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MAGNET SYSTEM FOR A PROTON/HELIUM ECR ION SOURCE

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Abstract

The study of the magnetic system of ECRIS with operating frequency of 2.45 GHz for producing protons and double-charged helium ions has been carried out. The results of the numerical simulation of the ECRIS magnetic system based on permanent magnets have been performed. The possibility of shifting the ring magnets in both injection and extraction regions is considered to adjust maximum and minimum values of the axial distribution of a magnetic field in a plasma chamber. The possibility of shifting the bar magnets of the hexapole is shown to provide the adjustment of the radial magnetic field B_{rad} at the chamber wall. Additional solenoids are introduced to the system for providing the required B_{inj} and B_{ext} adjustment and tuning the axial magnetic field distribution including the minimum on the axis B_{min}. Furthermore, the magnetic system allows to switch the operation mode of the ECR source to the microwave mode.

INTRODUCTION

High-energy accelerating facilities are vastly used nowadays whether for fundamental research or for other experimental fields like medicine, electronics or dose effect testing technologies. Particle sources are one of the major elements that are implemented to produce charged particles in modern accelerators. Ion sources based on the microwave plasma effects have been of giant interest for many research programs for the past few decades.

Two types of microwave plasma ion sources were considered as a fundamental base for the development of a new 2.45 GHz ion source with variable characteristics of the magnetic system. Depending on the ion parameters required, ion sources based on the electron-cyclotron resonance (ECR) or the microwave discharge can be used. The ECR ion source provides the interaction between electromagnetic field and plasma at the frequency of electron-cyclotron resonance and under the vacuum conditions. Unlike the first type, the microwave source does not require the resonance conditions to provide the field-plasma interaction; moreover, gas pressure inside the plasma chamber is several times higher than for the first type. According to the factors of plasma generation ion beam parameters can differ for these two types. ECR ion sources produce multiply charged ions with lower beam currents in comparison with microwave sources, which provide high beam currents of protons.

The aim of this research is to design a new ECR ion source for producing double-charged ions of helium and protons and light single-charged ions. This aim will be accomplished by meeting the following objectives: developing a magnetic structure of the source, calculating the magnetic field parameters of the source to determine the most feasible configuration of the application.

BASIC PARAMETERS OF ECR AND MICROWAVE ION SOURCES

Microwave discharge sources are usually feasible for generating the single-charged ion beams or proton beams with the current up to 100 μA and low emittance in both pulse and continuous-wave operation mode. High magnetic fields are used to increase the ion density. This type of a source can be distinguished by the frequency that is higher than for the ECR type. In contrast to the magnetic system of the ECR type, the microwave source configuration does not include hexapole magnets to confine plasma in the ECR region.

The magnetic field profile is important for the plasma generation as well as for the operation stability of the application. The magnetic field for this configuration is usually generated by two solenoids with variable currents. Figure 1 demonstrates the characteristic profile of the magnetic field axial distribution for a microwave discharge ion source [1].

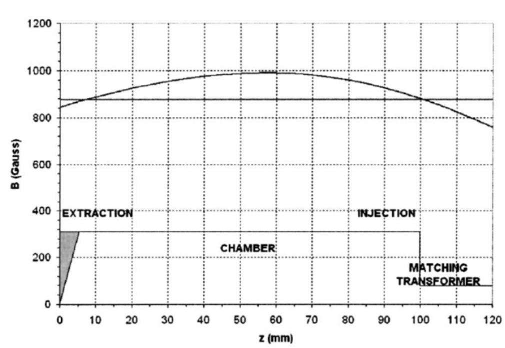

Figure 1: The most optimal magnetic field profile of a microwave discharge ion source. The stable line depicts the resonance magnetic field at the frequency of 2.45 GHz.

To accomplish the ion parameters required microwave plasma sources were considered, according to the following advantages: stability, long lifetime (up to a year), and high ion concentration, small energy spread in the beam, low emittance, compactness and ease of operation.

As compared to the microwave source magnetic system, the ECR source configuration is usually based on

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permanent magnets instead of solenoids. Sources with the stepped ionization are needed to generate the multiple-charged ion beams. Electrons are gradually knocked out from the external shell of the ionized atoms by electrons accelerated in an alternating field. Along with that, relatively slow ions continue to lose electrons because of the ionization, caused by the second time accelerated electrons. Slow electrons are confined by the magnetic field of the source.

A better confinement of high-density plasma is needed to provide the generation of the double-charged helium beams. In this case the specific magnetic field profile is required. Figure 2 demonstrates the characteristic field distribution required for the ECR operating mode [2]. The ECR plasma is radially confined by multipole magnets placed around the plasma chamber.

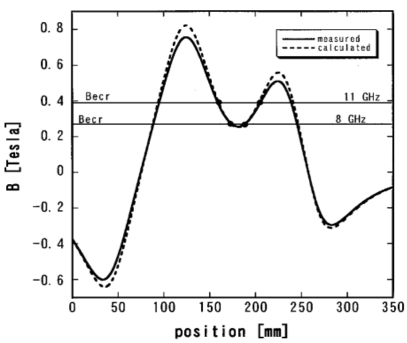

Figure 2: Magnetic field profile of the ECR ion source.

The efficiency of the RF power transmission into the plasma chamber depends on the magnetic plasma density distribution inside the chamber, which affects the dielectric parameters of the chamber space and consequently the effectiveness of the field-plasma interaction. This research is based on the most optimal configuration principles known as the “ECRIS Standard Model”.

THE MAGNETIC SYSTEM CONFIGURATION DEVELOPMENT

This section describes the development steps of the 2.45 GHz ECRIS magnetic system. The numerical simulation of the magnetic field parameters was made by the Finite Element Method (FEM). The initial model of the magnetic system is presented in the Fig. 3.

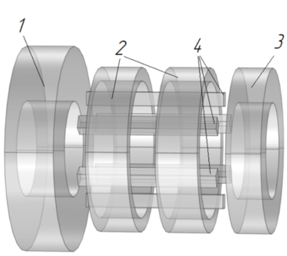

Figure 3: The magnetic system of the 2.45 GHz ECRIS. (1) Injection ring magnet. (2) Middle ring magnet. (3) Extraction ring magnet. (4) Hexapole magnet.

The model of the magnetic system was calculated, provided that the material of the magnets is selected to be NdFeB. The length of the hexapole bars was selected as 100 mm, which is equal to the length of the plasma chamber. The plasma chamber diameter is 50 mm, while the other dimensions were determined to keep the system compact. The optimization of the magnetic system was carried out by changing the size of the magnets and their relative position. The simulation results (axial and radial components of the magnetic field) are presented in the Fig. 4. Table 1 presents the magnetic system characteristics after the optimization.

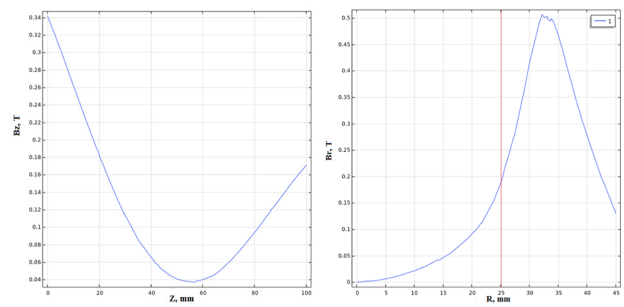

Figure 4: Axial and radial magnetic field profiles of the optimized magnetic system configuration.

Table 1: Optimized Parameters of The Magnetic System

	B_{inj}, T	B_{min}, T	B_{rad}, T	B_{ext}, T
Optim.	0.350	$0.058 < \lvert B\rvert_{min} < 0.087$	0.193	0.175
Calc.	0.342	0.036	0.190	0.171

THE SYSTEM MODIFICATION

Further optimization of the magnetic system design was performed to adjust the minimum of the axial field Bmin, while the ring magnets position is permanent, to make it possible to rebuild the magnetic system so that the developed ECR source could operate in the microwave source mode. Three to five solenoids were added to the model of the system to adjust the axial distribution of the magnetic field and to switch the source into the microwave mode.

Figure 5 shows a scheme of the magnetic system with solenoids. Axial field distribution, radial and azimuthal field distributions at the edge of the camera are shown in the Fig. 6.

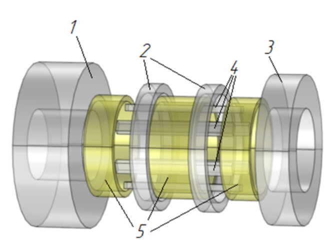

Figure 5: The model of the magnetic system modification with three solenoids. (1) Injection ring magnet. (2) Middle ring magnet. (3) Extraction ring magnet. (4) Hexapole magnet. (5) Solenoids.

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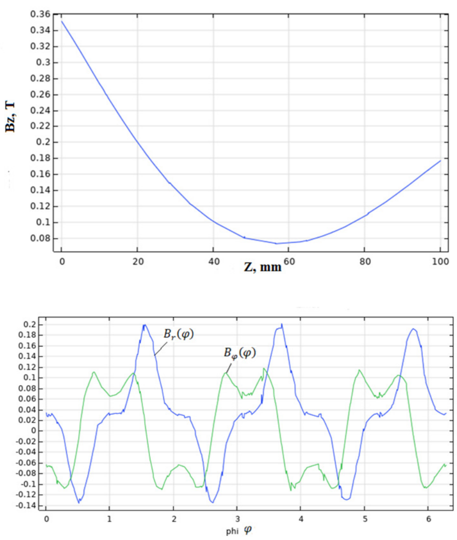

Figure 6: Magnetic flux density distributions of the system with the solenoids.

THE FINAL MODIFICATION

Before the final stage of the development of the magnetic system, additional conditions should be defined: the generation of double-charged ions must be provided in the absence of currents in the solenoids; the adjustment of the values of B_{inj} and B_{ext} must be carried out by shifting the magnets in the injection and the extraction regions, respectively. The final version of the system can be distinguished by the ring magnets size and the number of solenoids: five instead of three for more accurate adjustment of the magnetic field at the edges of the plasma chamber.

Figures 7 and 8 show the results of simulation of the final modification of the system. The distribution of the axial field in the microwave mode was also modified with the solenoid currents, so that the magnetic field at the edges of the chamber corresponds to the electron cyclotron resonance. Currents in the solenoids in the mode of single-charged ions generation (microwave source) with fixed position of permanent magnets are in the range from 80 to 285 A. Currents in the solenoids in the same mode with adjustable position of injection and extraction ring magnets are in the range from 0 to 50 A.

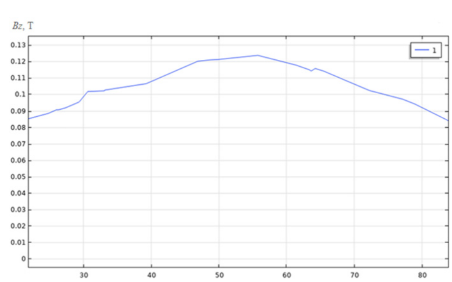

Figure 7: Axial magnetic field profile of the microwave source operating mode with the fixed position of the ring magnets.

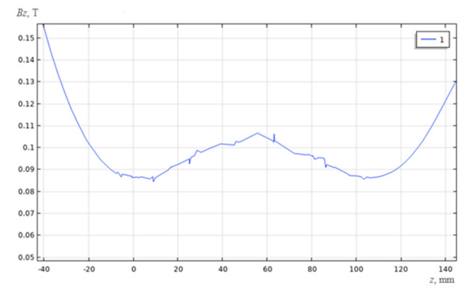

Figure 8: Axial magnetic field profile of the microwave source operating mode with the adjustable position of the ring magnets.

Table 2 presents the magnetic system characteristics in ECR operation mode after the optimization in the absence of currents in the solenoids.

Table 2: Optimized Parameters of the Magnetic System In ECR Operation Mode

	B_{inj}, T	B_{min}, T	B_{rad}, T	B_{ext}, T
Optim.	0.350	$0.058 < \|B\|_{min} << 0.087$	0.193	0.175
Calc.	0.351	0.073	0.190	0.177

CONCLUSION

A new ECR ion source with the operating frequency of 2.45 GHz is under development. The magnetic system with the variable parameters was calculated to provide the operation in two modes: ECR and microwave modes. To improve the parameters of the magnetic system the modification with additional solenoids was considered and calculated. The resulting system satisfies all the conditions required. The final modification of the source does not require currents in solenoids in the double-charged ions generation mode, the restructuring of the magnetic system can be carried out by moving the magnets of the injection and the extraction regions away from the plasma chamber and by imposing currents to the solenoids.

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