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3D SIMULATION STUDY AND OPTIMIZATION OF MAGNETIC SYSTEM OF DECRIS ION SOURCE WITH THE PUMPING FREQUENCY 28 GHz

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Abstract

A superconducting magnet system for a 28 GHz ECR ion source (DECRIS) was studied in order to select its parameters and optimize performance.

Parametric magnetic models were performed for two design configurations, conventional ("sextupole-in-solenoid") and reversed ("solenoid-in-sextupole"). For both configurations, the magnetic effect of the booster and the steel poles on the magnet performance was investigated from the point of view of critical parameters of the system – currents, fields, and forces.

Results of the parametric computations were used to optimize the geometry and sizes of the magnet as well as the magnetic shield, the booster, and the poles.

A comparison of the obtained parameters was used to select the candidate magnet configuration for further design and manufacture.

INTRODUCTION

A 28 GHz ECR ion source DECRIS will be used for the Superheavy Elements Factory (SHE) at JINR, Dubna, which allows to ensure desired mass and energy ranges and the beam intensity in accelerators.

Operation at the 28 GHz demands efficient magnetic configuration capable to provide the axial field as high as 4 T at the injection side in the plasma region.

In order to generate high confining fields DECRIS utilizes a superconducting magnetic system. Efremov Institute is responsible for the magnetic system (MS) design and optimization. Key parameters of the magnetic system are listed in Table 1.

Table 1: Key Parameters of the Magnet System

Warm bore diameter	142 mm
Plasma chamber internal diameter	125 mm
Field peak-to-peak axial distance	420 mm
$B_{\mathbf{inj}}$ on axis	4 T
$B_{\mathbf{extr}}$ on axis	2÷2.5 T
Minimal axial field $B_{\mathbf{min}}$	0.5÷0.8 T
Field module $\lvert\mathbf{B}\rvert$ at R = 62 mm	2.02 T

The magnet system consists of two groups of coils capable to generate min-B confining fields in the plasma region. The axial mirror field is produced by a segmented solenoid. The radial field is generated by a sextupole formed with six racetrack coils assembled in a circle so that their poles alternate.

RESULTS FOR TWO MODELS

Two principal coil layouts are briefly discussed focusing on optimal magnetic performance: a *conventional* ("sextupole-in-solenoid") configuration and a *reversed* ("solenoid-in-sextupole") option. In the "sextupole-in-solenoid" design racetrack coils of the sextupole are located inside the solenoid (Fig. 1a). In the "solenoid-in-sextupole" design the coils arrangement is reversed (Fig. 2a). Both configurations have been well proven in existing ECR sources. Particularly, VENUS for the Facility for Rare Isotope Beams at LBNL utilizes "sextupole-in-solenoid" magnets [1]. An example of the "sextupole-in-solenoid" magnet design is SECRAL-II for the Heavy Ion Facility in Lanzhou, China [2].

Figures 1b-2b show similar models with iron. The racetrack coils contain steel poles. All the coils are enveloped with a steel booster. All steel components are saturated during operation.

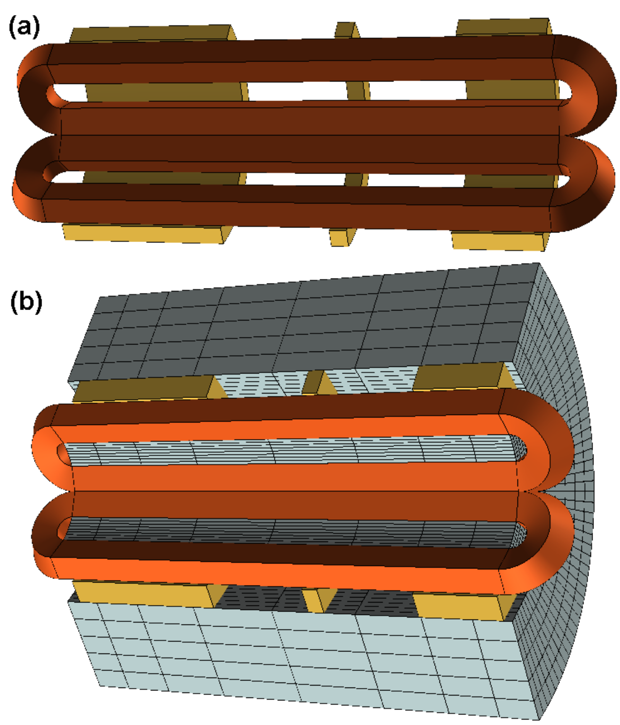

Figure 1: Conventional (sextupole-in-solenoid) magnetic system. Model without (a) and with (b) iron.

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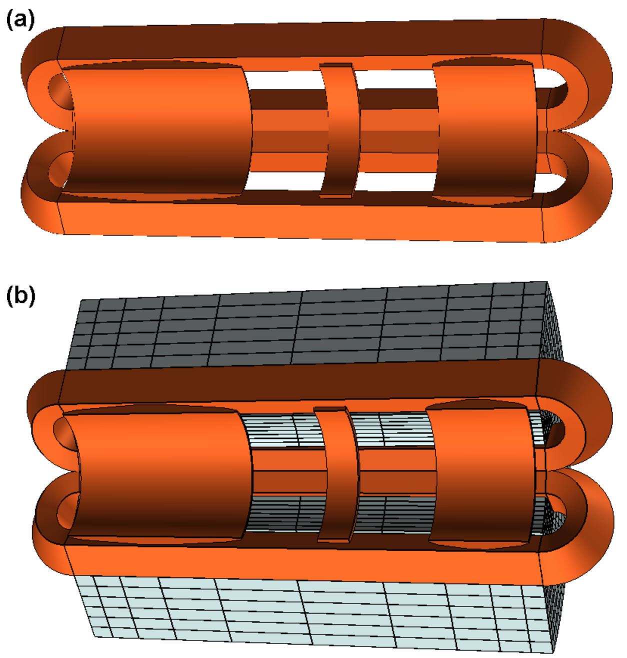

Figure 2: Reversed (solenoid-in-sextupole) magnetic system. Model without (a) and with (b) iron.

Table 2 summarizes the achieved magnetic parameters of these systems.

Table 2: Total Current I_t, Current Density J_e, and Maximum Field B_{max} in Conductor for Considered Options

Parameter	Conventional		Reversed	
	Fig. 1a	**Fig. 1b**	**Fig. 2a**	**Fig. 2b**
		Sextuple		
I_t, kAt	353	288	622	482
J_e, A/mm^2	316	258	304	235
B_{max}, T	8.0	7.6	8.6	7.8
		Solenoid from injection side		
I_t, kAt	1088	961	865	842
J_e, A/mm^2	218	192	416	405
B_{max}, T	7.3	7.3	7.3	7.1

As seen from Table 2, the steel components sufficiently decrease the field in conductor and coil current.

Parametric simulations were performed for two design options to investigate magnetic effect of the booster and the poles on the magnet performance. Results of computations were used to optimize the geometry and sizes of the magnet.

For better reliability and validation of the result, computations were performed with two codes, KOMPOT and KLONDIKE, utilizing the differential and integral formulations, respectively [3, 4]. The obtained parameters allowed selection of a candidate magnet configuration for further design and manufacture. Table 3 summarizes comparative evaluation of the basic parameters for both design options.

Table 3: Magnetic Parameters for Two Options

Parameter	Conventional, Fig. 1b	Reversed, Fig. 2b
	Max field in conductor, T	
Sextuple	7.6	7.8
Solenoid	7.3	7.1
	conductor current density, A/mm^2 (calculated/ NbTi design)	
Sextuple	258/264	**235/222**
Solenoid	192/270	**405/369**
	Others	
Stored energy, kJ	135	230
Conductor length, km	9.3	6.0

Figure 3 presents the current density in a NbTi cable as a function of the field.

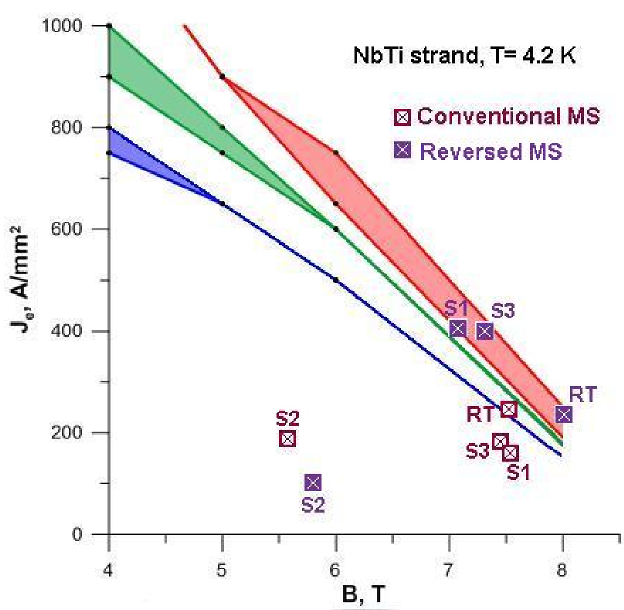

Figure 3: Current density J_e vs. magnetic field B in superconducting ECR magnets. S1, S2, S3 – solenoids, RT – racetrack coil.

The blue, green, and red lines outline, respectively, the reliable, recommended, and risky mode of operation. Markers show the achieved values of current density. Figure 3 shows, that conventional design is favourable and allows using an NbTi conductor for the winding.

Figures 4 and 5 demonstrate field maps (in T) in two planes X = 0 and Y = 0, corresponding to racetrack poles centre and racetrack outer boundary. ECR heating zone R < 62 м is marked in yellow. Solenoid cross-sections are purple, racetracks – orange, and racetrack poles – grey.

Conceptually the conventional option is presented in Fig. 6.

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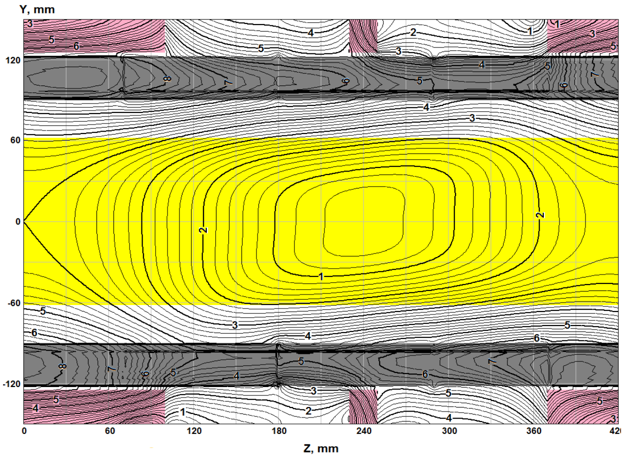

Figure 4: Simulated field map in plane X = 0.

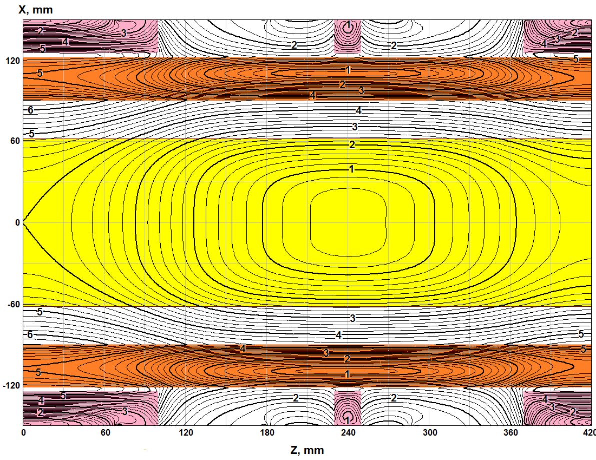

Figure 5: Simulated field map in plane Y = 0.

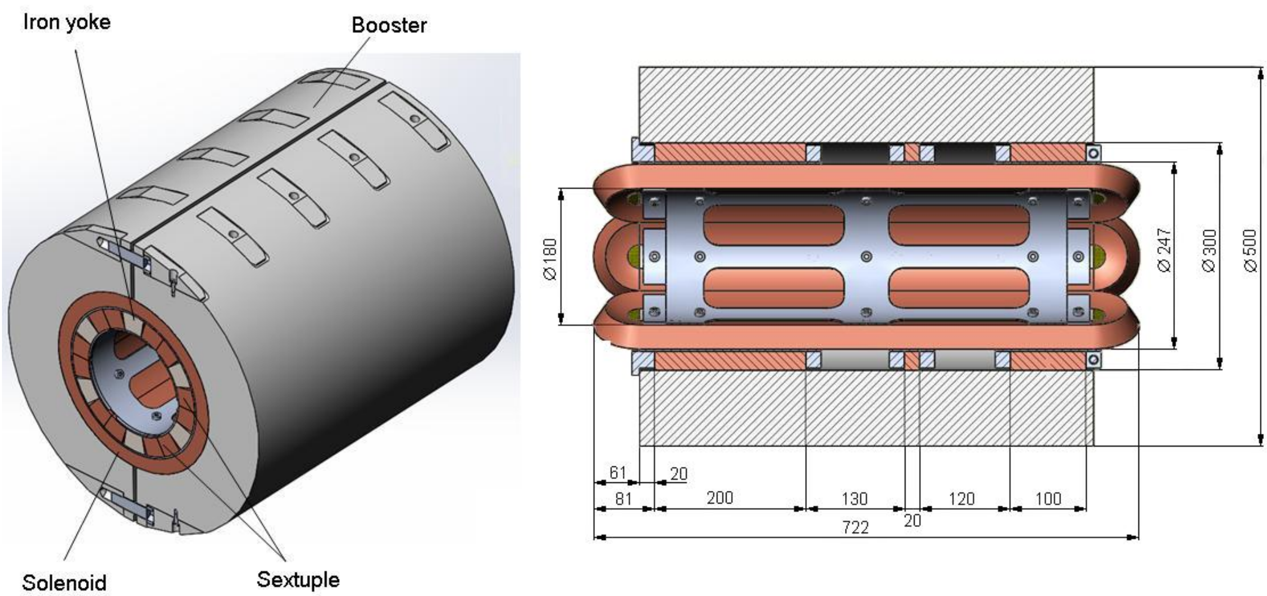

Figure 6: Conceptual design of magnetic system.

CONCLUSION

The simulations have revealed that even with the optimized design the operating current in the "solenoid-in-sextupole" configuration is close to the critical value. This greatly increases conductor loading and deteriorates reliability of the ECR source operation.

For this reason, the conventional "sextupole-in-solenoid" design has been proposed as preferable for further development and construction.

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