DIPOLE MAGNET FOR CHARGE ANALYSIS OF AN EXTRACTED COCKTAIL ION BEAM FROM ECR3 IN VECC

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Abstract

The K500 superconducting cyclotron can accept a range of light and heavy ion particles depending on the *Q/M* ratio (0.1- 0.5) of the ions produced by ECR ion source. The extracted beam from ECR-3 will be consisting of ions of various charge state of various species forming a cocktail beam. There is a requirement of an analyzing dipole magnet for selecting certain charge states (*Q*) of certain species and injecting into the cyclotron for accelerating it to high energy. A description is given of designing a dipole magnet with incorporation of focusing of beam, which can be accomplished either using proper rotation of pole face at the entrance and exit edges or using a special profile of pole surface near the median plane to produce negative field index. The magnet has been constructed and a jig system too to map the magnetic field in the median plane.

INTRODUCTION

The plasma chamber of an ECR ion source (ECRIS) is fed with either gas or vapour of a pure element or compound of the element meant for ionizing it to high charge state ions (HCI). To boost the confinement of the ions of main element some lighter gas is fed also to cool them and produce HCI. While extracting the ions of the main element, mixed light element and some impurity elements of various charge state are also extracted forming a cocktail ion beam. There is a need of selecting ions of particular charge state of the main element and a charge analyzing dipole magnet is needed. Focusing effect in a dipole magnet is introduced by two methods, either incorporating pole face rotation (PFR) either at one or both the edges of the dipole facing the beam or introducing field index ($n=-(r/B)(dB/dr)$) in the magnetic field by properly designing pole surface curvature along the radius.

Pole-face Rotation

Let the gap between the flat poles be 'g' and the required uniform magnetic field, (B_0) depends on the gap, magnet structure and the magneto-motive force (NI). The bending angle, $\theta = HH'/R_0 = (qB_0L_{eff})/p$ is estimated from momentum (p) charge (q) and central field (B_0) and the effective length, $L_{eff}=(1/B_0)\cdot\int B(l)dl$ of the field along the central trajectory CHH'C'. The fringing field extent at the pole face is $\boldsymbol{a}=(L_{eff}-L_{geo})$ where L_{geo} is the geometric arc length of the magnet pole at the central trajectory. If no PFR is needed (ε=0) then on can have radial cut at the pole face but with the reduced radius (R') of the magnet geometry at the central trajectory as per $R'=R-\boldsymbol{a}/\theta$. The PFR angle ($\varepsilon$) is found as an output parameter through beam optics calculation and is to be incorporated during design of the dipole and it has to be ascertained after construction and field mapping. The radial cut has been rotated by an angle AHA'=ε (rad) in positive direction as in Fig. 1, which introduces a focusing power at the edge $1/f=-\tan(\varepsilon)/R$ in the vertical direction. The geometrical width of the pole at various higher (lower) radius corresponding to +(-) sign is $(R'\pm x)$ must be given by eq. (1) assuming equal PFR at entrance and exit faces.

$$L_{\pm geo} =(R'\pm x)\,\theta-(\pm 2\,\varepsilon x) \qquad (1)$$

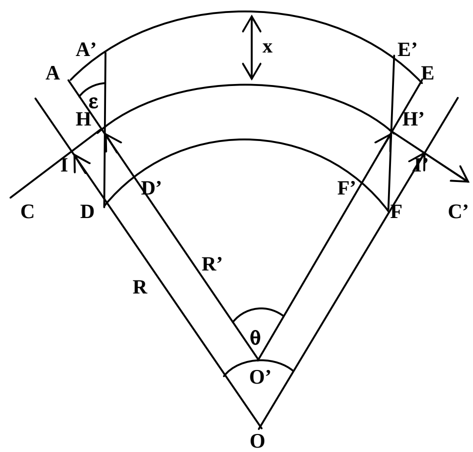

Figure 1: Incorporation of PFR angle, ε.

The magnetic field when measured in the median plane, the PFR can be obtained. Dipole field analysis is done to find the excitation curve, field uniformity, effective length and the PFR of the magnet [1]. The PFR can be evaluated using eq. (2) at higher (lower) radius corresponding to upper (lower) signs, where $L_{0,eff}$ and $L_{\pm x,eff}$ are effective lengths at the central trajectory and arcs shifted x distance radially away from it.

$$\varepsilon_{\pm x} =\pm\{(R\pm x)L_{0,eff} -R\,L_{\pm x,eff}\} / (2R\cdot x) \qquad (2)$$

Pole-surface Curvature and Field Index

Another method of designing dipole magnet with focusing is by introducing surface curvature such that proper field index is obtained with radially decreasing field (increasing pole gap), so $B(r) \propto r^{-n} \Rightarrow g(r) \propto r^{n} \Rightarrow g(r)=g_0\ (r/r_0)^n$. If n=0.5, there is equal focusing in the vertical and horizontal plane as per the betatron frequencies $\nu_z=\sqrt{(n)}$ and $\nu_r=\sqrt{(1-n)}$ respectively, g(r) is the gap between the poles which varies with radius and shown in Fig. 2 for n =0.5, g_0 =10 cm (minimum gap) and r_0 =51 cm (minimum radius). The average beam radius is 60 cm for which proper field and NI has to be fixed to rotate it by 110^{o} while analyzing the cocktail beam.

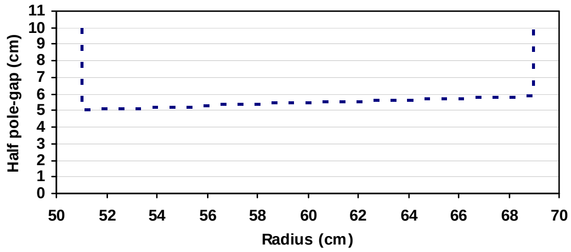

Figure 2: Plot of pole surface profile of the dipole.

DESIGN OF THE ANALYZING MAGNET

The analyzing dipole magnet geometry of the upper half used in calculating the field and field index is shown in Fig. 3 taking the upper pole surface profile (Fig. 2). Some shims have been used at the edges of the lower and higher radius and optimized to get uniform field index of the order of 10^{-2} in a span of ~12 cm width (POISSON code [2]). The magnet parameters are listed in Table 1.

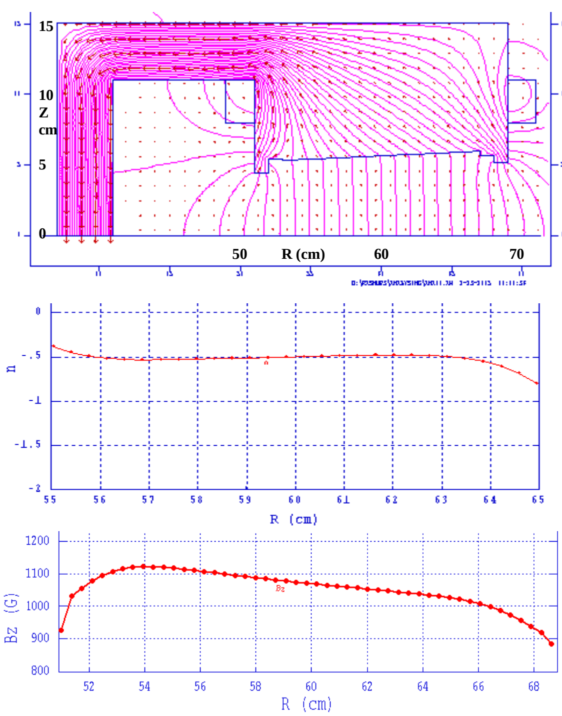

Figure 3: Plot of the magnet geometry (top), field index (middle) and magnetic field (bottom).

Table 1: Parameters of the designed analyzing magnet

Parameters	Values	Parameters	Values
Gap at r=60 cm	11 cm	Conductor(mm^2)	6x6
Field ar r=60 cm	1068G	Cur.den. (A/mm^2)	5.7
MMF(A-Turn)	4920x2	Power(kW)	3.02
Max. current (A)	165	Temp-rise/panc.	9.1^{o}C
Turn No.	5	LCW (lpm)	5.05
Pancakes No.	3x2	Total weight (kg)	950
Pole arc (cm)	104.7	Eff. length (cm)	~115

ANALYZING SYSTEM OPTICS

The analyzing system comprises a weak focusing Glaser lens with a biplane steering magnet inside and the dipole. An inherently diverging multi-component beam (cocktail beam) is extracted from the ECR3 and is focused immediately by a Glaser lens. The lens of 50 cm focal length matches the beam to the dipole also.

Beam optics calculation of the lens was done with second order effect of the space charge [3, 4]. The optics of the system ensured that the beams injected into the cyclotron are of the desired charge state, Q. The beam envelope together with the positions of the extraction orifice, solenoid, object slit, analyzing magnet and the image slit are shown in Fig. 4 by ‘or’, ‘sol’, ‘so’, ‘bend’ and ‘si’ respectively (TRANSPORT code [4]). The dispersive property of the analyzing dipole magnet is used to separate beam components that differ in momentum because of a difference in charge state (and/or mass). Relation between the momentum resolution ($\delta P/P$) and the charge resolution ($\delta Q/Q$) of ions is given by eq. (3).

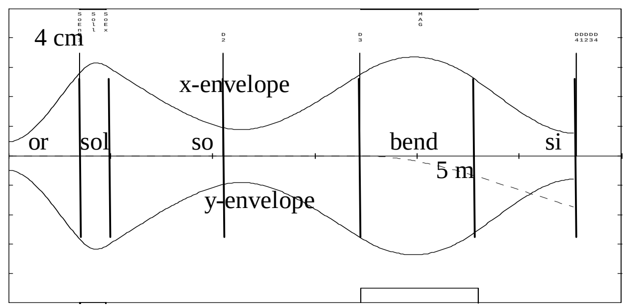

Figure 4: The beam envelope and system elements.

$$\frac{\delta P}{P}=\frac{\sqrt{Q+1}-\sqrt{Q}}{Q}\approx\frac{1}{2}\frac{\delta Q}{Q} \qquad (3)$$

CONCLUSION

Higher the bending radius better is the resolving power, we decided the average radius of curvature to be 60 cm. The object and image distances were optimized to 1.344 m and 0.922 m respectively. Taking object beam size to be ~1.2 cm, the beam is well resolved at the image point for heavy ions like U to maximum Q of 83 and 84 for $R_{16}/R_{11} \approx 2.9$. The ECR3 and the analyzing magnet has been assembled and the field mapping jig to map the magnetic field by a Gauss-meter has been constructed.

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