PRODUCTION OF SUPERCONDUCTING MAGNETS AND CRYOGENIC SYSTEMS AT IHEP*

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Abstract

Results of the development of fast-cycling superconducting magnets for the FAIR project (European Research Centre of Ions and Antiprotons, Germany) are presented. Largest in Russia cryogenic system of 280 W refrigeration capacity at 1.8 K temperature for cooling with superfluid helium of superconducting RF separator for the OKA experimental complex to produce a separated Kaon beam from U-70 proton accelerator was developed and commissioned at Institute for High Energy Physics (IHEP). Experience of the cryogenic system operation is discussed.

RESULTS OF ACTIVITY

New generation of high energy proton accelerators is based on fast cycling superconducting (SC) magnets [1]. From 2002 IHEP collaborated with GSI, Darmstadt, Germany. SC high field fast cycling dipole model was developed and produced for SIS300 accelerator of FAIR project (European Research Centre of Ions and Antiprotons). The dipole is shown in Fig. 1 and its parameters are presented in Table 1 [2].

Figure 1: SIS300 SC high field fast cycling dipole model.

Figure 2 presents the magnet training curve. The dipole reached its operating current at third quench. The quench current continued to increase and finally reached 7738 A (about 6.8 T magnetic field). The ratio between maximum current on the load line and nominal current is 7738/6720 = 1.15. During the training, quenches occurred alternately in the upper and lower poles. This shows that the two poles have the same quality as well as the same level of stress.

Table 1: Parameters of the SIS300 SC dipole

Magnetic field, T	6
Operating current, kA	6.72
Field ramp rate, T/s	1
Number of layers	2
Strand number in cable	36
Stored energy, kJ	260
Inductance, mH	11.7
Coil inner diameter, mm	100
Length of SC coil, m	1
Mass of magnet, ton	1.8

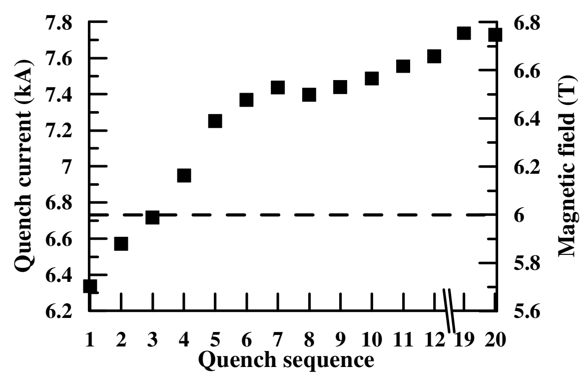

Figure 2: Training curve of the SIS300 dipole model.

Figure 3 presents quench currents for different ramp rates. One can see that the quench current did not decrease up to 1300 A/s (1.2 T/s).

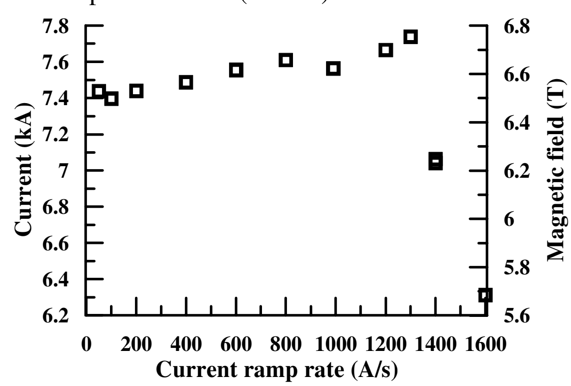

Figure 3: Ramp rate dependence of the SIS300 dipole model.

Special design of SC wire and cable with stainless steel core was developed for this dipole to decrease AC losses. Measured AC losses exceeds computed values at currents more than 3 kA because of eddy current losses in the iron

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yoke [2]. 6.8 T magnetic field in dipole aperture was reached and it retains up to 1.2 T/s ramp rate.

Prototype of SIS300 fast cycling quadrupole was produced and tested in 2011 [3, 4]. The dipole is shown in Fig.4 and its parameters are presented in Table 2.

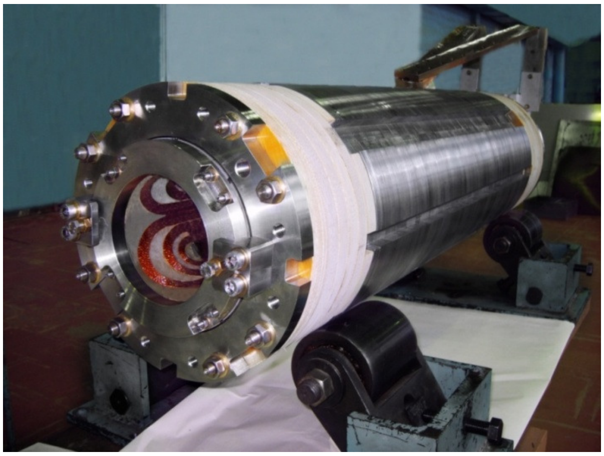

Figure 4: General view of SIS300 fast cycling quadrupole prototype.

Table 2: Parameters of the SIS300 SC quad prototype

Central gradient, T/m	45
Operating current, kA	6.26
Rate of central gradient, T/m/s	10
Stored energy, kJ	38
Inductance, mH	2
Coil inner diameter, mm	125
Effective length, m	1
Number of layers	1
Number of turn in coil	80
Strand number in cable	19
Thickness of collars, mm	22
Thickness of iron yoke, mm	52
Magnet outer diameter, mm	324

Figure 5 presents training of the SIS300 quadrupole prototype. The quench current of the magnet reached 8199 A in the first quench and 8734 A in fifth quench that corresponds to 39% current margin. Measurements of the quench current at various ramp rates showed that the quench current was higher than 8.5 kA up to 5 kA/s (36 T/m/s, 2.8 T/s) ramp rate.

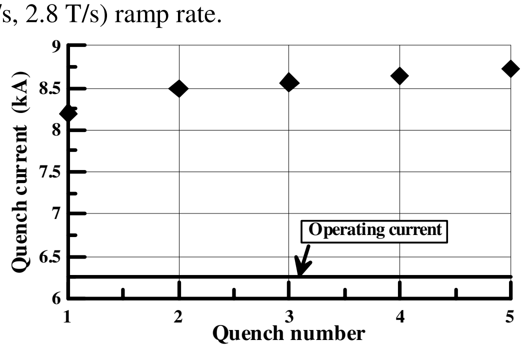

Figure 5: Quadrupole quench current vs. quench number.

Magnetic measurement results showed that measured and calculated quadrupole gradient values practically coincide. Figure 6 shows modules of the central and integral lower harmonics at 3 kA current. Injection current of SIS300 quadrupoles is 1.4 kA. One can see that values of the harmonics are less than 2×10^{-4} (the acceptable level) at current higher than 1.4 kA.

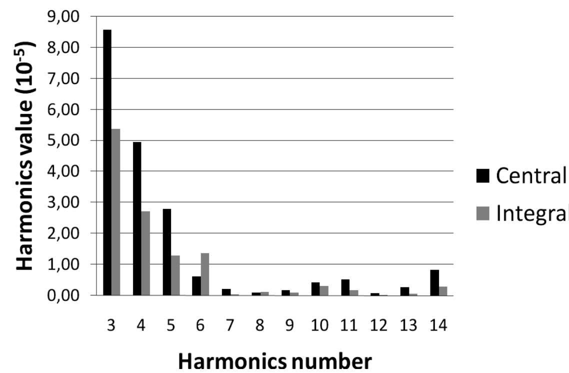

Figure 6: Modulus of lower central and integral harmonics of quadrupole magnetic field at 3 kA current.

At present prototypes of SIS300 fast cycling corrector magnets are developed [5]. Main requirements to these magnets are presented in Table 3, where L is magnet length, t – time of powering to nominal magnetic force. Inner diameter of the magnets is 250 mm, operating current up to 250 A. In 2012 production and test of SIS300 steering magnet prototype is planned.

Table 3: Requirements to SIS300 corrector magnets

Type of corrector	Force	L, m	t, s
Chromaticity sextupole	130 T/m^2	0.78	0.21
Resonance sextupole	325 T/m^2	1	0.5
Steering magnet:			
Vertical dipole	0.5 T	0.65	2.27
Horizontal dipole	0.5 T	0.65	2.27
Multipole:			
Quadrupole	1.8 T/m	0.65	2.25
Sextupole	60 T/m^2	0.65	2.18
Octupole	767 T/m^3	0.65	2.24

IHEP takes part in development of cryogenic system of SIS300. SC fast cycling magnets of SIS300 have increased AC losses as magnetic field ramp rate of the magnets is higher by order of magnitude than the ramp rate of TEVATRON, HERA, LHC magnets. According to calculation heat load for 4.5 K temperature level in SIS300 equals 4.3 kW. SIS300 magnetic ring of 1.1 km length will be halved for cryogenic strings cooled by supercritical helium [6]. UNK cryogenic scheme was took for basis but increased heat load in magnets required using of four additional helium heat exchangers in SIS300 cryogenic system in order to decrease maximal temperature of single-phase helium in cryogenic strings to 4.7 K that it necessary for stable SC magnets operation (Fig. 7).

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Proposed scheme solution allows to realize cooling of SIS300 magnets down to 4.5 K during 60 hours, that is acceptable time. At present configuration and technical requirements for cryogenic system equipment are defined.

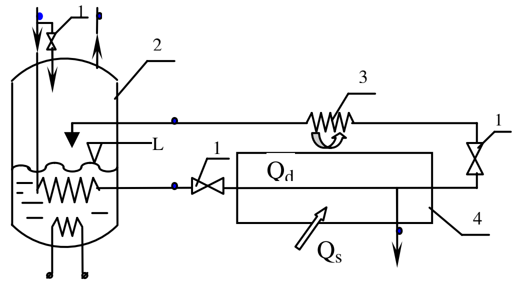

Figure 7: Flow scheme proposed for cryostating the string of SIS300 superconducting magnets. 1 - valves, 2 - subcooler, 3 – heat exchanger, 4 – SC magnets string.

In 2007 the largest in Russia cryogenic system for cooling SC devices by superfluid helium was put in operation at IHEP for separated kaon beam. The system cools two SC RF cavities by superfluid helium at 1.8 K temperature [7]. Design refrigeration capacity of the cryogenic system is 280 W at 1.8 K and it should deliver 5 g/s of liquid helium per the each cavity. Main parts of the system are satellite refrigerator and KGU-500 cryogenic plant (Fig. 8), cryogenic transfer line with distribution box, pumping group. Liquid helium plant of the KGU-500 type to feed the satellite refrigerator is commercially produced by GELIYMASH Company, Moscow, and it has liquefaction rate of 150 l/hr. Satellite refrigerator consists of cryogenic helium vacuum heat exchanger, intercooling helium bath and two small helium heat exchangers placed near each SC RF cavity. These equipments were developed and produced by IHEP.

Figure 8: Cryogenic plant and large helium heat exchanger of superfluid refrigerator system of kaon channel.

To reach 1.8 K the pumping group is to pump helium tanks down to 1.64 kPa. Pumping group is arranged in 3 stages: 8 Roots blowers of the 2DVN-1500 type of the first stage compress helium from 1.5 kPa to 2.5÷3.0 kPa, 8 Roots blowers of the 2DVN-500 type of the second stage compress helium to 4.0÷5.0 kPa, and the third stage of 8 slide-valve pumps of the AVZ-180 type finally compress helium up to 103 kPa.

Control system of the cryogenic system includes 240 channels of data collection and remote control, 72 electronic modules, 5 computers for inputting and outputting information in two control rooms.

Successful operation of the cryogenic system allowed to supply necessary parameters of SC RF cavities and record more than one million of kaon decay events.

CONCLUSION

IHEP successfully develops superconducting fast cycling magnets and cryogenic system for SIS300 accelerator of FAIR project. 6.8 T magnetic field in aperture of the dipole model was reached and the magnetic field value did not reduced up to 1.2 T/s ramp rate. Combination of these dipole parameters is unique in world practice.

The critical current of SIS300 quadrupole prototype is 8734 A that corresponds to 39% current margin. The critical current was higher than 8.5 kA up to 5 kA/s (36 T/m/s, 2.8 T/s) ramp rate.

SIS300 cryogenic system supplies maximal temperature of single-phase helium in cryogenic strings to 4.7 K that it necessary for stable SC magnets operation.

Successful operation of the cryogenic system for separated kaon beam at IHEP allowed to supply necessary parameters of SC RF cavities and record more than one million of kaon decay events.

REFERENCES

[1] GSI. (2006). Baseline technical report. [Online] Available:http://www.gsi.de/fair/reports/btr.html.

[2] S. Kozub et al. SIS 300 Dipole Model, IEEE Trans. on Appl. Supercond. V20, N3, June 2010, p. 200.

[3] E L. Tkachenko et al. Development of Quadrupole, Steering and Corrector Magnets for the SIS 300, IEEE Trans. on Appl. Supercond., V20, N3, June 2010, p. 159.

[4] S. Kozub et al. SIS 300 Fast-Cycling Superconducting Quadrupole Prototype, IEEE Trans. on Appl. Supercond., V22, N3, June 2012, p. 4001104.

[5] L. Tkachenko et al. Development of Corrector Magnet Designs for the SIS 300, IEEE Trans. on Appl. Supercond., V22, N3, June 2012, p. 4002804.

[6] S. Zinchenko, Cooling System of the SIS300 Accelerator, Proc. of RUPAC-2010, p. 303.

[7] A. Ageyev et al. Starting -up and Adjustment Works on Cryogenic and Vacuum System of the Superconducting Radio-Frequency Separator, Proc. of RUPAC-2008, 2008, p. 282.

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