DESIGN AND STUDY OF A SUPERFERRIC MODEL DIPOLE AND QUADRUPOLE MAGNETS FOR THE GSI FAST-PULSED SYNCHROTRON SIS100*

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Abstract

New experimental results from the investigation of a model superferric Nuclotron-type dipole and quadrupole magnets are presented. The magnets operate at pulse repetition rate f = 1 Hz, providing the peak magnetic field B = 2 T and the field gradient G = 34 T/m in the dipoles and quadrupoles respectively. The superconducting coil is made from a hollow multi-filamentary NbTi cable cooled with two phase helium flow. Different possibilities were investigated to reduce AC power losses in the case of a cold iron yoke (T = 4.5 K). The achieved results are discussed. The value of 9 W/m has been obtained for dipole magnet with the yoke at T = 50 K. The first 50 K yoke quadrupole was designed and tested.

INTRODUCTION

Superconducting synchrotron SIS100 is one of the principal components of the proposed "international Facility for Antiproton and Ion Research (FAIR) at GSI" [1]. SIS100 should provide acceleration of U28+ ions from 0.1 GeV/u to 1 GeV/u for 0.5 s with a repetition rate of one pulse per second. Thus the required beam intensity of $1{\cdot}10^{12}$ ions per second can be achieved. Acceleration of high intensity proton beams also should be provided. The SIS100 magnet system, specified in [1], consists of 120 dipoles of 2.6 m length operating at maximum field of B=2T, the field ramp of dB/dt = 4 T/s and a repetition frequency up to 1 Hz. The magnet aperture of 55 mm (vertical) x 110 mm (horizontal) was taken as suitable for R&D. Several 1.4 m model dipoles were constructed and studied in the frames of collaborative works. The tests were performed at the Laboratory of High Energies in Dubna and some results were already presented at the MT-17 [2], EPAC2002 [3], ASC2002 [4] and MT-18 [5]. The results presented below were obtained during the period from November 2003 to July 2004.

Reduction of AC power losses in the yoke is a first priority task for the 4 K iron magnet option. The original Nuclotron 1.4 m dipole has AC losses at the level of 53 W. The losses were reduced to 45 W with the first model magnet 4KDP1 [2]. Nevertheless, the expected value was about 22 W less. The dipole magnet versions, named 4KDP2, 4KDP3 (a, b, c, d), 4KDP4, 4KDP5 were constructed after that to provide detailed measurements of AC losses in the yoke and test the possibilities to reduce the mentioned value.

A Model PDP1s

The PDP1s dipole was constructed based on the model 4KDP1. The modification was connected with the yoke ends. Stainless steel end plates of the yoke and lamination

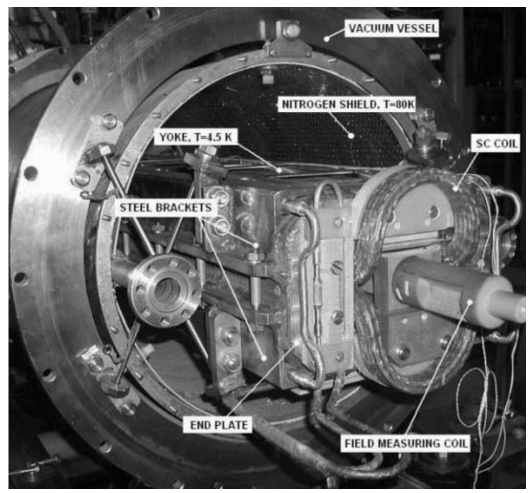

Figure 1: PDP1s dipole inside cryostat.

were cut partially and replaced with G10 plates and insertions made from new magnetic material SMP1321 (Corovac) [6]. The measurements of the B-H curve of this material at liquid helium level, performed for the first time at LHE in July 2003, have shown only very weak dependence of the magnetic permeability on the temperature (Fig. 2).

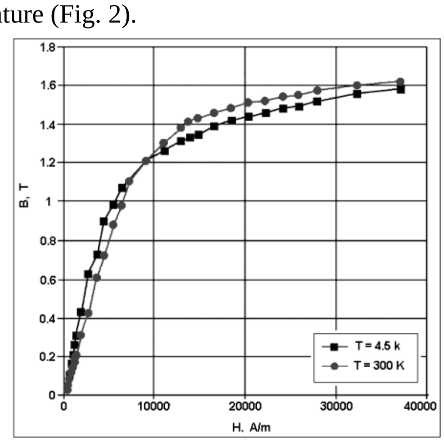

Figure 2: The B-H curves of the Corovac sample.

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Note the axial length of the insertions (l = 50 mm) was lower then the needed optimum (z_0 > 150mm).

The magnet was equipped with additional coils for the measuring different components of fringe magnetic field near the yoke and SC coil end parts (Fig. 3).

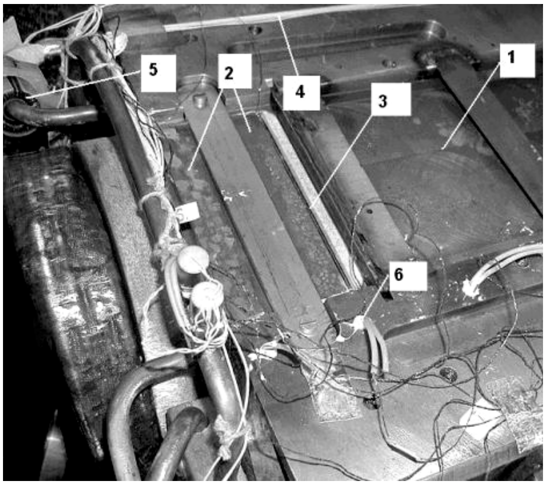

Figure 3: Top view of PDP1s dipole end part with measuring coils: 1 - regular laminated yoke, 2 – the insertion from SMP 1321, 3 – flat coil, sensitive to the longitudinal Bz component, 4 – coil, wounded around the bracket, 5 – Rogowski-coil around the cooling tube, 6 – temperature sensors.

Test results

Two test runs were performed with PDP1s. No any training was performed. The measured value of quench current in the cycle was 8100 A, while the operating one is about 6000 A. The AC power losses in the yoke is presented in Fig. 4.

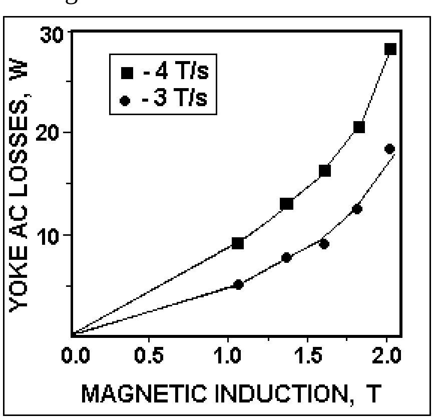

Figure 4: AC power losses in the yoke as function of Bm.

Magnetic fields in the yoke steel bracket from the main flux and induced by the fringing vertical By – component near the end were measured. These values are 0.44 T and 0,36 T respectively. The values of the Bz – component measured in front of the Corovac insertion and behind it were about 0.6 T and 0.3 T respectively. An induced current of 450 A was detected by Rogowski coil in the cooling tube.

The main dipole field and higher harmonics were measured at an aperture radius of 25 mm separately for the central part and the end parts using rotating coils. The magnetic field distributions in the central part of PDP1s and 4KDP1 magnets are practically the same. The comparison between end fields is shown in Fig. 5.

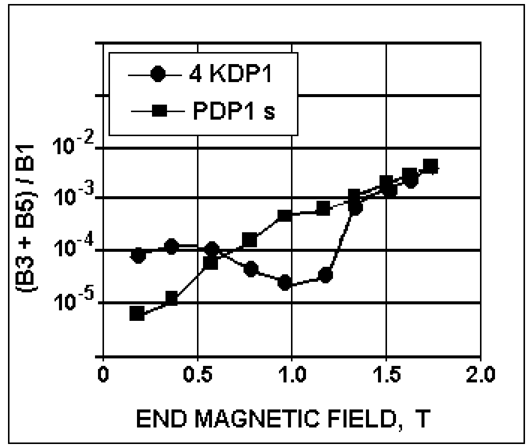

Figure 5: The sum of sextupole and decapole harmonics as function of the main magnetic field.

B Model 4KDP5

Based on the analysis of the previous experimental data it was decided to modify partially the yoke frame and cooling tubes, namely, to remove major part of steel from the yoke brackets and replace the part of copper cooling tube with stainless steel one. The model magnet 4KDP5 was prepared for that purpose and have been tested in April. The AC losses at dB/dt = 4 T/s are presented in Fig. 6. The yoke AC losses value of 24.6 W, obtained with 4KDP5 model, is minimal by the present time.

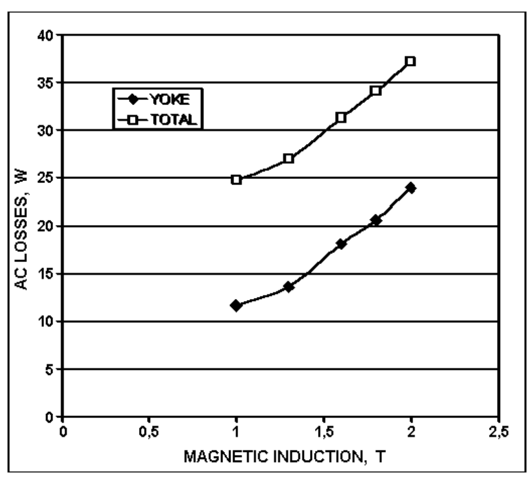

Figure 6: AC power losses in the model 4KDP5.

C Dipole AC losses analysis

The measurements performed with different 1.4 m model dipoles made it possible to separate the sources of AC losses. Specification of the yoke AC losses at B = 2 T, dB/dt = 4 T/s and f = 1 Hz is shown in Table 1.

The value Qyoke includes contribution of magnetization (Qhyst), different components of eddy current loss generated in the yoke frame, namely: in the end plates (Qe.p) and brackets (Qb). The component Qrest includes the losses coming from fringe Bz-component in lamination, eddy currents in cooling tubes and possible mechanical vibration of the lamination sheets estimated at the level of 1 W.

Table 1: Yoke AC power losses specification

Dipole option	Qyok (W)	Qhyst (W)	Qe.p (W)	Q_b (W)	Qrest (W)
Nuclotron	40,4	9.5	14,6	7,2	9,1
4KDP1	32,6	9.5	5,9	7,2	10
PDP1s	28,4	9.5	1,2	8	9,7
4KDP5	24,6	10.5	0,8	4	9,3
PDP2s	15.7	9.5	1,2	2	3

Numerous measurements of the coil AC losses have shown the average value of Qcoil = 12.6 ± 1.0 W for the given SC wire and SC coil design. The expected reduction of AC losses in the yoke for the next model dipole PDP2s is presented in the last line of the Table 1.

MODEL QUADRUPOLES

The Nuclotron superferric quadrupole was taken also as the model 4KQP1 for the SIS100. A view of the magnet is shown in Fig. 7. The length of the quadrupole is 0.4 m and the aperture sizes are 63 x 120 mm^2. Nominal operating gradient of 34 T/m is reached at supply current of 5600 A.

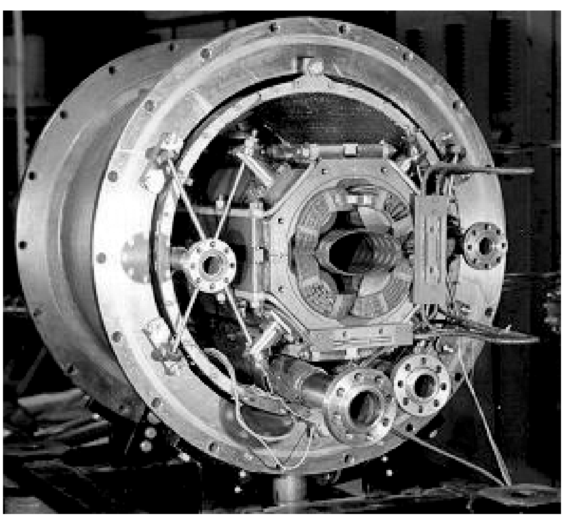

Figure 7: Cross section of the model quadrupole.

The main collaborative R&D goal is also a significant reduction of AC losses at the SIS100 nominal operating cycle, corresponding to G =34 T/m, dG/dt = 68 T/m*s and f = 1 Hz. The AC power loss of the reference quadrupole is about 34.6 W. The achieved progress is illustrated in Fig. 8.

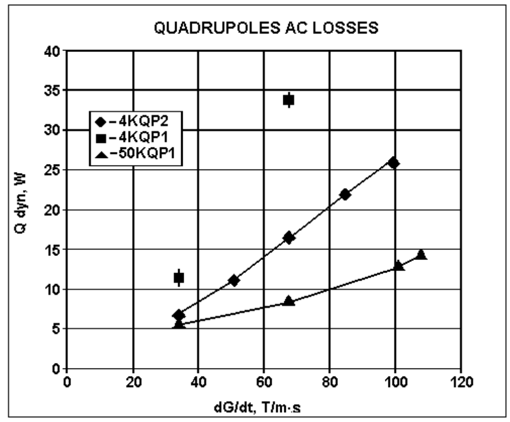

Figure 8: AC losses at 4K in model quadrupoles 50KQP1 and 4KQP2 as function of dG/dt. (G = 34 T/m)

The model 50KQP1 represents the first 50 K yoke quadrupole. SC coil at T = 4.5 K is separated from the yoke at T = 50 K with the gap of 1 mm. A special mechanical structure was designed for support and alignment of the coil inside the yoke. The model 4KQP2 differs from 4KQP1 by the modification of the yoke frame only.

SUMMARY & OUTLOOK

Substantial progress in reduction of AC losses has been achieved with the new model dipole and quadrupole magnets aimed for SIS100. The losses at 4.5 K level for the 4 K dipole yoke were reduced from 40.4 W to 24.6 W. The measured AC losses in 50 K yoke quadrupole and improved 4 K yoke quadrupole were 7 W and 15.6 W respectively, i.e. about factor of 5 and 2.2 less compared to the reference Nuclotron quadrupole. The works on improvement a fast-cycling superconducting dipoles and quadrupoles operating performances are in a progress.

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REFERENCES

[1] An International Accelerator Facility for Beams of Ions and Antiprotons. Conceptual Design Report, (2001), <http://www.gsi.de/Future/>, also W.Henning (this Conference)

[2] A.D.Kovalenko et al. "Optimization of a superferric Nuclotron type dipole for the GSI fast pulsed Synchrotron". *Presented at MT-17*, Geneva, September 2001. *IEEE Trans. on Appl. Superconductivity*, vol.12, n1, pp.161-165, March, 2002.

[3] A.D.Kovalenko et al. "Superconducting fast-cycling dipole magnets for the GSI future accelerator facility". *EPAC 2002*, Paris, June 3 - 7, 2002.

[4] A.D.Kovalenko et al. "Superferric model dipole magnet with the yoke at 80 K for the GSI future fast cycling synchrotron". *ASC2002*, Houston, August 2002. *IEEE Trans. on Appl. Superconductivity*, vol. 13, N2, pp.1335-1338, June, 2003.

[5] A.D.Kovalenko et al. " Progress in the design and study of a superferric dipole magnet for the GSI fast-pulsed synchrotron SIS100. MT-18, Morioka, Japan, October 2003. IEEE Trans. On Applied Superconductivity, vol.14, No.2.

[6] http://www.smp-online.com.