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 constant 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 \( n_e \leq \frac{e_0 m_e \omega_{RF}^2}{2e^2} \) and given in per cc by \( n_e \leq 1.11 \times 10^{10} \frac{f_{RF}^2}{\omega_{RF}^2} \) 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]; \( B_{max} \geq 2B_{ECR}, B_{max} = B_{mag} \geq B_{wall} \) and \( B_{max} \leq B_{ij} \), where \( B_{ECR} = \left( \frac{f_{RF}}{2.8} \right) \text{kG} \); \( B_{max} \) 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, \( <Q_{op}> \propto \log(B_{max}) \), where \( B_{max} \) is the maximum field achieved on the axis and extracted beam current of charge state \( Q^+ \), \( I^{Q^+} \propto \left( \frac{e_0 n_e V_p}{A_i^\alpha \tau_i} \right) \), where \( V_p \) is the plasma volume, \( A_i \) and \( \tau_i \) are the ion mass number and the ion confinement time at the extraction region. The parameter \( \alpha \) 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, \( (BH)_{max} \).

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magnet made of 24 strips is depicted in Fig. 3, in which the inner half strips having radial magnetization have been replaced by highly...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