DESIGN AND FIELD CONFIGURATION FOR A 14.4 GHz ECR ION SOURCE IN KOLKATA

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Abstract

The K500 cyclotron under construction will be capable of accelerating ions like O^{6+} , Ne^{4+}, Ar^{16+}, Kr^{27+} etc. We aim to get ~200 euA maximum intensity of the extracted beam of O^{6+} from the ion source and decided to have >2B_{ECR} magnetic field on the cylindrical surface and the injection ends of the plasma chamber (P Ch) and slightly less than this at the extraction end. The success of the high field operation of ECRs at other places (U-AECR at LBL [1]) suggests generation of proper magnetic field configuration for the 14.4 GHz microwave heating. The absolute composite magnetic field have been evaluated due to the coils (C1,C2) at the two ends and a –ve coil (NC) at the mid-length and a Halbach type sextupole (PM-Hex).

1 THE MAGNET SYSTEM

The magnet system is the base of the ECR source of multicharged ions. The magnet system serves two purpose plasma confinement and electron cyclotron resonance heating. The increase of the magnetic field affects not only the mean electron temperature and the ion confinement time, but also the electron density. The parameters of the magnet system are listed in table 1.

Table-1 : Parameters of the new ECRIS

	Hex.	**C1, C2 each**	**P Ch.**	
I D(cm)	7.60	25.00	6.96	0.1 gap
OD(cm)	22.00	57.60	7.56	
L (cm)	26.60	16.4, 19.6	26.60	
Field (kG)	11.5	13.0 (Inj.) 9.6 (Ext.) 3.2 (Centre)		
Power		~2 x 9 kW		
L C W (l/min)		1.75 at 150 PSI water pressure	0.5 at 150 PSI water pressure	
ΔT (°C)		~15	~3.2	

1.1 Coils and Axial Magnetic Field

The axial field is generated by two main yoked coils (C1, C2) made up of 8 mm square copper conductor with a 4 mm diameter centre hole for water cooling. The C1 and C2 coils (9 pancakes each) can generate maximum field with 1,50,000 Ampere Turn (AT). The unyoked NC coil made up of 6 mm square conductor with a 3 mm diameter centre hole can produce miminum field at the centre with 25000 AT. It can control the central-field and therefore the mirror ratio. These coils together can create an axial mirror ratio of ~4. The value of the field at the centre of the chamber length is strongly dependent on the position and thickness of yokes Y1 and Y2 of the two coils at the centre.. The geometrical dimension for the coil field calculation by the POISSON [2] code is shown in Fig. 1. The coil field on the axis and chamber surface are plotted along the length (Fig. 2). From the calculation it is seen that the iron plugs P1 and P2 concentrate the lines of force at the chamber ends.

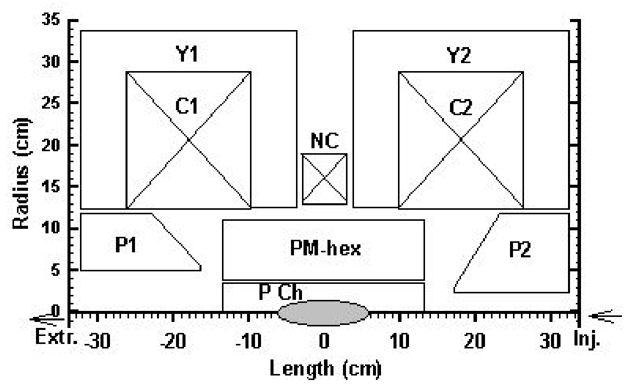

Figure 1: Geometry used for coil field calculation.

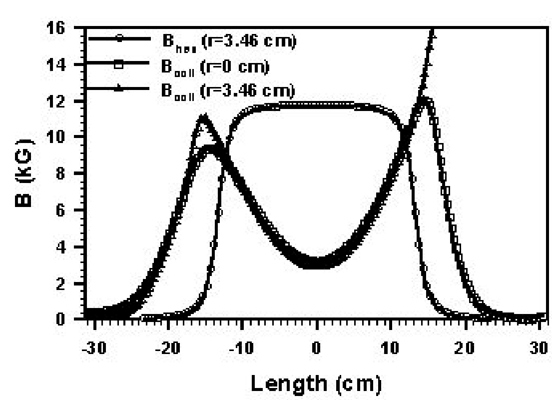

Figure 2 : Coil and sextupole field along the length.

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Cooling calculations of the coil pancakes and the surface of the plasma chamber were done [3]. It was found that the maximum rise in temperature (Δ**T**) is ~15^{0}C due to dissipation of ~2.0 kW of power in each of the pancakes and ~3.2^{0}C due to assumed absorption of ~1 kW power on the wall of the chamber as a result of cooling by low conductivity water (Table 1). So the working ambient temperature of the coils is expected to be ~ 40 ^{o}C, below it for the NC and much below it for the plasma chamber.

1.2 Sextupole and Radial Magnetic Field

The radial magnetic field is produced by a Halbach [4] type of sextupole structure made of Neodymium-Iron-Boron (Nd-Fe-B). The permanent sextupole magnet is made up of 24 trapezoidal segments, where the angle of magnetisation varies by 60^{o} from one segment to the next, enclosed in a nonmagnetic cylindrical casing made of stainless steel having magnetisation vector **M** in the plane perpendicular to the longitudinal axis. The radial field component of the coils will add up to the de-magnetising field in some of the blocks, so choice of permanent magnet material having trade name VACODYME 396 HR was natural because it gets demagnetised a little at as high as 60^{o}C whereas the working temperature may be ~40^{o}C. The permanent magnet material chosen has the intrinsic coercivity of 1.84 MA/m and should offer sufficient safety against de-magnetisation. The maximum radial demagnetising field due to the coils at the position of the permanent magnet blocks was found to be 0.60 MA/m. To be on the safer side, we used 1.06 MA/m coercive force for the field calculation due to the permanent magnet blocks. The material has maximum remanence of 12.0 kG and used

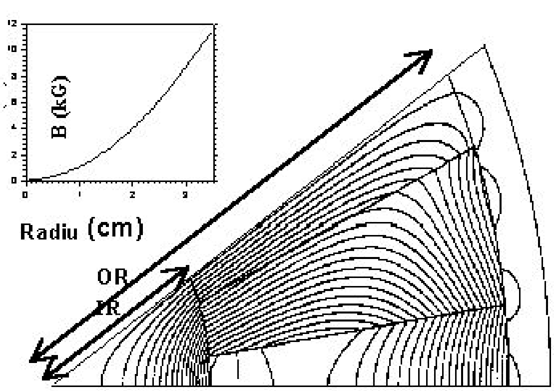

Figure 3 : One-sixth geometry of the PM-hex for calculation. The calculated field is shown in the inset.

11.6 kG for actual field calculation by PANDIRA code (Fig.3). The end effect of the sextupole was evaluated with the help of the TrapCAD [5] code by feeding the Pandira output data for obtaining 3D field distribution of the sextupole.

1.3 Optimised Iron Plugs

The value and position of the field maxima at the ends of the chamber are decided and fixed greately by the structure and position of plugs. The angles subtended by the slant surface of the plugs with the axis was optimised for maximum axial field at the position of the peaks but minimum axial field at the centre. The optimised angle of the slant surface of P1 and P2 are 39.0^{o} and 67.0^{o} respectively for maximum field peaks. The plugs will not hinder the placement of extraction electrodes, gas feeding lines etc. because of sufficient space left for them.

1.4 Magnetic Field Analysis

The drop in radial magnetic field becomes significant from about 2.0 cm inside the ends of the sextupole. The size and position of the plasma corresponds with the iso-Gauss field surface at resonance field (5.143 kG).

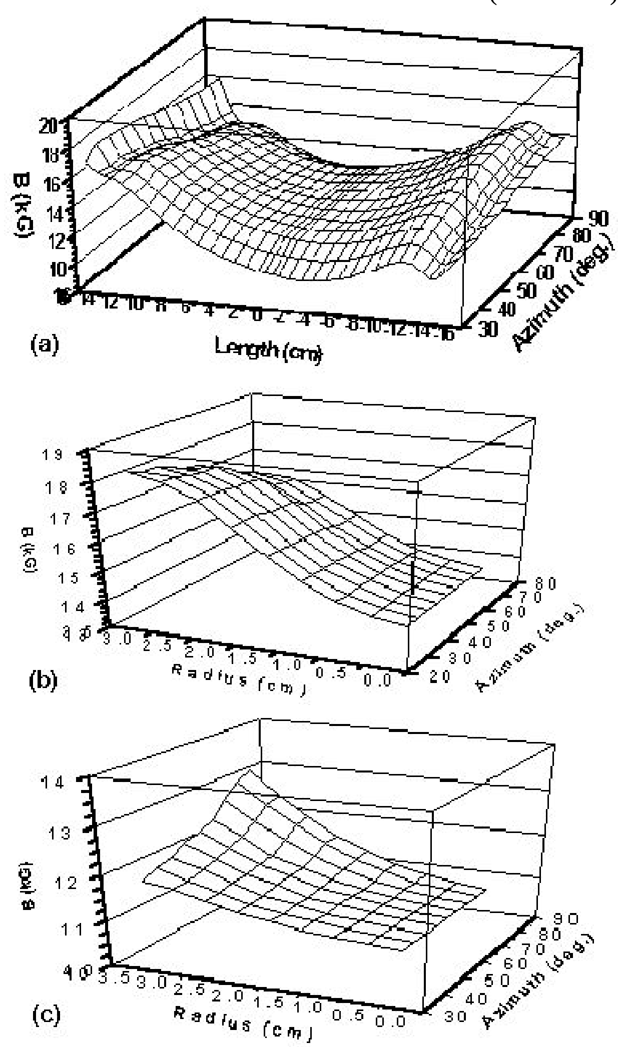

Figure 4: 2D field plot on the surface from peak to peak (a), at the injection end peak (b) and at the extraction end peak (c) of the chamber.

corresponding to the 14.4 GHz *RF* frequency. The absolute composite field on the surface of the plasma chamber after adding the components due to the coils and the sextupole including the end effect has been plotted (Fig. 4a, 4b, 4c). This evaluation was done for azimuth from 30^0 to 90^0 only because the field from 30^o to 0^o and from 30^0 to 60^0 is the same in order and magnitude both and similarly the field from 90^0 to 60^0 and from 90^0 to120^0 is the same.

2 SOURCE DESCRIPTION

2.1 Source Detail

The yokes Y1 and Y2 are 5 cm (Fig.5). The plasma chamber is made of double walled nonmagnetic stainless steel. In between the walls there are water circuits for cooling the plasma chamber. The plugs P1 and P2 are kept in position by bolting with teflon insulators. A positive high voltage upto 20 kV will be applied to the source while the puller electrode will be at ground potential initially. The microwave power (~2kW) will be fed by rectangular wave guide from the injection side. The turbo molecular pumps 53 l/s and 500 l/s will be in the injection and extraction side respectively. A biased aluminium plate B will inject cold electrons into the plasma at the injection end.

2.2 Extraction

The puller electrode E will be supported to the end flange of the source and kept at ground potential. The distance between the puller and plasma electrode having

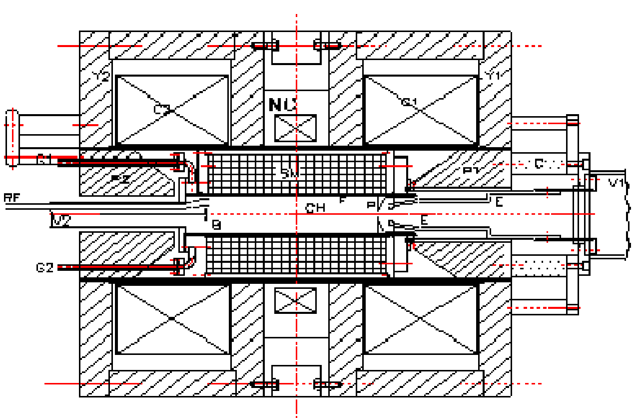

Figure 5 : The schematic diagram of the source with gas inlets (G1,G2), vacuum pipes (V1,V2) and RF feeding etc.

initially at 3.0 cm can be adjusted. The plasma electrode (P) is made of aluminium and has 1.2 cm diameter aperture for beam extraction. A thin aluminium sheet (F) of 0.05 cm thickness and 7.0 cm length will be fitted on the plasma chamber wall near the extraction side to improve electron density in the extraction zone. The current density (*J*) of the beam formed after extraction from the plasma is given by [6] :

$$J = 1.72\,(q/A)^{1/2}\, V_0^{3/2}(kV)/d^2\ [mA/kV^{3/2}]$$

where, the gap d in mm and others have usual meaning.

The emittance of the beam extracted through a fringing magnetic field is given as [7] :

$$\varepsilon = 50.0\,\pi B_0(z)\, r^2_{start} / B\rho \quad [mm\text{-}mrad]$$

where, the fringing field ($B_0(z)$) starting beam radius (r_{start}) and rigidity of the extracted beam (Bρ) are in kG, mm and kG-cm respectively.

2.3 Fabrication

Fabrication work of the most of the components has started already. The winding of the coils will be completed very soon. Most of the power supplies are also under construction. The sextuple magnet was received from M/S Danfysik recently for mapping the field and subsequent installation.

3 CONCLUSION

We conclude here the properties of this new ECRIS :

- Higher axial magnetic field peak.
- Halbach type of sextupole made of high retentivity magnets giving higher field on the P Ch surface..
- Easy to get variable mirror ratio by the NC which will help in optimising the extracted beam.
- Use of Al foil on the chamber-surface for injecting secondary electrons in the extraction region.
- Large plasma volume and surface area to get high current of multi-charged ion beam.
- Provision to get solid ion-beam too.
- The estimated current and emittance for O^{6+} for 2 cm gap (d), 20 kV extraction voltage, 2.0 kG fringing magnetic field and 12 mm diameter circular aperture was calculated to give > 0.2 mA current and < 350 mm-mrad emittance.

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