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MAGNETIC SYSTEM WITH VARIABLE CHARACTERISTICS FOR A 2.45 GHz ECRIS

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Abstract

The study considers the development of the magnetic system of the 2.45 GHz ECRIS for the production of protons and double-charged helium ions. The magnetic field configuration is shown to be based on permanent magnets. The results of the simulation made by the Finite Element Method have been performed. To adjust the axial magnetic field profile the configuration with the alternating position of the ring magnets was analyzed. The double series construction of the bar magnets provides the adjustment of the radial magnetic field B_{rad} at the chamber wall. Additional solenoids were introduced to the system for a corrective tuning of theB_{inj} and B_{ext} parameters and the axial profile minimum B_{min} of the magnetic field distribution. Thus, the magnetic system is appeared to provide the mode switching between the ECR and the microwave operating modes.

INTRODUCTION

A new ECR ion source for the light ion linac is under development at MEPHi. It is designed for the generation of both protons and double charged helium ions. The choice of the operating frequency of 2.45 GHz is specified by several factors: the wide range of elements available at the microwave wavelength, working experience in this frequency range, the compactness of the magnetic system as well as the adjustment ability of the magnetic field distribution inside the plasma chamber.

In order to obtain the required proton intensity and ensure the helium production at the frequency of 2.45 GHz, 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 sourceprovides 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 currentsin comparison with microwave sources, which provide high beam currents of protons.

The aim of this research is to design a new ECRIS for producing double-charged ions of helium and protons. This aim will be accomplished by meeting the following objectives: developing a magnetic system and calculating the magnetic field parameters to determine the most feasible configuration of the source in order to provide the operation in both ECR and microwave modes.

BASIC PARAMETERSOFECR 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 mA 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.

To accomplish the ion parameters required microwave plasma sources were considered according to the following advantages: stability, long lifetime, 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 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.

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".

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THE MAGNETIC SYSTEM CONFIGURATION DEVELOPMENT

This section describes the main steps of the 2.45 GHz ECRIS magnetic system development. The numerical simulation of the magnetic field parameters was made by the Finite Element Method (FEM). The initial model of the magnetic system was described in the previous papers [1,2]. Further optimization of the magnetic system design was made to adjust the minimum of the axial field B_{min}. Three solenoids were added to the model of the system to adjust the axial field profile. The initial model is presented in the Fig. 1. The simulation results are presented in the Fig. 2.

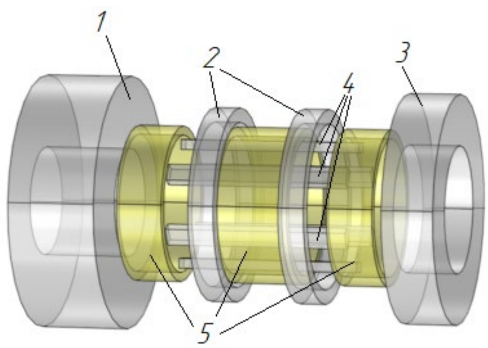

Figure 1: The model of the magnetic system of the 2.45 GHz ECRIS. (1)Injection ring magnet.(2)Middle ring magnet. (3)Extraction ring magnet. (4)Hexapole magnet. (5) Solenoids

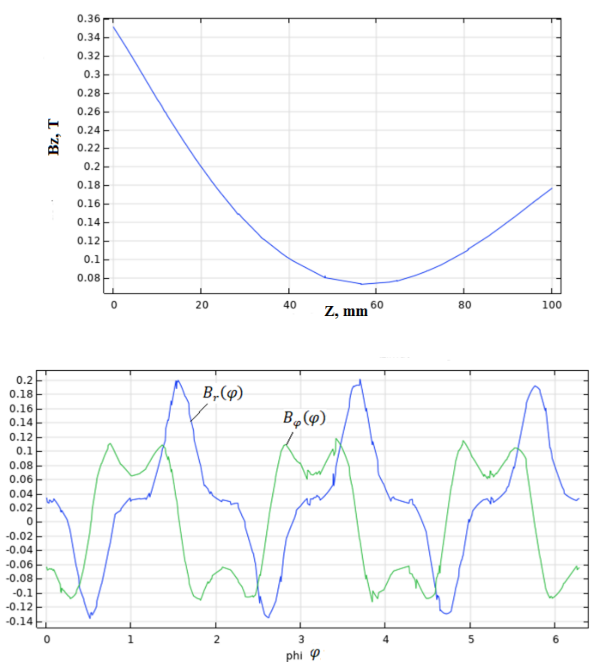

Figure 2: Magnetic flux density distributions of thesystem with the solenoids.

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. Table 1 presents the magnetic system characteristics after the optimization.

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

The solid rings with a small inner diameter and radial magnetization are quite complicated for the manufacturers to be produced. According to these technological peculiarities, ring magnet assembly made of trapezoidal elements is more technologically applicable than the whole ring magnets. The configuration suggested in this paper is also expected to avoid longitudinal displacement of the ring magnets, described in the previous papers, as the magnetic assembly provides the radial tuning of the magnet elements position instead. This design prevents the exceedance of the longitudinal space limits and also reduces the size of the whole magnetic system assembly. The central ring magnets are composed of the rectangular magnet bricks to provide the adjustment of the axial magnetic field minimum by the radial or axial displacement of the magnets. Finally, the more accurate profile tuning can be reached by the geometrical adjustment or the additional solenoids currents selection.

Figure 3 shows a model view of the magnetic assembly with solenoids. Axial field distribution for the ECR operation mode is presented in the Fig. 4.

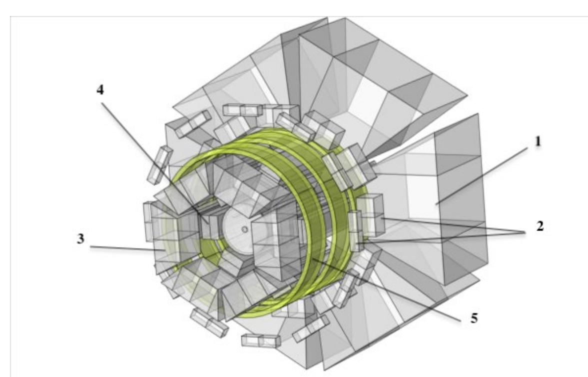

Figure 3: The model of the ECR mode magnetic system. (1) Injection ring magnet. (2)Middle ring magnets. (3) Extraction ring magnet. (4) Hexapole magnet. (5) Solenoids.

The resulting currents of the solenoids are: 70, 0 and -100 A. Current research appears to reveal the slight discrepancy between the simulation results for the described modifications of the system: the minimum of

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the system assembly resulting profile exceeds the optimal parameter given above. Further investigation is needed to adjust the lowest point of the axial magnetic field.

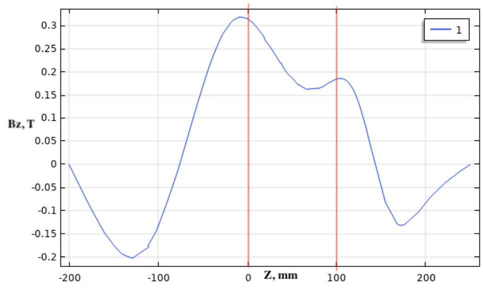

Figure 4: Magnetic flux density distributions of the system with the solenoids.The red lines depict the plasma chamber boundaries.

Table 2 presents the magnetic system characteristics in the ECR operation mode.

Table 2: Magnetic System Parameters

	B_{inj}, T	B_{min}, T	B_{ext}, T
Optim.	0.350	0.058 < $\lvert B\rvert_{min}$< <0.087	0.175
Calc.	0.321	0.163	0.178

THE MICROWAVE MODE MODIFICATION

Figure 5 depicts the simulation model of the magnetic system of the microwave mode.

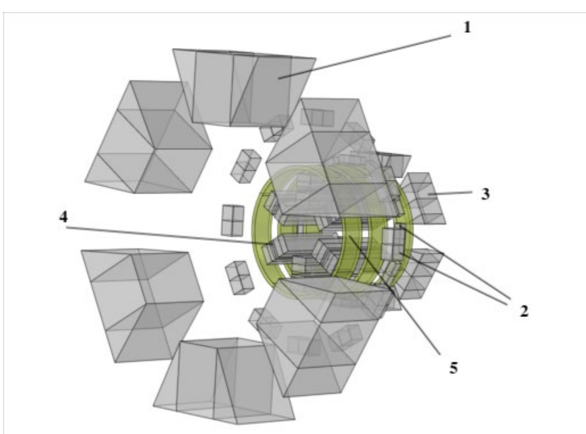

Figure 5: The model of the microwave mode system modification. (1) Injection ring magnet. (2) Middle ring magnets. (3) Extraction ring magnet. (4) Hexapole magnet. (5) Solenoids.

The results of simulation of the microwave mode modification are presented in the Fig. 6. The distribution adjustment in the microwave mode was also carried out by solenoid currents, so that the magnetic field at the edges of the chamber corresponds to the electron cyclotron resonance. The resulting solenoid currents are: 5, 0, and 45 A. Table 3 presents the magnetic system characteristics in microwave operation mode after the final optimization.

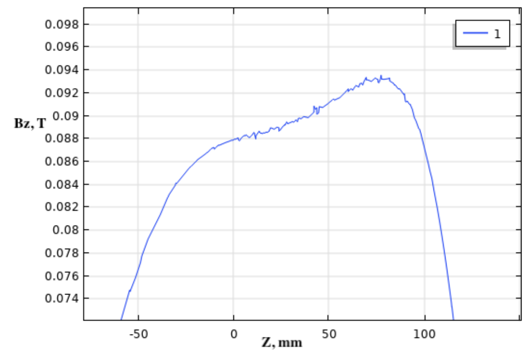

Figure 6: Axial magnetic field profile of the microwave source operating mode with the adjustable position of the ring magnets.

Table 3: Optimized Parameters of the Magnetic System in the Microwave Operation Mode

	B_{inj}, T	B_{ext}, T
Optim.	0.087	
Calc.	0.088	0.087

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 the magnetic assemblywas considered and calculated. The resulting system satisfies the required parameters; however, the lowest point of the field distribution in the ECR mode needs to be adjusted.The solenoid currents provide an accurate magnetic field tuning and displacement of the magnet assembly elements keeps the possibility of the mode selection.

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