BEAM INJECTION SYSTEM OF THE KOLKATA SUPERCONDUCTING CYCLOTRON

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Abstract

In this paper the design of injection beam transport line and the related beam dynamical issues in the injection system of the Kolkata superconducting cyclotron will be discussed. Two ECR ion sources of frequency 14.4 GHz will provide low energy beam for the cyclotron. Horizontal beam transport lines from each of the sources merge to a common horizontal beam line. Then a 90° bending magnet bends the beam in the vertical beam transport line for axial injection in to the cyclotron. Four quadrupoles will be used in the common horizontal line for beam matching and a sinusoidal double drift buncher will be used. An electrostatic spiral inflector will be used to feed the beam in to the acceleration plane at the cyclotron central region. We discuss the beam dynamical issues governing the design of the spiral inflector and the injection system through the axial hole of the cyclotron. In the design calculations maximum beam rigidity 0.058 T-m and emittance 100 π-mm-mrad have been considered. The central region has been designed for 1st harmonic mode of operation.

INTRODUCTION

The low energy beam line for coupling two ECR Ion sources to the superconducting cyclotron is being installed at present. The layout of horizontal part of the beam line, starting from two ECRISs to the centre of the cyclotron, is shown in figure 1. That of the vertical part is shown in figure 2. For beam optics calculation the computer code TRANSPORT has been used [1]. The beam line is designed for the maximum beam rigidity of 0.058 T-m, which corresponds to ions with specific charge ($\eta = q/A$) equals to 0.12 and energy equals to ($20*\eta$) keV/nucleon, 20 kV being the extraction voltage of ECR Ion source. The envelope of the beam from ECRIS-2, starting from the object point of the 110° analyzing magnet AM1 to the matching point on vertical line, is shown in figure 3. From this point charged particle trajectory calculation has been done to match the beam to the centre of the cyclotron with a solenoid and an spiral inflector.

BEAM OPTICS

The optics design has been done in modular fashion, to achieve point-to point focusing with unit magnification in both transverse planes at the final beam-matching point (Faraday-Cup FC$_4$),i.e., $|R_{11}| = |R_{33}| = 1$ and $R_{12} \approx R_{34} \approx 0$.
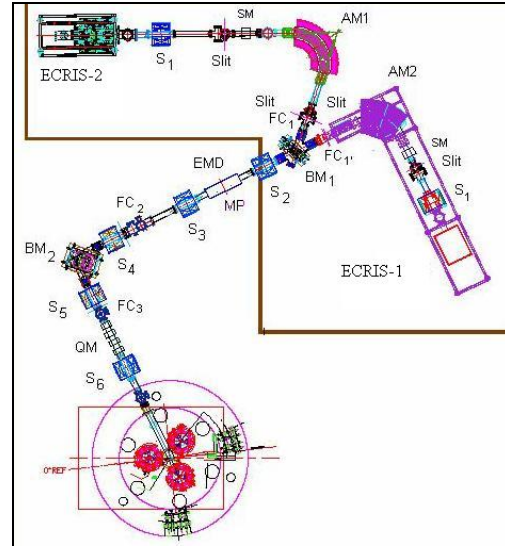

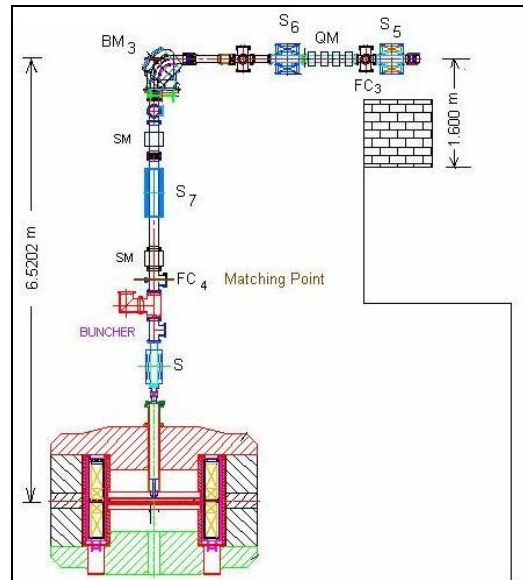Figure 1: Layout of horizontal part of injection beam line.

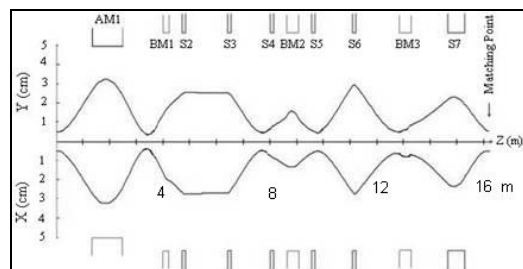Figure 2: Layout of vertical part of injection beam line.
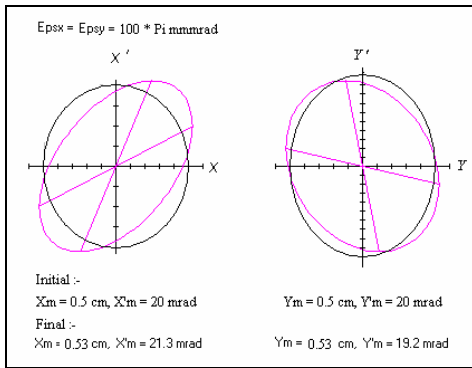

Figure 3: Beam envelop in injection beam line.

Figure 4: Initial and final transverse beam ellipses.

The analyzing magnet AM_1 (field index n=0.5, bending radius ρ=60 cm) in the ECR-2 line has a 110° bending giving good resolution (Δm/m=1/80) in the horizontal plane at its image point (FC_1). The 45° horizontal bending magnet BM_1 (bending radius ρ=30 cm, pole-face rotation 17.5° at both the edges) and solenoids S_2 and S_3 focuses the beam at FC_2. The parameters of the elements and their positions have been chosen in such a way that FC_2 serves as the common beam matching point, i.e., either of the beams extracted from ECR-1 or ECR-2 has unit magnification at FC_2. A micropulser (MP) system and a fast emittance measuring device (EMD) are being designed and will be stationed between the solenoids S_2 and S_3. The module from FC_2 to FC_3 consisting of solenoid S_4, 90° horizontal bending magnet BM_2 (bending radius ρ = 30 cm, Pole-face rotation 33.5° at both the edges) and solenoid S_5 has been made mirror-symmetric and will be used to change the image size as desired. The final module FC_3 to FC_4 has unit magnification and transports the beam to the vertical line matching point (FC_4). In this section the beam is bending downward by a 90° bending magnet (BM_3) to inject the beam in to cyclotron through the vertical axial hole. This section is designed such that the overall value of R_{21} is quite small. Four small quadrupole magnets (QM) will be used between S_5 and S_6 for beam matching at the cyclotron centre during injection. This will be useful for beams with low q/A.

Figure 5: ECRIS 1 along with analysing magnet (AM2), installed on the high bay of cyclotron building.

The solenoids S_1 to S_6 have got a compact design with 14.2 cm effective length, 5.12 kG maximum central field

and inbuilt X-Y steering magnet. To avoid physical interference with the RF structures, the solenoid in the vertical line, S_7, has been made axially longer and radially smaller with effective length 63.5 cm and maximum central field 1.57 kG.

All the components of the beam line are fabricated and at present, the beam line is being assembled on the high bay (figure 5).

Particle Tracking Through Yoke Hole

The magnetic field along the axial hole of the cyclotron has sharp gradient. Large fringing field exists up to several meters from median plane (~10 mT at 4m), as shown in figure 6. A solenoid of 50 cm length is required just above the cyclotron yoke (centered at z=2.1m) for efficient beam transmission and matching to the small aperture of spiral inflector (4mm).
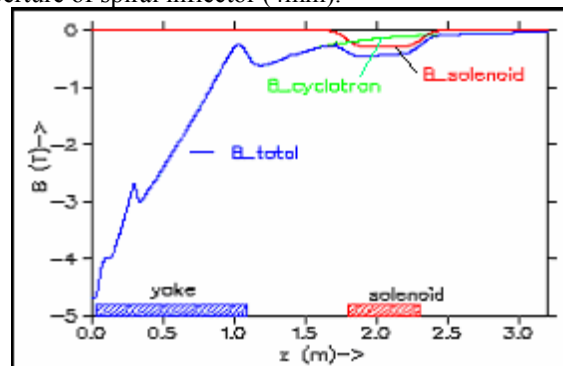

Figure 6: Magnetic field along axis of the cyclotron.

A charged particle code has been developed to study the required beam properties at the injection point (IP) at z=3.25 m. A bunch of 100 particles are tracked upwards from inflector entrance (z=2.1cm), considering double waist requirement at inflector entrance with half width 1mm and emittance 100 π-mm-mrad in both transverse phase spaces. We considered two ion species with limiting rigidities, as given below,

q/A	Bo(T)	Vinj (kV)	Final T (MeV/A)
0.5	3.45	18.4	64.5
0.16	4.7	10.94	12.2

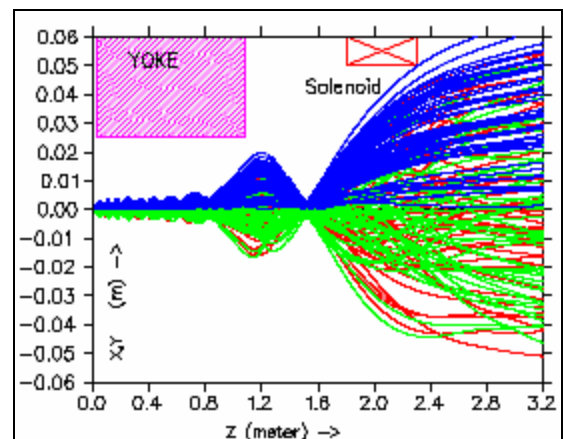
Figure 7: Beam profile for q/A=0.5 with B_{sol}=0 Gauss.

For q/A=0.5, with B_{sol}=0, the beam diverges due to fringing field, as shown in figure 7. Adjusting the solenoid field a double waist can be achieved at the IP (z=3.2m) for B_{sol}=560G (figure 8), which is shown by upright ellipses at IP (figure 9, left). A lower (460G) and higher solenoid field (660G) cause a converging and diverging beam respectively (figure 9, right).

Similar calculation for q/A=0.16 shows that, due to larger fringing field (B_0=4.7 T), an optimum solution (not double waist at I.P.) requires higher field B_{sol}= 3kG. To reduce the required field (2 kG) the solenoid should be longer (70 cm), which is constrained by space limitation.
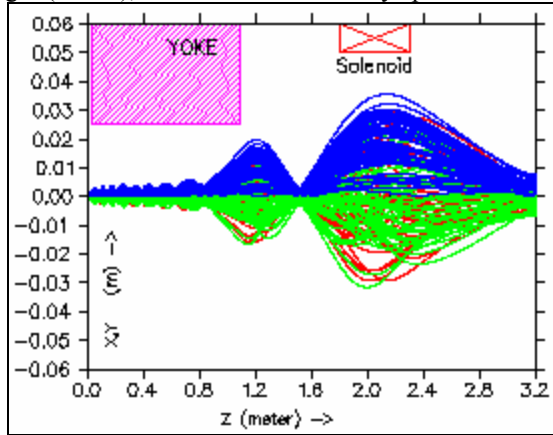

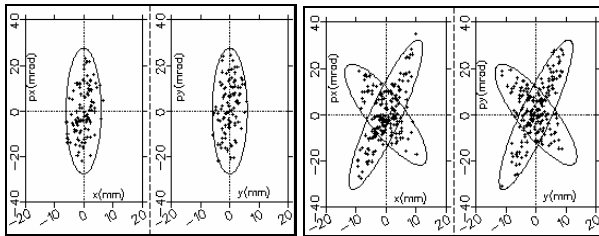Figure 8: Beam profile for q/A=0.5 with B_{sol}=560 Gauss.

Figure 9: Phase space ellipses at the injection point with Bsol=560G (left) and Bsol=460G, 660G (right).

Optimization of Solenoid Using TRANSPORT

The position, length and strength of the solenoid has been optimized has been done using TRANSPORT (figure 10), for Bρ=0.058 T-m and ε=100 π-mm-mrad, approximating cyclotron field by a series of solenoids. The beam executes more than 3 rotations around the axis. The matrix for spiral inflector has been calculated using CASINO code and incorporated in TRANSPORT calculation. At the inflector entrance ellipse parameters are as follows: x_m=2mm, x'_m=90.5mrad, α=52° and same for y-p_y phase space. At inflector exit $ε_x$= $ε_y$ =144 π-mm-mrad, x_m=2mm, x'_m=138mrad, $α_x$=50°, y_m=4mm, y'_m=187mrad, $α_x$=75°, which may be acceptable by cyclotron.

Spiral Inflector and Central Region

A spiral inflector will be used to bend the beam in to the cyclotron median plane. To design the inflector and the cyclotron central region electrode structures, several computer codes has been used, e.g., CASINO,

RELAX3D, Z3CYCLONE, PHYSICA etc. The characteristic parameters of the inflector are as follows: magnetic radius (R_m)=8 mm, height=2.1 mm, gap 4mm.
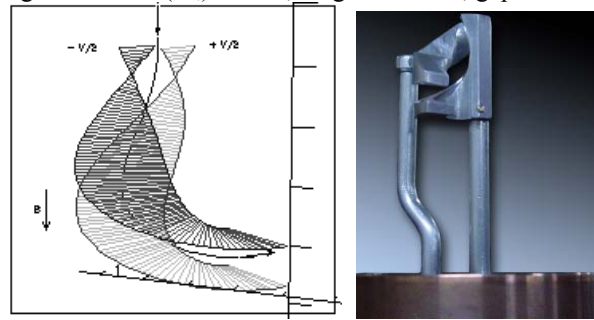

Figure 10: The simulated spiral electrode surfaces and the fabricated spiral inflector.

In figure 11, two orbits are shown corresponding to starting time τ = 240 and 270 RF degrees, for Z/A=0.249, B_0=38.35 kG, ECRIS extraction voltage 11.36 kV, final extraction energy (E/A) ~20 MeV/nucleon and V_{dee}=58.9 kV. The shaded area shows the phase width (30 RF degrees) selected by the central region. Figure 12 shows the central region structures installed on the main magnet.
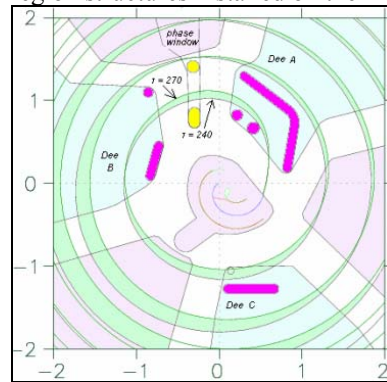

Figure 11: Trajectories in inflector and central region

Figure 12: Central region for 1st harmonic operation.

At present the injection system is being installed. The beam line is scheduled to be commissioned by the end of this year.

REFERENCES

[1] U. Rohrer, PSI Graphic Transport Framework based on a CERN-SLAC-FERMILAB version by K.L. Brown et al.