CHARACTERISTICS OF BEAM EXTRACTION SYSTEM OF K500 SUPERCONDUCTING CYCLOTRON

S. Paul#, J. Debnath, M.K. Dey, J. Pradhan, A. Dutta, C. Mallik, R. K. Bhandari
Variable Energy Cyclotron Centre, 1/AF Bidhannagar, Kolkata 700 064

Abstract

Extensive Magnetic Field measurement of the K500 Superconducting Cyclotron has been completed. In this paper we report the beam dynamical calculations along the extraction system based on the measured magnetic field data. The beam matching to the external beam transport system, for different ion species spanning the operating region is also explored.

INTRODUCTION

The K500 Superconducting Cyclotron at VECC, Kolkata uses 2 electrostatic deflectors, 8 passive magnetic channels and 1 active magnetic channel as its extraction elements [1]. Except for the active magnetic channel, all the other elements are radially movable, typically by ± 0.25 inches around a centre position. Th is maneuverability is due to the fact that not all the ions spanning the operating region of the cyclotron will have the same optimum beam extraction radius. Though it is possible that by adjusting the position and electric field of the electrostatic deflectors only, one can guide the extracted trajectories along a fixed common path, it is extremely difficult given the azimuthal length of the extraction path (~330^0), the total number of extraction elements involved, and the large variations in orbit scalloping across the anticipated range of magnetic fields. During the magnetic field mapping exercise, the magnetic field and magnetic field gradient along the extraction path has been measured both in the absence and presence of the magnetic channels at its central position, at different main magnet excitations, using a specially designed flexible zig and hall sensors.

The extraction elements

The different parameter of the extraction elements that affects the beam behaviour is listed in Table 1. For the deflectors, the septum to electrode gap is set to 6mm and the maximum voltage is set at 100 kV. To compensate the field perturbation effects of the magnetic channels on the inner orbits, 2 compensating bars (C_1 and C_2) are used, whose locations are also enlisted. C_1 compensates the effect of M_1 while C_2 compensates the overall effect of the remaining magnetic channels. The entries in Table 1. are as follows:

θ_i , θ_f : Initial and final azimuth of the element listed,
R_i , R_f : Average central ray radius at the initial and final azimuth of each element,
B : Magnetic field for the element
$\delta B/\delta x$: Gradients for the element.

spaul@veccal.ernet.in

Table 1: Extraction element's parameter

Element	θ_i (deg.)	θ_f (deg.)	R_i (in)	R_f (in)	B (kG)	$\delta B/\delta x$ (kG/in)
E_1	-23	32	26.6	26.93	-	-
E_2	94	137	27.1	27.68	-	-
M_1	140	153	27.7	27.76	1.14	8.3
M_2	200	206	28.28	28.39	1.14	8.3
M_3	226	232	28.89	29.08	1.04	13.3
M_4	236	242	29.21	29.44	1.04	13.3
M_5	256	262	30.09	30.46	1.04	13.3
M_6	266	272	30.75	31.24	1.04	13.3
M_7	276	282	31.62	32.31	1.14	8.3
M_8	286	292	32.88	33.95	0.96	11.6
C_1	320	334	27.75	27.75	-	-
C_2	46	58	28.95	28.95	-	-

SYSTEM CHARACTERISTICS

Figure 1. shows a plot of the magnetic field and radial gradient ($\delta B/\delta x$) across a typical magnetic channel. The field and the gradient is constant within ± 5 % across the beam width (~ ± 0.15 inch) and is therefore quite sufficient.

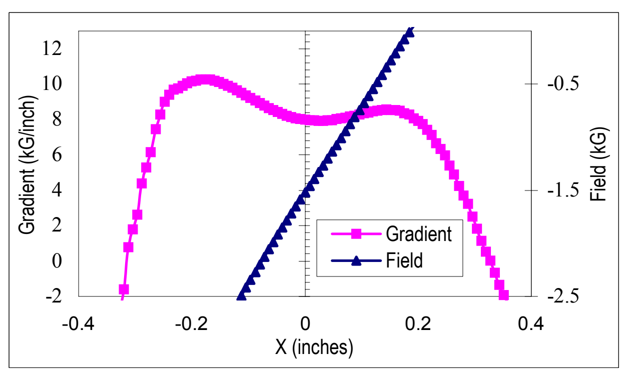

Figure 1: Field and gradient across a magnetic channel.

The properties of beams from the K-500 Superconducting Cyclotron were calculated by the ray-tracing method. In this calculation, the effect of the magnetic channels were included using the result of the magnetic field measurement. Three different species (Table 2.) spanning the operating-region of the cyclotron were chosen such that they correspond to different level of cental main magnetic field (B_0) of the cyclotron.

Table 2 : Beam Characteristics of investigated ions

Q/A	T/A (MeV/A)	B_o (kG)	E_{def} (kV/cm)	R_{def} (inch)
0.5	56.0	31.08	105.5	26.32
0.25	20.0	38.35	64.6	26.29
0.25	30.0	46.50	118.0	26.26

The trajectories of these 3 species are shown in Figure 2. on a Cartesian (R,θ) plot. The effects of the different scalloping of the orbits are quite evident.

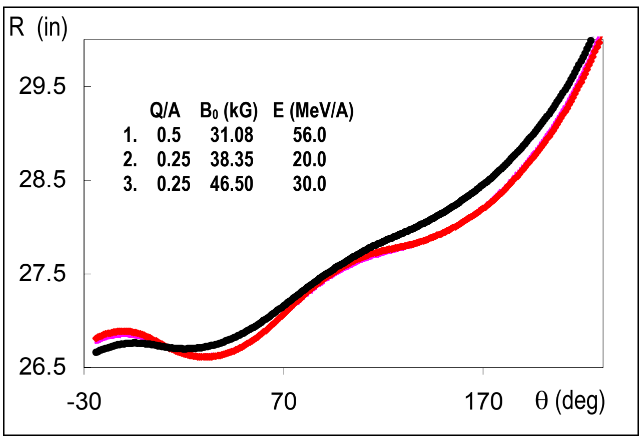

Figure 2: Extraction trajectories on Cartesian (R,θ) Plot.

The radial and angular dispersion of the extracted beam generated by the energy spread in the beam itself is also an important characteristic of the extraction system and has to be known while designing the optics of the external beam handling system. These effects have been calculated up to the slit (@ R = 44.4", θ = 317.5°) placed before the active magnetic channel (M_9) by ray-tracing beams corresponding to energy spreads of $\Delta E/E = \pm 0.1\%$ around the reference particle. These calculations are made by starting with the appropriate non-monochromatic phase space ellipse at the entrance of the first electrostatic deflector, and are therefore fully consistent. Table 3. lists the dispersive effects of the 3 species at M_9 slit in terms of R_{16} and R_{26}, namely the radial and angular dispersion respectively, as defined in the beam transfer code TRANSPORT [2], i.e. cm (or mrad) per percent of momentum spread.

Table 3: Dispersion parameters of investigated beams

Q/A	T/A (MeV/A)	R_{16} (cm/%Δp/p)	R_{26} (mrad/%Δp/p)
0.5	56.0	-6.45	-67.29
0.25	20.0	6.59	59.82
0.25	30.0	5.79	32.31

The radial and axial phase space ellipses of the different beam species obtained by tracking the corresponding eigen ellipses from the deflector entry to the M_9 slit passing through the extraction path were also investigated. The radial and axial ellipses obtained for 2 such species are shown in Figure 3 and 4.

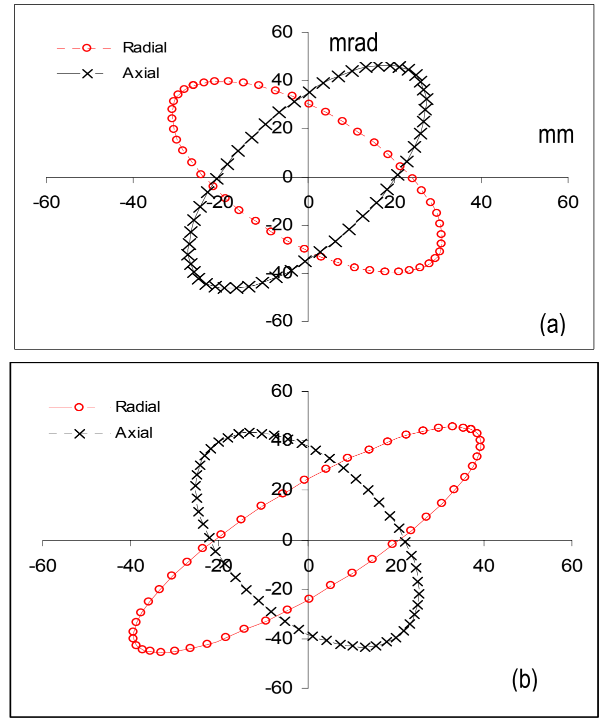

Figure 3: Phase space ellipse at (a) deflector entry (b) M_9 Slit for ions with Q/A=0.25, T/A=20 MeV/n, Bo=38.3 kG.

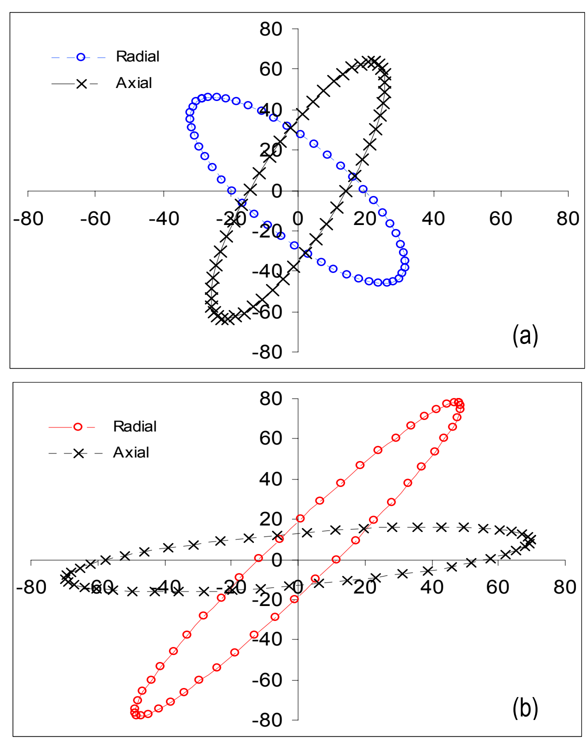

Figure 4: Phase space ellipse at (a) deflector entry (b) M_9 Slit for ions with Q/A=0.5, T/A=56 MeV/n, Bo=31.08 kG.

The initial ellipse is obtained by running the equilibrium orbit code GENSPE [3] in the main magnetic field of the cyclotron and the emittance is taken as 0.04 square inches.

REMARKS

The calculation and characteristics of the extraction system of K-500 Superconducting Cyclotron that has been reported in this paper covers up to the slit before the active magnetic channel (M_9). The subsequent tracking of the beams through the yoke field and M_9 has also been carried out and reported in this conference [4].

REFERENCES

[1] S. Paul, et.al , “Simulation Study of the Extraction System of K500 Superconducting Cyclotron in VECC, Kolkata”, presented in InPAC’05 (2005).

[2] K.L.Brown, D.C.Carey, Ch. Iselin & F. Rothacker, “TRANSPORT, A Computer Program for Designing Charged Particle Beam Transport Systems”, Yellow Reports, CERN 73 – 16 (1973) & CERN 80 – 04 (1980).

[3] M.M.Gordon, “Computation of closed orbits and basic focussing properties for sector-focussed cyclotrons and the design of CYCLOPS”,Particle Accelerators, 1984, Vol. 16, p 39 – 62.

[4] J. Pradhan, et. al, “Characteristics of the magnetic channel in the yoke hole of K500 SCC”, Presented in this conference.