ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-WEPRI083

THE SIS100 SUPERCONDUCTING FAST RAMPED DIPOLE MAGNET

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Abstract

The first dipole magnet of the superconducting SIS100 accelerator was delivered by industry and its thermodynamic, electrical and magnetic field performance was measured. We describe the build of the test facility, the infrastructure and its performance, outline the chosen measurement methods along with the optimisation of the magnet end required for obtaining the requested integral field quality. The measured AC loss parameters will be discussed in respect of the possible operation performance of the whole machine, the relevant cooling conditions of the main dipole.

INTRODUCTION

The SIS100 Dipole main magnets (see Fig. 1), one of the core components of the SIS100 accelerator are a complete new type of superconducting magnets. These were ordered to industry without building and testing a model magnet in house. Thus the current tests of the **F**irst **o**f **S**eries magnet are not solely conducted to verify the magnet design itself but also evaluates the producers production process. Further the test facility had to be upgraded so that the magnet could be tested. These upgrades are reported together with the magnet test results.

TEST FACILITY UPGRADE

While the magnet was produced in parallel the test facility was upgraded so that all parameters of the magnet could be derived, in particular:

- The original power converter at the test station was upgraded to 22 V or 66 V (selectable at the transformer) and 20 kA. In this upgrade it was also converted from an original analogue controlled system to a digital controlled one using the adaptive control unit (ACU) for power converters of FAIR. This power converter is the first one controlled by the ACU using thyristor benches and an active filter.

- High Temperature Superconductor (BCCSO) current leads were designed, built and successfully tested up to a current of 17 kA and a ramp rate of 28 kA/s. The design was adjusted to the sole available coolant (Helium at 4.2 K). This design is now adapted for the series test facility and the SIS100 machine (Helium coolant at 4.2 K and 50 K) [1].

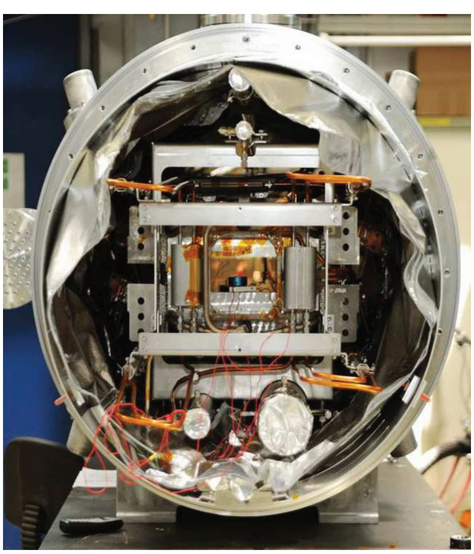

Figure 1: The SIS100 dipole

MAGNET PERFORMANCE

The **F**irst **o**f **S**eries SIS100 main dipole was delivered last year and its testing campaign has been conducted since last December with a successful cool down, measurement of the virgin field curve, required for field optimisation calculations, and finished with a successful training.

The coil structure was found to provide an insulation of 3 kV already at the factory test. The yoke and coil were instrumented with additional temperature sensors not required within the SIS100 machine, which limited the high voltage tests at the test station to 600 V, well above the maximum voltages expected during energy extraction.

Quench Performance

During the first run the magnet quenched slightly below the nominal current (see Fig. 2) with the second quench already above nominal field. All different quenches were explainable as mechanical stabilisation. The thermal cycle showed hardly any retraining. In total the magnet has reached up to now a maximum current of 15.7 kA and thus shows sufficient operation margin.

Measured Losses

The AC losses produced by the SIS100 main dipole magnet are one of the main loads on the cyroplant. The measured losses (see Fig. 3) are well below the expected value of 70 W for a triangular cycle of 1 Hz. This is considered explainable by the choice of iron (M600-100A silicon steel), the superconducting low loss wire with a CuMn matrix and extra inserts at the magnet ends, foreseen for optimising the end field quality.

The loss measurements are being refined but seem that these can be modelled by the model given in [2]. It consists of scaling the measured loss $\bar{P}$ to a pure triangular cycle $P_{\wedge}$

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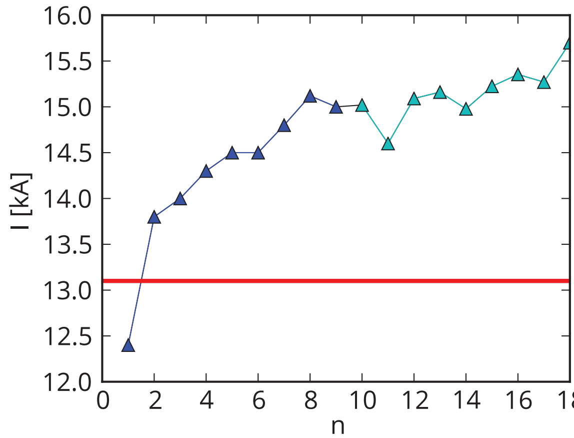

Figure 2: SIS100 FOS Magnet Quench Performance. Blue triangles…quenchs during the first run, cyan triangles…quenchs after one thermal cycle, red thick line…current at nominal field.

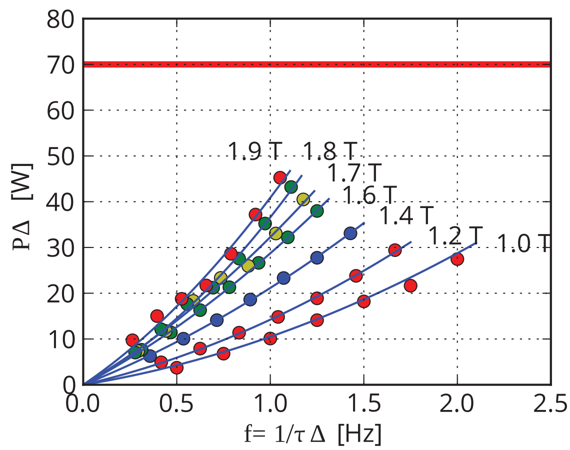

Figure 3: The magnet loss for the different operation cycles. The loss for the different cycles are given versus its frequency. The maximum field is given at the end of the lines.

using

$$P_{\wedge} = \bar{P}\frac{\tau_{cyc}}{\tau_{\wedge}} \quad \tau_{\wedge} = 2B_{max}/\dot{B} \quad \tau_{cyc} = \tau_{\wedge} + t_d \qquad (1)$$

with t_d the used delay. The data are sorted for the different used ramp rates (0.5 - 4 T/s with 0.5 T steps) and fitted with the function

$$P_{\wedge} = q_h(B_{max})f + q_e(B_{max})f^2 \quad f = 1/\tau_{\wedge}. \qquad (2)$$

The equations for q_h, q_e are being evaluated, a good approximation is currently obtained by

$$q_h = h\,B_{max}^2 \qquad q_e = eB_{max}^{2.5}. \qquad (3)$$

The parameters h and e as found for the model magnets S2LD and CSLD and the magnet described here are given in Table 1. The results show an unexpected low dependence on f and rather high for f^2; further measurements are outstanding and will be published elsewhere [3].

Table 1: SIS100 Dipole AC Loss

	S2LD	C2LD	FOS
h [J]	12	12	3.4
e [Js]	4.8	4.2	6.2

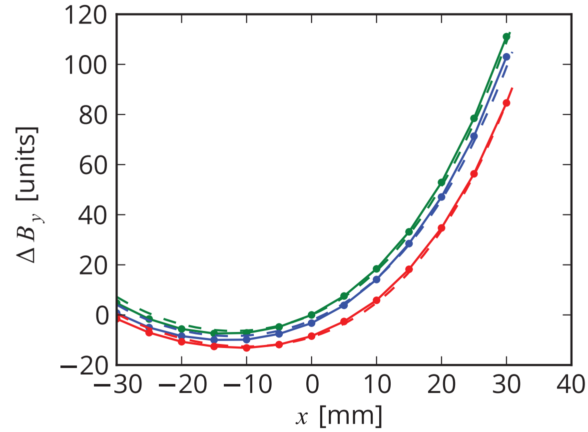

Figure 4: End field homogeneity at injection level (≈0.25 T). dots connected with lines…mapper data (blue…y = +10 mm,green…y = 0,red…y = -10 mm). dashed lines field reconstructed from the rotating coil probes.

MAGNETIC FIELD

The dipole was measured using different methods: a hall probe mounted on a mapper, a single stretched wire system and rotating coil probes at different locations.

Main Field

The main field of the magnet was measured using a hall probe at the centre of the magnet (see Fig. 6a) and its integral field strength was measured using a single stretched wire system from which the magnet length was deduced (see Fig. 6b). The main field depends quite linearly on the current and only shows little saturation effects despite a field strength of 1.9 T.

Field Quality

The superferric magnet design requires a small gap used by the beam to a large extend. These requirements demand a thorough understanding of the field quality and its harmonic content; achieved by measuring the field with rotating coil probes at different positions and combining the measurements [4, 5]. The obtained field data were cross checked using mapper measurements. These data match within acceptable range for the end field of the magnet (see Fig. 4). The field deviation is rather large, thus an insert in the end

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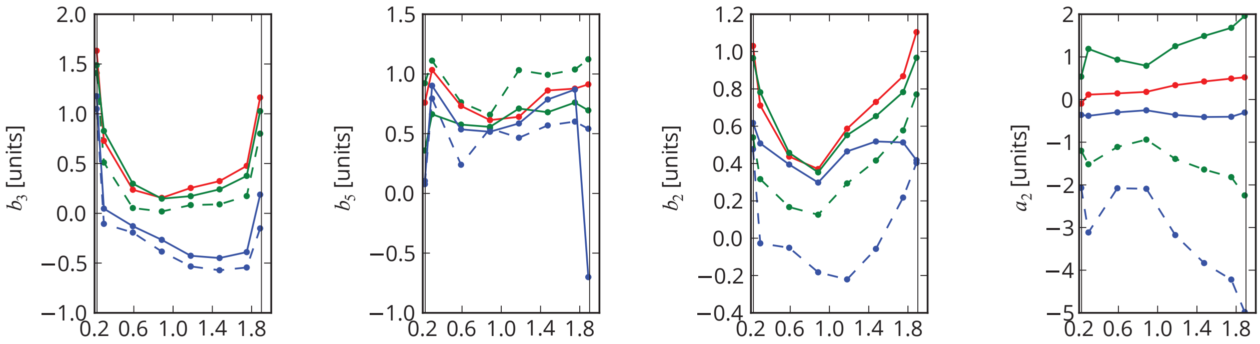
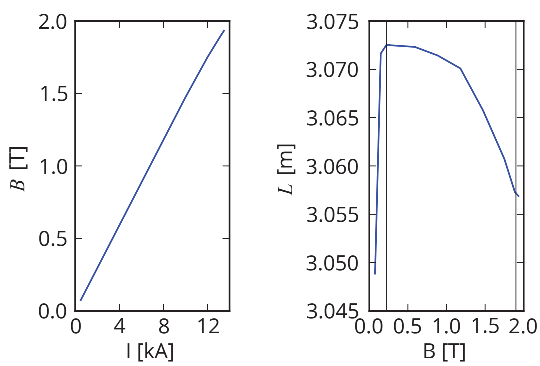


(a) b_3 (b) b_5 (c) b_2 (d) a_2

Figure 5: First allowed relative harmonics next to the skew and normal quadrupole at different longitudinal positions versus the main field strength (in Tesla). blue dashed line. . . z = - 900 mm, green dashed line. . . z = - 300 mm, red solid line. . . z = 0, green solid line. . . z = + 300 mm, blue solid line. . . z = + 900 mm. Vertical black lines. . . foreseen operation range.



(a) B (b) L

Figure 6: SIS100 FOS Dipole: main field in the centre B and its length L. The vertical lines indicate the foreseen operation field.

was foreseen which will be machined for reducing its deterioration [6].

Given that this new measurement method gave acceptable results the harmonic content of the magnet was evaluated (see Fig. 5), which showed that the allowed harmonics are acceptable, but the skew quadrupole and sextupole is larger than anticipated. Currently their cause is investigated using FEM methods next to measuring the yoke aperture and coil position to a higher accuracy. Based on this results manufacturing improvements will be implemented in the series.

CONCLUSION

The FOS SIS100 dipole magnet has been tested intensively starting from December 2013. It surpassed the nominal current already at the second quench and achieved a current of 15.7 kA. No significant retraining was observed after the thermal cycles. The main field and its homogeneity were measured; despite its maximum field of 1.9 T the main field is quite linear with respect to the current. The allowed harmonics are acceptable; some skew harmonics shall be brought under control for better machine performance so their source is being investigated. After having implemented and tested appropriate mitigation actions the series of magnet production can start.

ACKNOWLEDGMENT

The authors acknowledge the contribution of all colleagues from GSI and partner institutes in particular Dirk Acker, Vitalij Bezkorovaynyy, Peter Borisch, Holger Brand, Antonio Coronato, Eric Floch, Walter Freisleben, Florian Henkel, Franz Klos, Thomas Knapp, Henning Kummerfeldt, Thomas Mack, Ron Mändel, Vassili Maroussov, Fahrid Marzouki, Thorsten Miertsch, Henning Raach, Claus Schroeder, Gerd Schulz, Andrzej Stafiniak, Kei Sugita, Piotr Szwangruber, Vasileios Velonas, Detlef Theuerkauf, Franz Walter, Mischa Weipert, Harald Weiss, Horst Welcker.

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