. The magnet is 2.64 m high and 6.4 m in diameter. Two cavities installed into the valleys of the magnet will accelerate beam 4 times per turn. In such kind of machine, the bright external source and high efficiency injection system become one of the bottleneck problems for intense beam generation. The preliminary design and some R&D about the H^- source, injection line and central region are investigated and will be described in this paper.

H^- CUSP SOURCE

As part of the cyclotron Research and Development effort, a test stand was set up in 1997 to study the H^- cusp source and axial injection. In 2000, 5.2 mA of H^- beam with a normalized emittance ~0.65 π mm mrad were extracted and transported to the inlet of an inflector in the central region of the cycltron with trasmission better than 80%. To get higher beam intensity and keep the emittance within the desired value from the cyclotron design, a new cusp source had been developed based on TRIUMF's experience[2] since 2002.

Design Features of Cusp Source

The source assembly consists of a tubular plasma chamber (inner diameter: 98 mm; length: 150 mm) with 10 columns of permanent magnets to provide a multi-cusp field and serve as a virtual filter, a three electrode extraction system, a top cover with a confinement magnet inside and a pair of electrical feed throughs for single or double filament installation. In the extraction system, there is a pair of small permanent magnets embedded in the extractor for electron filtration and a compact electric magnet ring enclosed on the ground electrode for x-y steering of the beam. A picture of the source is shown in Figure 1.

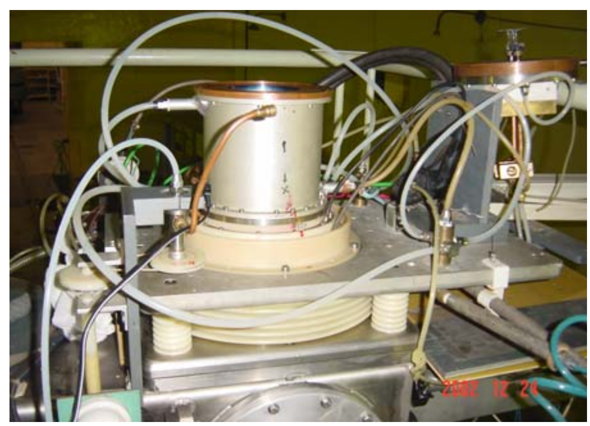

Figure 1: The H^- source

Experiment Setup and Test Results

The new cusp source was fabricated in August of 2002 and all related power supplies for the test stand have been upgraded to meet the requirements of increased beam current. The cooling water system was also modified to improve cooling on key parts of the ion source, e.g. filament stems, cavity wall, extractor and ground electrodes.

The following work has been done during the beam test: different filament materials (Ta and W) and shapes (single arch and multiple ring) were tried, the relation between dimension of extraction outlet and beam

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intensity was measured, the electron filter magnetic field was optimized, and initial tests of the effects of vacuum and electric parameters on beam performance were made. When the single arch shape filament was used, 11 mA of H^- beam with a normalized emittance ~0.65 π-mm-mrad was extracted. Table 1 gives the relationship between the dimension of the extraction hole and beam profile. It was measured by a specially designed Faraday cup ~35 mm downstream from the outlet of the source. The extracted beam stability is shown in Figure 2.

Table 1: Beam Profile Vs Dimension of Extraction Hole

Extraction hole, D (mm)	Beam intensity, I (m A)	Width of profile at 10% height (mm)
6.0	3.5	8.0
8.0	6.4	7.4
10.0	9.3	6.6
11.0	11.0	8.7

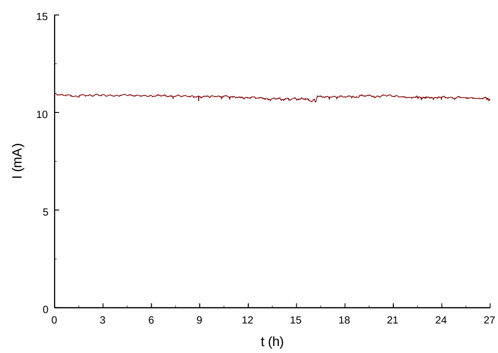

Figure 2: The extracted beam stability of H^- cusp source

INJECTION LINE

From our operation experience of the 30 MeV cyclotron, we know ES system is able to control effectively the envelope during beam injection. However, as the beam intensity increasing, the envelope becomes bigger and the emittance is deteriorated. So as to inject intense beam into the spiral inflector with an inlet of 8 mm x 16 mm, adjusting of ε_x and ε_y is necessary to match the acceptance of cyclotron central region better. The TRIUMF's experience[3] shows us that the SQQ[4] (Solenoid and Doublet) system has a high beam handling capability. It suggests us to modify the injection line to ESQQ (Einzell Lens, Solenoid and Doublet) system.

Simulation

The simulation started from the old layout based on the ES (Einzell Lens and Solenoid) system in CIAE's 30 MeV machine and SQQ system (Solenoid and doublet) in TRIUMF's machine, shows that a ESQQ system should be able to match the injection optics better for higher intensity beam injection. The thin lens is used as an equivalent of Einzell Lens so as to use TRACE 3-D[5] for this simulation.

In order to inject the 10 mA H^- beam with a normalized emittance of ~0.65 π-mm-mrad, energy of ~28 keV just got from CIAE's cusp source into the cyclotron central region, the code TRACE 3-D is used to calculate the injection optics of a bunched beam by the 100 MeV cyclotron's RF frequency of 50 MHz. The beam intensity of 0 mA, 0.5 mA, 1.0 mA and 1.5 mA are used for the simulation of space-charge forces linearly through the whole line. It means that we consider a 10 mA injected beam with different neutralization rate of 100%, 95%, 90% and 85% in average or with a fix rate of 90% but the beam increasing from 0 mA, 5 mA, 10 mA to 15 mA. For the ESQQ system, just downstream of the ground electrode of the source, there is an Einzell Lens used. A double gap ($1/2\,\beta\lambda$) buncher is set right outside the cyclotron magnet. A Faraday cup for intensity and profile measurement and an isolating valve are installed in both side of the buncher. The half height of the cyclotron magnet is 1.32 m. The Solenoid and doublet are put inside the magnet axially. The layout of injection line for 100 MeV cyclotron is given in figure 3.

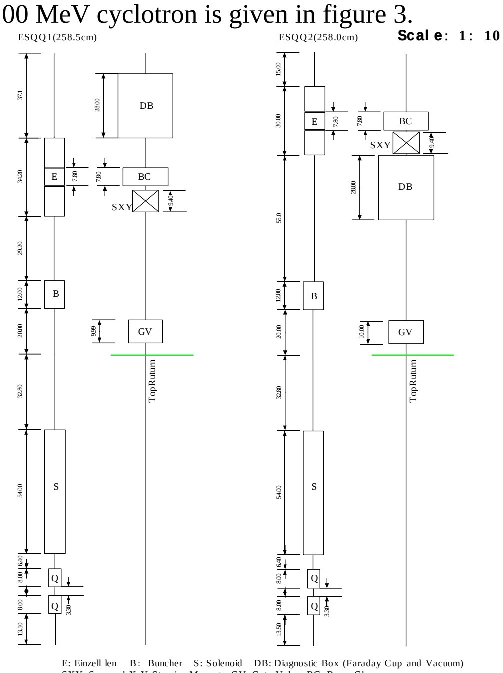

Figure 3: The layout of injection line

Results Discussion and Test Stand

The simulation results from ES, EQQS and ESQQ system for various beam intensities, 0 mA, 0.5 mA, 1.0 mA and 1.5 mA show us that ES and EQQS is difficult to control the envelope effectively though a wide range of electric parameters are tried during the simulation if the calculated beam intensity is over 1.0 mA. For ESQQ system, its result from 1.5 mA calculation shows that the injected beam is under well control. The main parameters are list as: beam spot at the inlet of inflector is $2.51mm \times 3.56mm$, the maximum envelope is 28.9 mm, and the bunched beam is in 32×1.87 Deg.keV when the initial longitudinal phase-space is 36 Deg with energy spread 50 eV. So, the Dee tips design for first tune in the central region is become more important for high intensity injection since we need to select the suitable phase for acceleration from the bunched beam in this case.

For a flexible arrangement of the injection line during the experimental study, S and QQ, which will be installed inside the cyclotron magnet, are carefully design by 3D FEM code. Both of them have the same inner diameter of 60 mm and outer diameter of 118 mm. A test stand shown in figure 6 for H^- source and injection line is set up for the transmission test. The performance of ES, EQQS and ESQQ will be investigated on this stand and the final result will be selected for the detail design of 100 MeV cyclotron.

CENTRAL REGION

The design of spiral inflector and central region is in progress. The magnet structure at the central region is being modified to adjust the field distribution at the central region. The average field in the central region is shown in Figure 4.

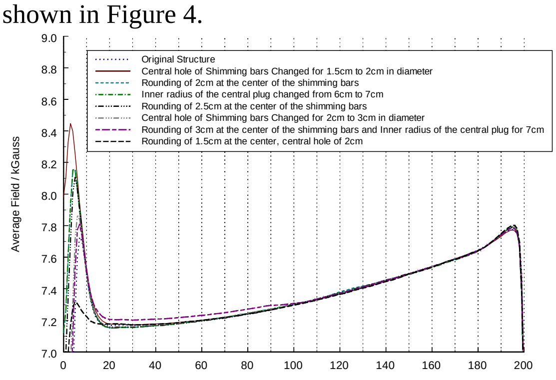

Figure 4: Average field adjusting for central region design

Spiral Inflector

The spiral inflector, shown in figure 5, is calculated by the code CASINO[6]. Its parameters are given in table 2.

Table 2: Parameters of Spiral Inflector

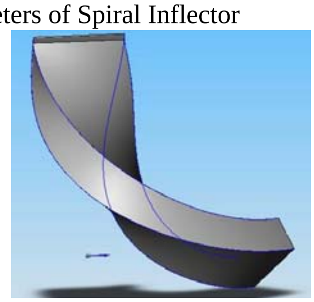

Figure 5: The spiral infjector

Height of the spiral inflector	4.0 cm
Magnetic radius, Rm	3.969 cm
Electric radius, A	4.172 cm
k’	-0.77

Central Region

From the outlet of the spiral inflector, orbit tracking is done by CIAE’s code CYCCEN and TRIUMF’s code CYCLONE[7]. The result is illustrated in figure 6 and figure 7. The shape of electrodes and the magnetic field should be adjusted further to get a better beam from the central region. And phase selectors will be used to select ±20° of RF phase from 65° shown in figure 6.

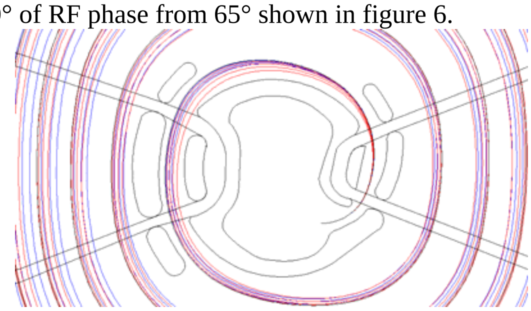

Figure 7: The geometry of central region and the orbit with RF phase width of 65°

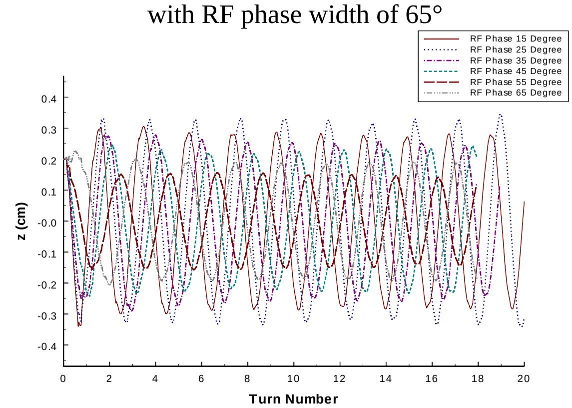

Figure 8: The vertical envelop of the injected beam with RF phase width of 50° at the first 20 turns

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