MANUFACTURING OF THE FIRST OF SERIES SIS100 DIPOLE MAGNET

W. Walter, W. Gärtner, S. Sattler, H. Scheller, R. Schönbein Babcock Noell GmbH, Würzburg, Germany
E. Fischer, J.P. Meier, H. Müller, P. Schnizer, GSI, Darmstadt, Germany

Abstract

Babcock Noell (Würzburg, Germany) manufactures the First of Series (FOS) SIS100 dipole magnet for the FAIR project. This contribution reports on the progress during the design-phase, performed together with GSI, and on the manufacturing- and assembly-processes. Special emphasis will be given on new or special techniques adopted to fulfil the stringent requirements demanded by such a magnet. The new tooling systems and machines which were developed and brought into operation for this FOS magnet will be discussed.

INTRODUCTION

The SIS100 is a Heavy Ion Synchrotron with a magnetic rigidity of 100 Tm. It is a major part of the Facility for Antiproton and Ion Research FAIR. The design of the SIS100 dipoles is driven by the required high field quality and fast periodic ramp rate (2 T, 4 T/s, 1 Hz) [1]. The design is originally based on the experience obtained at the Nuclotron Synchrotron at JINR Dubna, especially the concept of the Nuclotron cable cooled by two phase forced Helium flow and the superferric window-frame design.

During the last decade GSI followed a strategy to optimize the design of the SIS100 Dipoles [2], [3] on one side with respect to the technical requirements derived from the SIS100 parameters and on the other side towards a robust design ready for a series manufacturing in industry.

For the industrialization process of the SIS100 magnets industry was incorporated within a 6th Framework program, afterwards the SIS100 Dipole Prototype was manufactured by industry 2007-2008 [4] and since 2012 the First Of Series (FOS) Dipole, see Figure 1, is being build by Babcock Noell.

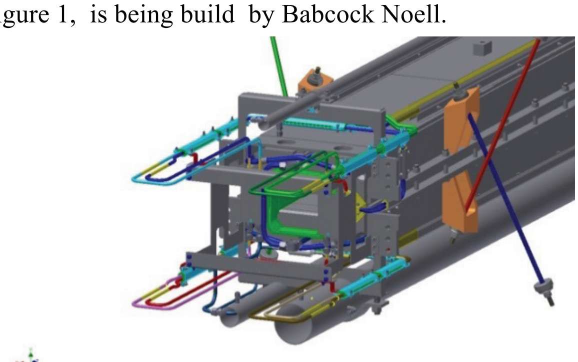

Figure 1: 3D view of the SIS100 FOS dipole cold mass.

THE SIS100 DIPOLE MAGNET

The SIS100 industrialization follows the same principle strategy successfully applied by CERN for the LHC Main Dipoles: after a design and development phase follows a prototype phase, then the pre-series phase and finally the series manufacturing [5].

The main goal of the design and development phase is the definition of the requirements for the product. In the prototype phase, the detailed design of the final production is verified. The FOS Magnet can be considered as a pre-series of one magnet. Within this phase parts are already fabricated according to the final specification and only slight modifications should be introduced. Procedures and tools are tested for the series manufacturing and leading staff is trained for the series manufacturing.

Evolution from Prototype to FOS Magnet

The SIS100 FOS Magnet has significant design improvements compared to the previous Prototype. The former 2-layer straight magnet design of the Prototype is now a 1-layer curved design, see Table 1. The main advantages of this new design are:

- Four times lower hydraulic resistance of the SC coil, cooled by forced two phase helium flow. This makes it possible to ramp the magnet with a continuously cycling threeangular mode with 4 T/s
- The curved magnet design allowed to reduce the peak field from 2.1 T to 1.9 T. This reduces also the field errors in the iron saturation limit significantly.

Table 1: Comparison SIS100 Dipole Prototype and FOS Dipole

Parameter	Prototype	FOS
Effective length	2.756 m	3.062 m
Bending angle	0 deg	3.33 deg
Bmax	2.1 T	1.9 T
Max. ramp rate	4 T/s	4 T/s
Layers*turns	2*8	1*8
Operating current	7 kA	13 kA
Outer diameter of cooling tube	5 mm	5.7 mm
Number of strands	31	23

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Parameter	Prototype	FOS
Strand diameter	0.5 mm	0.8 mm
Cable diameter	7.36 mm	8.29 mm

These design improvements created several new challenges for manufacturing the FOS magnet. Tools for the winding of a bend coil and the stacking of a curved yoke had to be developed. Additional challenges were e.g. the suspension of a bend magnet at its ends within in the cryostat. To allow for a 1-layer coil, the cable had to be modified, i.e. the diameters of the cooling channel and strands were enlarged. This reduced the space available for electrical insulation and structural material between turns which made the winding process overall and especially in the coil heads more demanding for the FOS.

SIS100 Series Dipoles

There are no principle design changes planned in going from the FOS Magnet to the series dipoles. For the SIS100 ring, a total of 108 dipoles plus one in the reference string are needed and additional four full spare magnets and 20 more spare coils will be manufactured and more than 16 km of cable will be produced [1].

MANUFACTURING OF THE FOS MAGNET

To qualify the cabling and coil manufacturing, dummy cable with Cu-wire instead of superconducting strands and a dummy coil have been manufactured in advance. In the following the main steps in the manufacturing process are described.

Cable Production

The Nuclotron type cable consists of a CuNi cooling tube, with the superconducting strands fixed on the outside by a NiCr wire and a Kapton insulation on top, see Figure 2 [6].

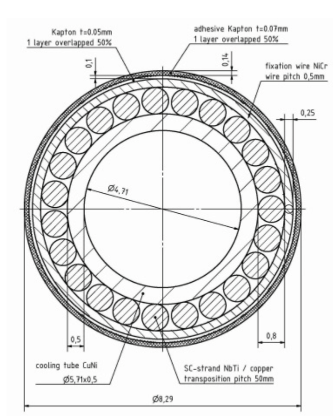

Figure 2: Cross section of the FOS cable.

The cabling machine was originally used for Rutherford cable, see Figure 3. The spinner that places the individual strands on the CuNi cooling tube is custom-made. For the FOS dummy coil and the FOS coil 114 m of cable are needed each (including busbars).

Figure 3: Cable production.

Coil Manufacturing

A dedicated winding tool was developed for the bend FOS coil and qualified by producing a dummy coil. The coil is wound by placing and gluing the cable with a 2-component epoxy resin into precisely pre-manufactured G11 structural elements. These structural elements will later ensure the precise placement of the coil with respect to the yoke and will avoid relative motion within coil and yoke during the cycling magnet operation. Therefore the cable and the structural elements are glued into a monolithic block with a reproducible heating process in a dedicated heating press.

Manufacturing of the Yokes

The yoke is laminated and consists of 1 mm thick magnetic steel sheets type M600-100A with Stabolit 70 coating on one side. First the laminations are stacked to packages of 200 mm length. A curved stacking tool is used to stack and press the laminations. The filling factor of the yoke is ensured by measuring length and weight of these packages. The packages are then glued with the Stabolit 70 in an oven at a temperature of about 200 °C. For the coil heads, dedicated packages with additional laser cut slids and a machined Rogowski profile to minimize AC losses were produced.

The half-yoke is assembled on a massive steel girder. First the premanufactured packages are placed on the girder and axially pressed. An adjustment of the defined filling factor of ≥98 % for the yoke with its given length of 3.052 m is possible at that stage by adding individual lamination sheets.

To complete the half-yoke, the cooling tubes are inserted as next step. Then the side and top covering sheets are placed on the half-yoke and welded together. Finally the consoles to support the coil suspension-rods later are welded on the half-yoke.

Busbars and Instrumentation

To operate the magnet, additional busbars are needed and for the supply of liquid Helium and the outlet of the gaseous Helium supply-lines are mounted to the cold mass.

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For separation of the supply-line of the liquid Helium from the electrical potential of the coil, potential separators are used.

To monitor the magnet during operation voltage tabs and temperature sensors are applied.

Assembly of Cold Mass and Magnet

For the assembly of the cold mass, a rotating device is used. First the lower half-yoke is mounted on the device, than the coil is put into the lower half-yoke and afterwards the second half-yoke is placed on top. To attach the busbars to the cold mass, the device can be rotated to access the top and bottom side of the cold mass. Then the potential breaks and instrumentation is attached and finally the Helium supply-lines are installed.

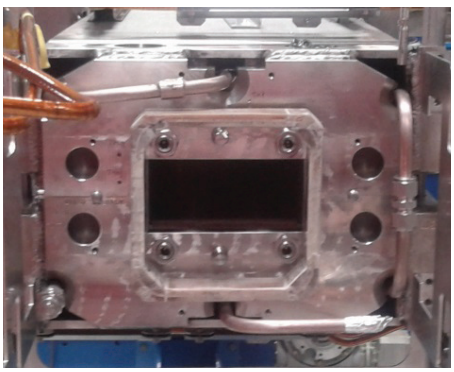

Figure 4: SIS100 FOS dipole cold mass.

For the assembly of cold mass, thermal shield and cryostat, a dedicated rig is used. First superinsulation is applied on the thermal shield and hung into the cryostat. Then the magnet is pulled into the cryostat and suspended. A laser tracker is used to position the cold mass with respect to the cryostat.

OUTLOOK ON SERIES

Tests of the FOS Magnet

Before the series magnet manufacturing starts, the FOS will be extensively tested at GSI with respect to:

- Magnet training
- Detailed magnetic measurements
- Magnetic end field optimization
- AC loss
- Hydraulic resistance
- Quench performance after one thermal cycle

Series Production

Previous to the FOS manufacturing, the series manufacturing of the SIS100 dipoles was analysed. It can be performed within Babcock Noell's site at Würzburg, see Figure 5. Some workstations must be multiplied, e.g. the station for assembly and welding of the yoke will be performed on three stations in parallel. Other manufacturing steps, such as the winding are not that time critical and will be done on one workstation also for the series.

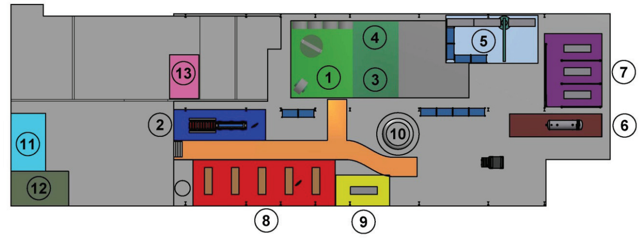

Figure 5: Manufacturing layout for SIS100 series production: 1 = winding, 2 = baking press, 3= coil insulation, 4 = electric tests of coils, 5 = yoke stacking, 6 = yoke heat treatment, 7 = assembly half-yokes, 8 = assembly cold mass into cryostat, 9 = geometrical measurements, 10 = coil He leak test, 11 = pre-manufacturing of busbars, 12 = component leak test, 13 = thermal shield manufacturing

Based on the experience from the FOS magnet, this analysis on the series production will be revised and optimized.

CONCLUSIONS

The manufacturing of the FOS magnet is an important step for the industrialization and serial production of the SIS100 dipole serial magnets.

Manufacturing concepts developed for the prototype have successfully been applied on the FOS. However several modifications were necessary to take into account the design changes between the two magnets. New problems were encountered and have been overcome to qualify the manufacturing process for the series. The next important step will be the testing of the FOS that should be the verification that design and manufacturing concept are ready for the series production of more than 100 dipoles.

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