Conventional field generated by permanent magnet for ECR ion source of 18 GHz

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Introduction

A conventional magnetic field is robust in achieving plasma confinement due to minimum-B or tandem mirror field configuration. The French group led by Geller pioneered constructing ECR ion source (ECRIS) like MAFIOS and its variants in 1970's and later [1]. Conventional ECRIS have the big advantage that nowhere magnetic field is null and so electrons have contant magnetic moment and execute adiabatic motion throughout the plasma chamber. But ECRIS has some problems too like i) the plasma generated is not axially symmetric, ii) the magnet system is complicated for generating axial and radial field and iii) injection and extraction regions are congested. The density n_e is deduced from $n_e \leq \varepsilon_0 m_e \omega_{RF}^2/e^2$ and given in per cc by $n_e \leq 1.11x10^{10} f_{RF}^2$ in practical notation, where the equality sign corresponds to the critical plasma density and the microwave frequency, f_{RF} in GHz.

It is essential to meet the following criteria concerning the magnetic field achieved in the chamber [2]; $B_{max} \geq 2B_{ECR}$, $B_{max} = B_{inj} \geq B_{wall}$, and $B_{ext} << B_{inj}$, where $B_{ECR} = (f_{RF}/2.8)$ kG; B_{max} is the maximum magnetic field at the injection end and B_{ext} is the magnetic field at the extraction end. From empirical scaling laws of ECRIS [3] average charge state, $<Q_{op}> \propto \text{Log}(B_{max})$, where B_{max} is the maximum field achieved on the axis and extracted beam current of charge state Q+, $I^{Q+} \propto (f^2 n_e V_p)/(A_i^{\alpha} \tau_i)$, where V_p is the plasma volume, A_i and τ_i are the ion mass number and the ion confinement time at the extraction region. The parameter α has value close to 1.

Axial Field using PM

Nowadays, Nd-Fe-B magnets are used in accelerators and ion sources because of their high remanent field (B_{rem}), coercive force (H_{cor}) and energy product, $(BH)_{max.}$

Table 1: Available Nd-Fe-B strong PM's.

Material (strength in MGOe)	**B_{rem} (kG)**	**H_{cor} (kOe)**
VACODYM 745HR (50)	14.4	14.0
NEOMAX 5563 (55)	15.0	13.5

A conventional field is defined as superimposition of two types of field axial and radial. The axial field is created by the arrangement of several coaxial permanent magnet (PM) rings around the central axis as shown in Fig. 1. The space for plasma chamber is near about the central axis marked as CH, which is surrounded by the hexapole magnet marked as HEX. The orientation of the magnetization vector in PM1 and PM4 are 200 and 90 deg. respectively with respect to the radial axis. The orientation of the magnetization in PM2 and PM3 are kept fixed at 180 deg. After optimization iteration for maximizing the field at the chamber ends and properly minimizing the field at the centre such that an axial mirror ration of ~3.4 is achieved. In this optimization process the PM and IRON geometry as well as their position were varied. The variation of field along z-axis is depicted by curve in Fig. 2. This field creats peak fields at the ends and have tendency of containing the plasma particles from loss at the ends (point cusps). But the peak height at the extraction region can be lowered by properly tailoring the position and geometry of the PM rings in this region for facilitating easy extraction of the multi-charged ions.

Radial Field using PM

The scheme of the Halbach type sextupole magnet made of 24 strips is depicted in Fig. 3, in which the inner half strips having radial magnetization have been replaced by highly permeable iron strips. Only 1/6 of the azimuth is shown because of 6 fold symmetry, which was utilized to calculate the magnetic field by PANDIRA code. There is a drastic improvement in the radial field of the sextupole. The magnetization direction in the permanent magnet region varies by 60 deg. with respect to the adjacent regions. The improvement in radial field plot is depicted in Fig. 4 due to the new PM sextupole.

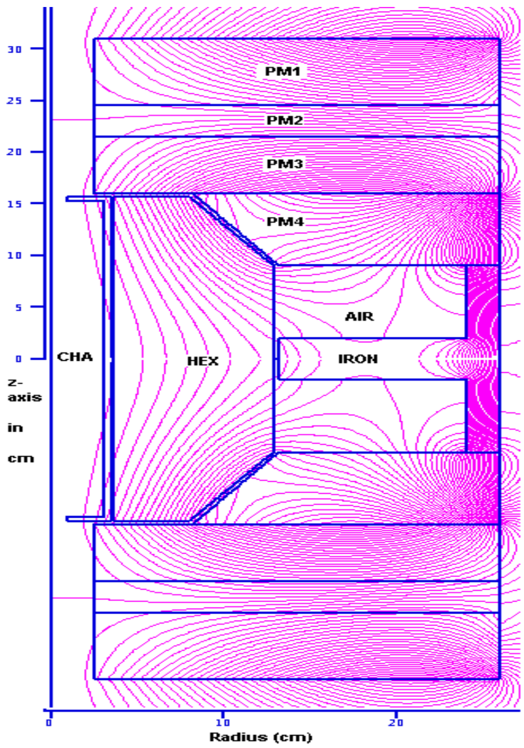

Fig. 1 Scheme to produce sufficient axial field

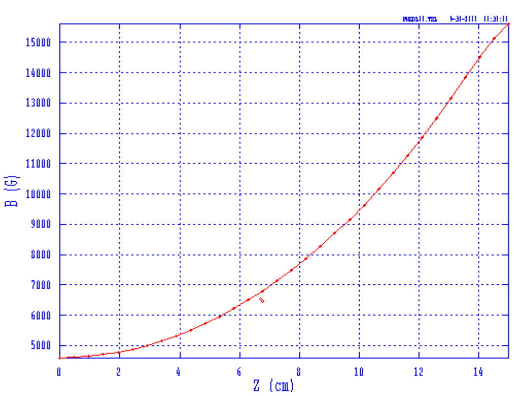

Fig. 2 Magnetic field plot along the z-axis

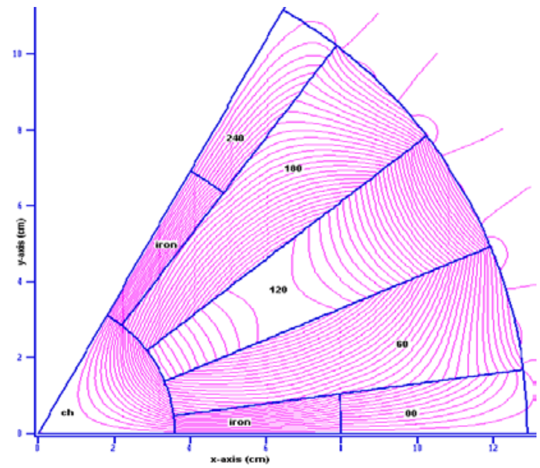

Fig. 3 1/6 model of the 24 strip sextupole magnet

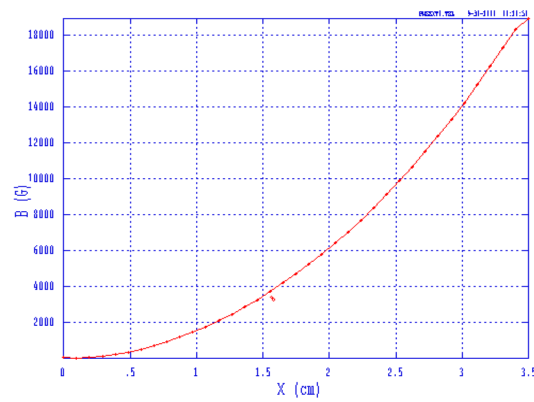

Fig. 4 Magnetic field plot along the radius

Conclusion

The field produced through simulation is very much improved in terms of magnitude by utilizing some new techniques like using some iron with PM's with proper magnetization direction. The constructed such a source will be easy-to-run and cost-effective without compromising the performance.

References

[1] R. Geller et al, NIM **A 243** 244 (1986); NIM **A 184** 293 (1981).
[2] D. Hitz et al, RSI **75** 1403 (2004).
[3] R. Geller, IEEE Tran. ... **NS-26** 2120 (1979).