SC MAGNET DEVELOPMENT FOR SIS100 AT FAIR

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Abstract

Superconducting magnets have been constructed and tested for the SIS100 (Heavy Ion Synchrotron with a magnetic rigidity of 100 Tm) of the FAIR project. The requested high quality of the magnetic field as well as the fast periodic ramp of the SIS100 (2 T, 4 T/s, 1 Hz) requires that any source of AC losses is tightly reduced by carefully optimising the 3D geometry of the yoke, choosing the appropriate iron material and minimising the eddy current loops. In addition optimal wire, cable and coil designs have been developed. The residual heat production will be reliable removed by an efficient cooling scheme. The beam pipe vacuum chamber must operate stably as a cryo-pump with surface temperatures below 20 K. The electromagnetic, thermal and mechanical aspects were optimised and finally investigated based on physical analysis, supported by FEM calculations and dedicated tests. The results obtained on the main magnets were used for dedicated development of the corrector magnets and their effective integration in the complete cryo-magnet complex of the accelerator. We describe the features of the final magnets and present the construction status of the SIS100 magnets.

INTRODUCTION

During the last decade the R&D strategy for the fast ramped superconducting magnets of the SIS100 accelerator was based on the experiences obtained on its ancestor, the Nuclotron Synchrotron at JINR Dubna that operates since 1993. The key element of its magnet design is the Nuclotron cable, cooled by a two phase forced Helium flow and wound into a coil with two layers with 8 turns for the dipole, two layers with 3 turns per pole for the quadrupole. The coils of the corrector magnets were built from superconducting strands cooled indirectly by heat conduction to the quadrupoles supporting the correctors mechanically. The operation current of the main magnets was about 6 kA. Our R&D had succeeded in a significant reduction of the AC losses in the iron yoke and in the coil, led to an improvement of the magnetic field quality and to a mechanical more stable coil design [1], [2]. The SIS100 main magnets will have also a larger effective length of 3 m and 1.3 m for dipole and quadrupole respectively. The SIS100 corrector magnets will be actively cooled using Nuclotron type cables with electrically insulated sc strands and the beam pipe will be additionally cooled to ensure their cryopump functionality for the operation with high intensity intermediate charge state heavy ions.

MAIN MAGNETS

The SIS100 main magnets will have a larger usable aperture of 60 mm x 120 mm and a high current coil. The higher operational current allows reducing the number of turns per magnet pole. In addition, the original Nuclotron cable was also redesigned with an increased inner diameter of the cooling channel that further decreased the final hydraulic resistance of the coil down to ¼ if compared to the originally design [3]. This was done to provide the necessary cooling rate to remove the AC loss heat production at the most intensive continues triangular operation cycle requested for beam dymanic operation modes.

Curved Dipole

The curved dipole coil consists of one layer with 8 turns and will operate at 13 kA for the maximum operation field of 1.9 T. The 3D model of the complete assembled magnet is shown in Fig 1, the main parameters are summarised in Table 1.

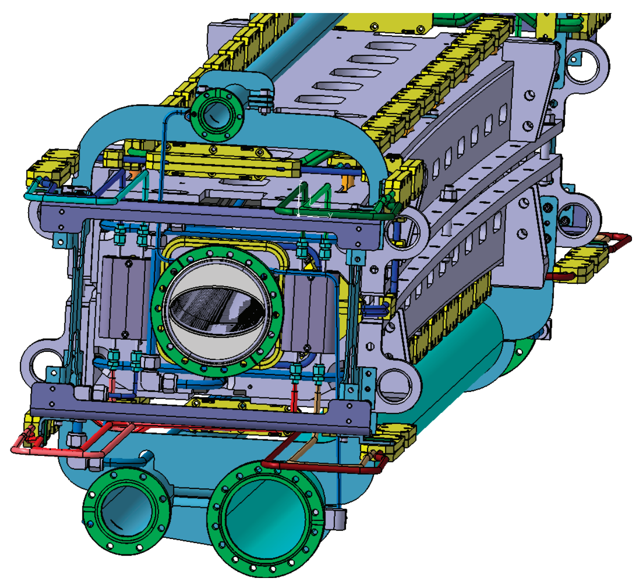

Figure 1: 3D View of the Curved Single Layer Dipole (CSLD). Brackets and end plates (in grey) support the laminated yoke. The end coil (indicated in yellow) is small and close to the vacuum chamber. Bus bars are mounted on top and at the bottom of the magnet (red, blue, light blue and turquoise tubes). The larger yellow elements keep them in place. The feeding and return helium headers are mounted below the magnet. The feeding helium header for the vacuum chamber is mounted on top of the magnet.

In the SIS100 ring there are 108 dipoles plus one in the reference string; additional four spare magnets will be produced. The series production is already contracted with industry (Babcock Noell GmbH Würzburg) and the production preparation of the first dipole has been started in I/2012. The first magnet is planned to be ready for

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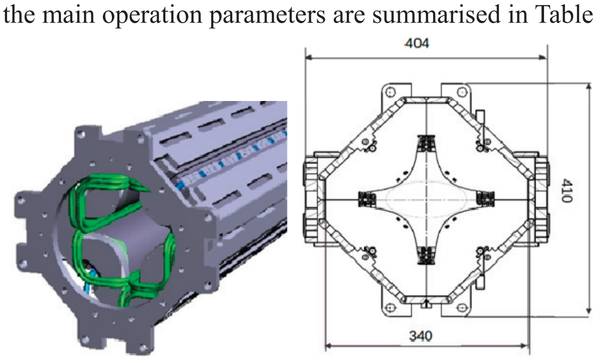
intensive tests at GSI Darmstadt beginning of 2013. The continuous production of all the dipoles should be finished until the end of 2016.

Table 1: Main Parameters of the Dipoles

Parameter	Units	Value
Number of magnets		113
Design		Superferric, window-frame, curved
Effective length L_{eff}	m	3.062
Usable aperture (h·w)	mm	60·115
Bending angle	deg	3.33
Bmin	T	0.228
Bmax	T	1.9
Max. ramp rate	T/s	4

Quadrupole

For the final layout of the SIS100 Quadrupole a 3 turn per pole high current coil design was chosen, described in detail in [2]. It is made of the same cable as for the dipoles and operates at a maximum current of 10.8 kA. Figure 2 presents the 2D and 3D design of the magnet, the main operation parameters are summarised in Table 2.



(a) (b)

Figure 2: View on the SIS100 Quadrupole. (a) 3D Modell of the quadrupole. The coil is given in green, yoke, end plates of the magnet and brackets are in grey. (b) Cross section of the magnet

Table 2: Main Parameters of the Quadrupoles

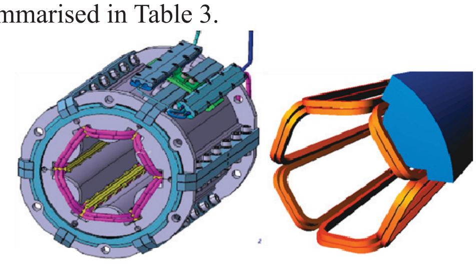
Parameter	Units	Value
Number of magnets		169 (+2)
Design		Superferric
Effective length L_{eff}	m	1.3
Usable aperture (h·w)	mm	65·135
Max. gradient	T/m	27
Bmax	T	1.9
Max. ramp rate	(T/m)/s	57

CORRECTOR MAGNETS

The cross section of cables for the corrector coils are similar to the original Nuclotron, except the improved design parameters of the low loss superconducting strands. The electrical insulation of each strand reduces the operation current below 300 A for the individually powered magnets. A detailed description of the magnets is given in [4].

Chromaticity Sextupole

Figure 3 shows the 3D design of the chromaticity sextupole and of the coil structure, the main parameters are summarised in Table 3.



(a) (b)

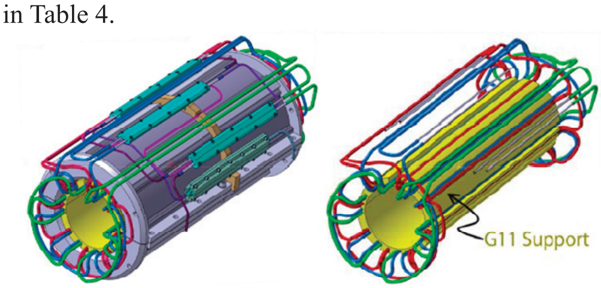
Figure 3: View on the SIS100 Chromaticity Sextupole Corrector Magnet (a) 3D model of the magnet, (b) 3D model of the coil.

Table 3: Parameters of the Chromaticity Sextupole

Parameter	Units	Value
Number of magnets		48
Design		Superferric
Effective length L_{eff}	m	0.5
Aperture radius	mm	60
Max. main field strength	T/m^2	175
Minimum ramp time to B_{max}	s	0.175

Multipole Corrector

The multipole corrector design is based on a structure of the nested quadrupole, sextupole and octupole coils as presented in Fig. 4, the main parameters are summarised in Table 4.



(a) (b)

Figure 4: View on the Multipole corrector magnet of the SIS100. (a) 3D model of the magnet, (b) Coil design: quadrupole corrector in green, the sextupole corrector in blue and the octupole corrector in magenta.

Table 4: Parameters of Multipole Correctors

Parameter	Units	Value
Number of magnets		12
Design		CosΘ, nested
Effective length L_{eff}	m	0.75
Aperture radius	mm	80
Max. B_2	T/m	0.75
Max. B_3	T/m^2	25
Max. B_4	T/m^3	334

Steering Magnet

The cross sections of the steerer and of the multipole corrector were reduced to minimise the field errors without mechanical collision of the cables of the nested coils (see Fig. 4 and Fig. 5). The parameters of the steerer are given in Table 5.

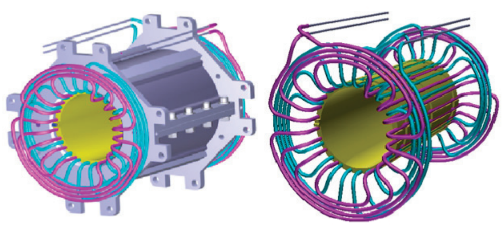


Figure 5: View on the SIS100 Steering magnet. (a) 3D model of the magnet, (b) Coil design: normal dipole in cyan, skew dipole in magenta.

Table 5: Parameters of Steering Magnets

Parameter	Units	Value
Number of magnets		48
Design		CosΘ, nested
Effective length L_{eff}	m	0.5
Aperture radius	mm	80
B_{max}	T	0.3
Minimum ramp time to B_{max}	s	0.2

CRYOGENIC DOUBLET MODULES

The quadrupoles and the corrector magnets will be mechanically connected within different units (see Table 6). There are three different electrical circuits for Quadrupoles two focusing (QF1, QF2) and defocusing (QD). Further corrector magnets: chromaticity sextupole (horizontal – CH or vertical - CV) and steerer (ST as well as a beam position monitor (BPM) and a collimator will be assembled in one cryogenic module.

Table 6: Types of Quadrupole Units

Type	1	2	3	4	5	6	7	8	9	10
Contents	QD	QD BPM	BPM QD	CV QD	ST F1	ST F2	ST F1 BPM	ST F2 BPM	ST F1 CH	ST F2 CH
Quantity	12	23	24	24	6	17	18	18	12	12

These quadrupole units will be finally combined into nine different types of cryogenic doublet modules and three special doublets for injection, extraction and a warm section as show for one example in Fig. 6. It is planned to finalise the design of these doublets already in II 2013 and start producing the first version already this year for intensive testing.

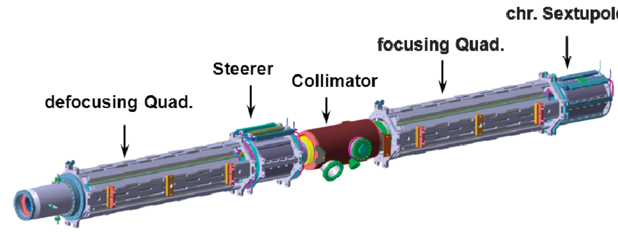


Figure 6: Typical content of a cryogenic doublet module placed in one common cryostat.

CONCLUSIONS

The design of the superconducting dipoles, quadrupoles and corrector magnets for the SIS100 heavy ion accelerator of FAIR have bin settled. The magnetic field characteristics, the AC losses and cooling conditions as well and a safe mechanical stability are analysed with help of analytical and FEM calculations. The preparation for series production of the dipoles is started. The quadrupoles and corrector magnets will be integrated in a common cryostat module containing two quadrupoles with different corrector elements. It is planned to complete the integration concept within one year and to launch the series production of the quadrupole doublets.

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