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Simulation of magnetic field profile in 2.45 GHz microwave ion sources

Asadi Aghbolaghi, Marzieh[1]; Abbasi Davani, Fereydoon[1,*]; Yarmohammadi Satri, Masoomeh[2]; Riazi Mobaraki, Zafar[2]; Ghasemi, Farshad[2]

[1] Department of Radiation Application, Faculty of Nuclear Engineering, Shahid Beheshti University, P.O. Box 19839-69411, Tehran, Iran

[2] School of Physics and Accelerators, Nuclear Science and Technology Research Institute, P.O.Box 14395-836, Tehran, Iran

* *Email: m_asadiaghbolaghi@sbu.ac.ir*

Abstract

In this paper, the required magnetic field produced by solenoids is simulated for microwave ion sources in COMSOL software. As these sources are categorized in two type of electron cyclotron resonance ion source and microwave discharge ion source, three main parameters such as number of coils, current and coils distance are important to investigate and achieve the field profile. Also, the required magnetic profile is optimized for ECR ion source by increasing the number of solenoid to three. The powered current for simple magnetic mirror field in ECRIS, optimized ECRIS and MDIS are 95, 170 and 90 ampere and the distance for mirror length are achieved as 16, 16.5 and 20 cm, respectively.

Keywords: Microwave ion source, ECRIS, MDIS, Magnetic field, Simulation, COMSOL

Introduction

Ion source is one of the most important part of particle accelerators. Among the sources, the microwave ion sources are more popular for achieving the ion beam with suitable characteristics and benefit alternating electric fields in the GHz frequency range to generate the plasma. These sources are categorized into two types, ECRIS (electron cyclotron resonance ion source) and MDIS (microwave discharge ion source). These sources are composed of: main chamber, material, ionization energy source, extraction system and magnets. The main differences between ECRIS and MDIS are: the operation frequency, the profile of applied magnetic field on the plasma chamber and application of the hexapole magnet. MDIS benefits from a frequency range smaller than 2.45 GHz and a flat-B profile. While, the applied frequency on the ECRIS is more than 2.45 GHz and min-B profile with 875 G for ECR magnetic field for heating and confining the plasma inside the source body [1, 2].

Also there are two different magnet designs: a) Solenoid (electromagnetic coil) works on DC power [3] and b) Permanent magnet [4]. In this paper, the first method is employed to produce a magnetic field produced by coils are placed around the plasma chamber. Size of the cylindrical plasma chamber is 15 cm and 20 cm in diameter and length, respectively, to fit the mirror length, equal to the peak to peak of the applied magnetic field profile. At first, we simulated two coils for ECRIS to investigate effect of the magnetic field strength on the resonance zone. Then, it is optimized by increasing the coils number to three to produce the desired structures. Also the simulation strategy is followed for the MDIS. The output results of the simulated ECRIS and MDIS are compared from the flat-B and min-B profiles point of view. The simulations of this study are operated on COMSOL software.

Specifications of magnets

The simulated coils are made from hollow copper metal with a square cross-section (5×5 mm) and a hole with 3 mm as diameter for water cooling. Insulation of layers consisting of the copper wires was satisfied by glass-cover. Then, the inside diameter of the magnets is defined by the plasma chamber diameter 15 cm. The two side coils structure is designed with 144 turns in 12 layers, Figure 1 [3]. The three coils design for the MDIS and the optimized ECRIS field profile has the extra coil which is made of 110 turns in 10 layers at the middle of the two coils with the same distance from each sides.

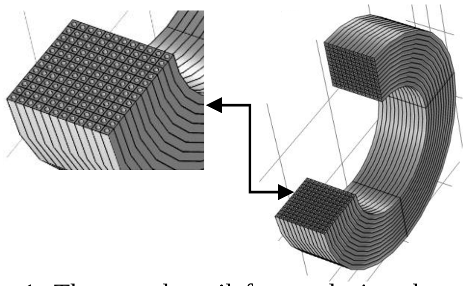

Figure 1. The sample coil for producing the magnetic field profile of the ECRIS and MDIS.

Simulation results

By powering the coils with a DC current, the magnetic field simulation is launched on COMSOL software to plot the generated magnetic field map. Figure 2 shows the magnetic flux line generated by the two and three coils for ECRIS.

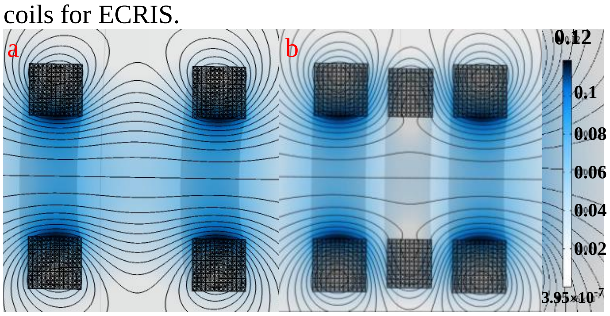

Figure 2: Magnetic field flux in Tesla is generated by: a) the two coils and b) three coils structures for ECRIS.

According to the coils material, if the coils structure are powered with less than 90 A, the desired magnetic field

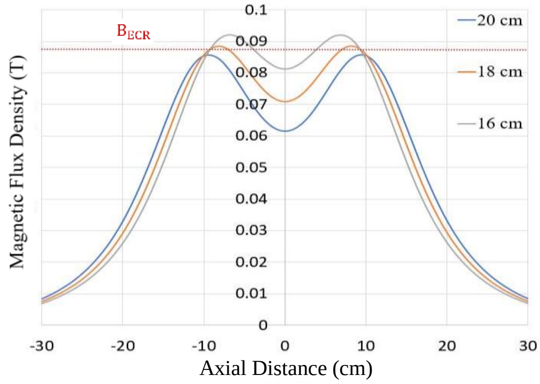

Figure 3: ECRIS magnetic flux along the central axis with two coils, powered with 95 A.

with a magnitude of 875 Gauss is not satisfied. Also the results are shown for the best choice of current to satisfy the ECR magnetic field. As Figure 3 shows, the magnetic field is generated by two coils on the central axis of the ECRIS. The selected distances is separation area between the center of the coils, Figure 2, a. As the distance decreases, the magnetic field increases between the coils and changes to more uniform. As Figure 3 shows, at distance value of 18 - 20 cm, the magnitude of the magnetic field is not appropriate for resonance phenomena. By decreasing the separation distance to 16 cm, the appropriate magnetic field is obtained for resonance at 875 Gauss.

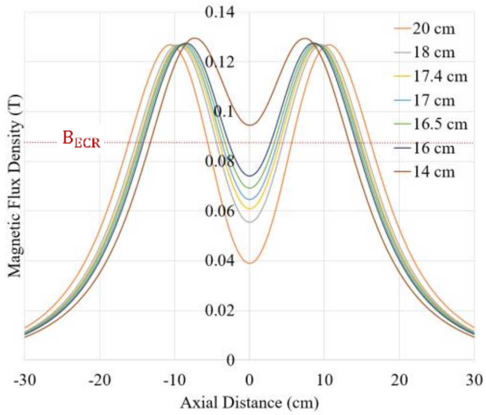

Figure 4: Optimized ECRIS magnetic flux along the central axis of the three coils structure, powered with 170 A and 110 A for the side and middle coils, respectively.

The optimization of the magnetic field for the ECRIS is obtained by increasing the number of coils to three, Figure 2, b. By powering the middle coil in the opposite direction, the minimum magnetic field due to the desired field map can be achieved and for 2.45 GHz ECRIS is about 700 G, Figure 4 [5]. As the distance decreases, the magnetic field increases between the coils and the minimum magnetic field gets closer to 700 G. As shown in the Figure 4, at distances more and less than 16.5 cm, the magnitude of the minimum field is not appropriate for resonance phenomena. For the distance of 16.5 cm, the desired magnetic field obtained due to resonance at 875 Gauss.

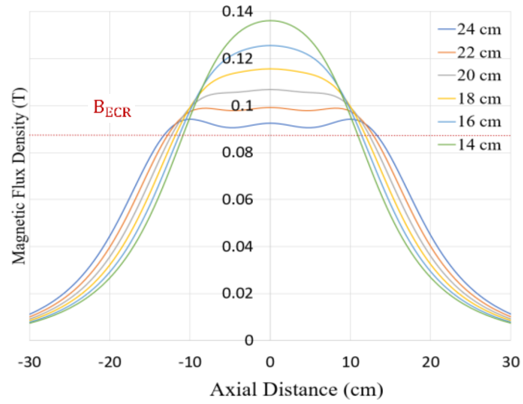

Figure 5: MDIS magnetic flux along the central axis of the three coils structure powered, with 90 A and 75 A for side and middle coils, respectively.

According to the required uniform magnetic field for MDIS, the same current direction of the three coils is necessary. In this case, the flat-B is more than 875 G. As shown in Figure 5, at distances between 14 to 18 cm and 22 to 24 cm, the magnetic field is not uniform. At 20 cm, the generated magnetic field is uniform and the length of this uniformity is limited to the plasma chamber. In Table 1, the values of solenoid ampere-turns for different designs are mentioned.

Table 1. The ampere-turns of coil structures.

Source type	ECRIS (two coils)	ECRIS (three coils)	MDIS (three coils)
Coil 1	13680	24480	12960
Coil 2	-	-12100	8250
Coil 3	13680	24480	12960

Conclusion

According to the simulation results out of the COMSOL software, the magnetic field profile of the ECRIS is designed and optimized by increasing the number of the employed coils structure to three. The desired value for powering the coils for the two and three coils magnet structure are obtained and the mirror length is fit to the plasma chamber cylinder with 20 cm as length and 15 cm as diameter. The optimized distances between the coils for two coils ECRIS, three coils ECRIS and MDIS are 16 cm, 16.5 cm and 20 cm, respectively.

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