Development of fast ramped superconducting magnets for SIS300

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INTRODUCTION

The accelerator SIS300 is the second of the two planned new synchrotrons at FAIR (Facility for Antiproton and Ion Research) in Darmstadt, Germany. The high field values of up to 4.5 T for the dipoles require a so called cos(Θ) design. The ramp rate of these magnets is 1 T/s, therefore special attention has been taken on the reduction of AC losses and the mechanical integrity of the magnets. For this, for example, new superconducting wires with small filament sizes of about 3 µm and a resistive CuMn matrix between the filaments has been developed. A full size model of a short curved dipole (4.5 m long) was designed, built and tested in a collaboration of GSI with groups of INFN in Genova, Milano and Salerno. Additionally, two quadruple magnets and a steering dipole have been produced and successfully tested at IHEP, Protvino. The magnet design activities over the past years as well as an outlook into the future will be summarized.

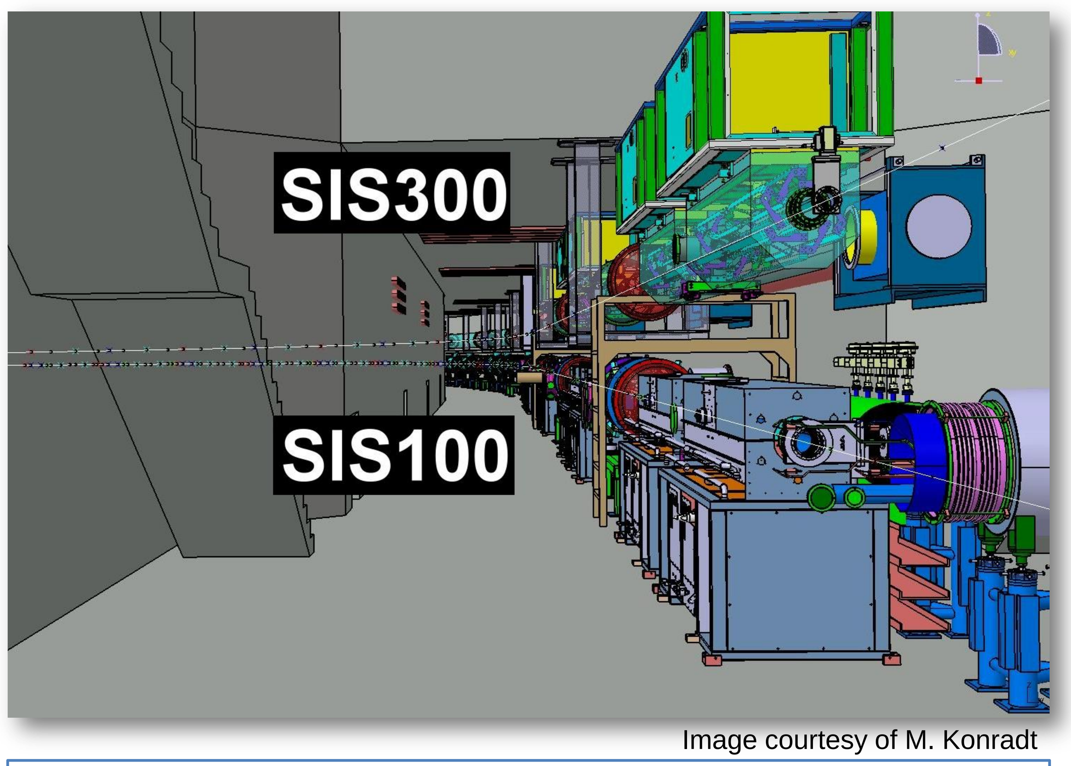

Image courtesy of M. Konradt

Figure 1: Front view of a straight section with the RF acceleration systems of SIS100 (bottom) and SIS300 (top) and connection box of the cryogenic bypass lines (right) which bridges the warm insertions.

Table 1: Comparison of the SIS300 dipole parameters with other accelerators.

	Aperture [mm]	B [T]	dB/dt [T/s]	Π	Q [W/m]
LHC	53	8.34	0.008	0.067	0.18
RHIC	80	3.50	0.060	0.210	0.35
SIS300	**100**	4.50	**1.000**	**4.500**	**<10.00**

Main dipole parameters

The technical parameters of the SIS300 (sitting atop on the SIS100, see fig. 1 and tab. 1/2.) lead to many challenges. The high ramp rate of 1 T/s usually leads to large AC losses which in turn lead to premature quenches and high demands on cryogenic supply.

Therefore, the development of a low loss cored cable was done and the magnet design adapted to loss minimization (eddy current reduction).

Additionally, the small radius of curvature (66.7 m) and the need for a lifetime of >10^7 cycles lead to even more demanding mechanical design and materials optimization to avoid fatigue, see fig. 2.

Table 2: Technical parameters of the SIS300 short dipole.

Geometric radius of curvature	66.7	**m**
Magnetic length	3.879	**m**
Bending angle	3 1/3	**°**
Block number	5	
Turn number / Layer	34 / 1	
Operating current	8 920	**A**
Cold mass outer radius	250	**mm**
Working point on load line	69	**%**

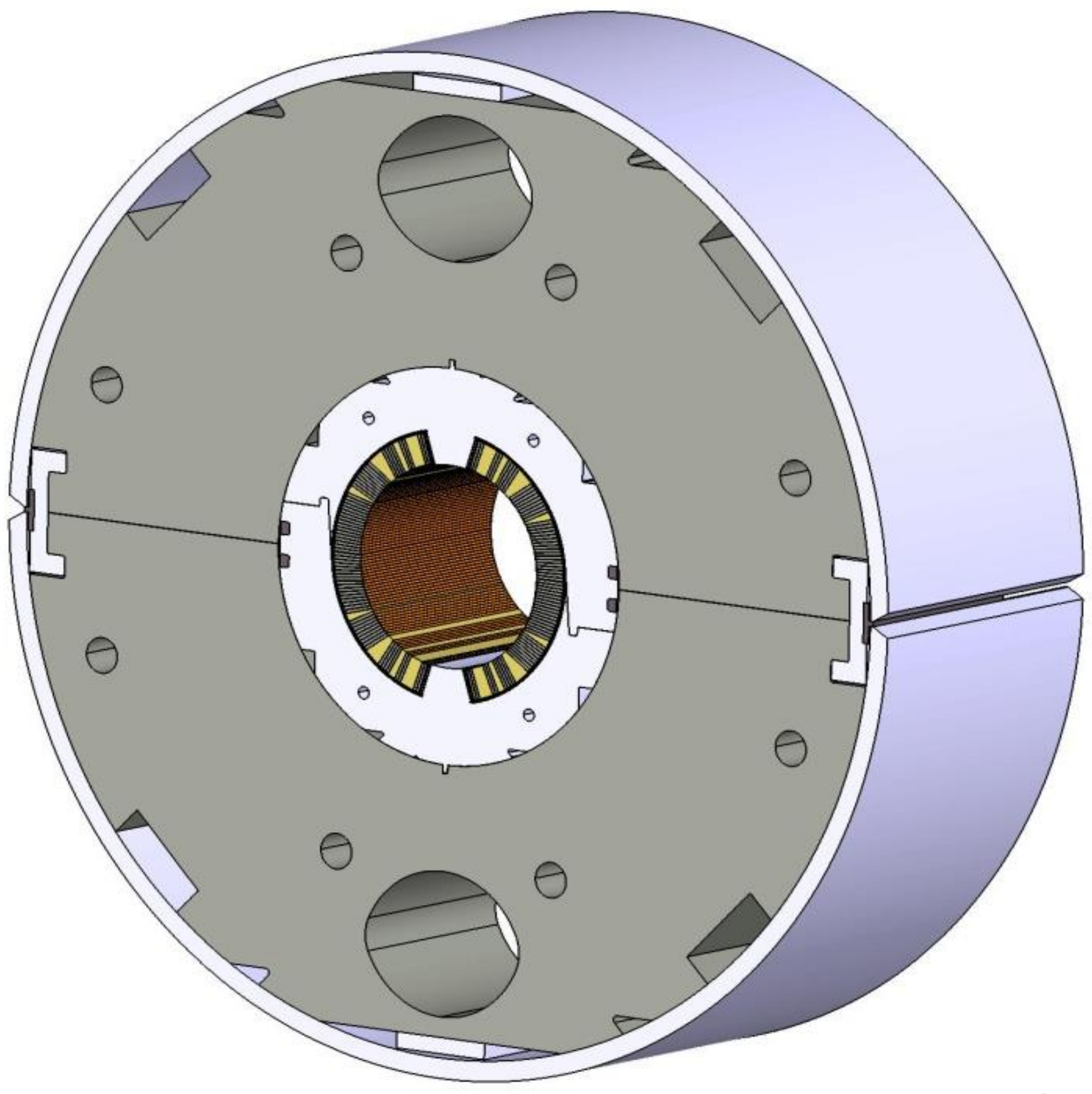

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Figure 2: Reference design of a short SIS300 dipole model. A one layer coil was chosen for simplest design; only collars have a mechanical role. The yoke limits the collar deformations, whereas the shell limits the cold mass deformations.

Low loss wire and cored cable development

Image courtesy of INFN

Figure 3: The low loss cable.

The superconducting wire has been developed at Luvata Pori together with INFN. Two wire generations were developed, the second one with a higher content of Cu-Mn. The low loss cored cable has been developed and successfully produced, see fig. 3.

Wire Parameter	Specified	Obtained
Diameter after coating / mm	0.825 ± 0.003	OK
Filament twist pitch / mm	5 +0.5 -0	6.6 (under 5 mm significant degradation of I_c)
Effective Filament Diameter / mm	≤ 3.5	3.2 1st gen 3.3 2nd gen
Interfilament matrix material	Cu-0.5 wt% Mn	OK
Ic @ 5 T, 4.22 K / A	> 541 (2530 A/mm^2)	470 A (2410 A/mm^2) 1st gen 515 A (2530 A/mm^2) 2nd gen
n-index @ 5 T, 4.22 K	> 30	32-33
Stabilization matrix	Pure Cu RRR100	RRR100-130
ρ_t at 4.22 K / nW·m	0.4 + 0.09 B [T]	0.3 @B=0 T 1st gen 0.4 @B=0 T 2nd gen
Cu+Cu-Mn : Nb-Ti ratio (α)	>1.5 ± 0.1	1.75 1st gen 1.63 2nd gen
Surface coating material	Staybrite (Sn-5 wt% Ag)	OK

Cable Parameter	Specified	Obtained
Number of strands	36	OK
Width, thin edge / mm	15.10 +0 -0.020	OK
Thickness, thin edge / mm	1.362 ± 0.006	OK
Thickness, thick edge / mm	1.598 ± 0.006	OK
Core material	AISI 316 L, annealed	OK
Core width / Core thickness	13 (mm) / 25 (µm)	OK
Transposition pitch / mm	100	OK
Ic @ 5 T, 4.22 K (A)	> 18 540 (2530 A/mm^2)	15 912 (2270 A/mm^2) 1st gen 17 676 (2415 A/mm^2) 2nd gen

Curved winding and collaring operations

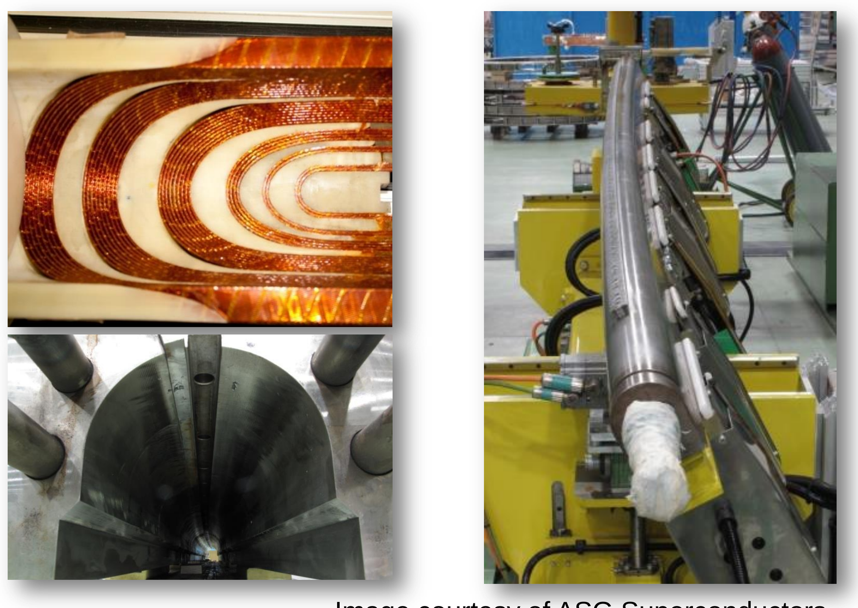

Image courtesy of ASG Superconductors

Figure 4: Special tools for curved winding and collaring of SIS300 dipole.

As the dipole, in contrast to other cos(Θ) designs, is curved, special tool development was necessary for the curved winding operations. This was done at ASG Superconductors.

The collars are 2.8 mm thick plates from high strength austenitic steel. Preassembly took place in straight blocks of 30 mm each. The yoke plates are 1 mm thick.

Cold testing

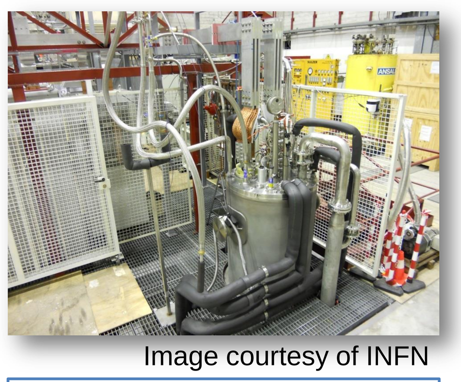

Image courtesy of INFN

Figure 5: Vertical cryostat test setup.

Testing of the dipole magnet took place at INFN, Milano in a 6.5 m deep vertical cryostat, see fig. 5.

The first training quench occurred at 92% of the nominal current; nominal current has been reached. The measured AC losses are lower than expected, see fig. 7.

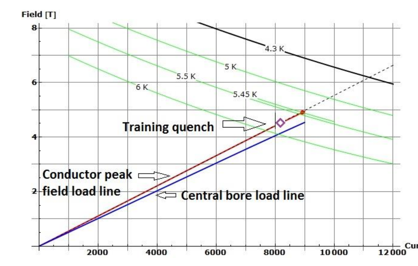

Figure 6: Measured magnetic field and critical current of cable.

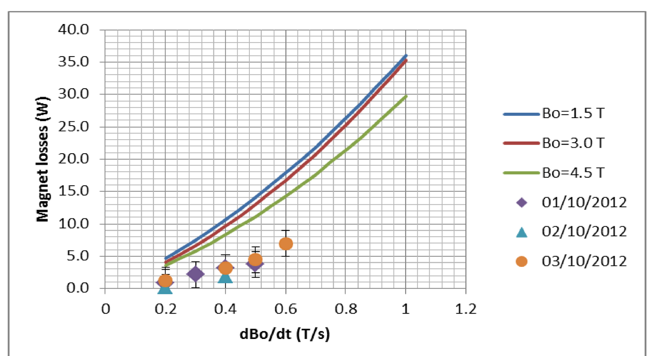

Figure 7: Measured AC losses.

SIS300 quadrupole prototype

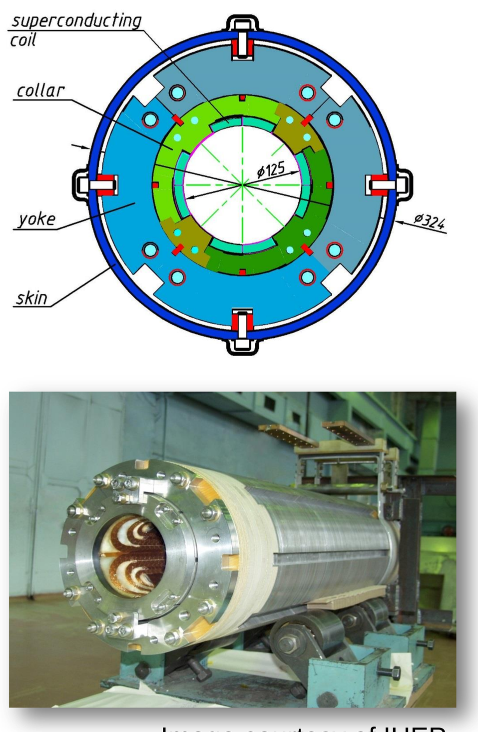

Image courtesy of IHEP

Figure 8: SIS300 quadrupole cross-section (top) and prototype (bottom).

Two quadrupole prototype magnets with 45 T/m central gradient and an inner diameter of 125 mm were produced by IHEP, Russia from UNK and Bochvar SC wire. Both were successfully tested. The quench training showed a critical current of more than 8.5 kA (nominal current is 6.25 kA), see fig. 9 and 10.

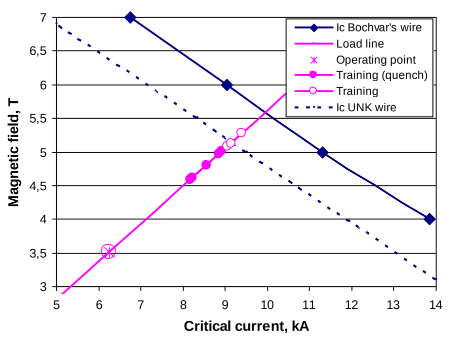

Figure 10: Measured magnetic field and critical current of the two cables.

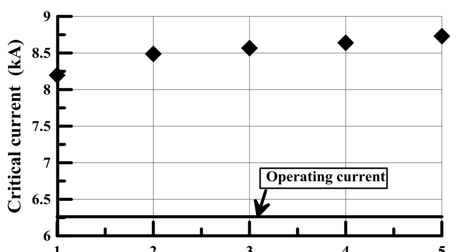

Figure 9: Quench training.

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