DEVELOPMENT AND PRODUCTION OF SUPERCONDUCTING AND CRYOGENIC EQUIPMENT AND SYSTEMS FOR ACCELERATORS BY IHEP

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Abstract

Superconducting and cryogenic programs at IHEP were got a powerful upsurge in the early eighties of the last century within the framework of the UNK project. More than hundred model superconducting magnets and the pilot batch of UNK superconducting dipoles and four quadrupoles were produced and tested with the help of cryogenic test facilities built for this purpose. Cooperation with international scientific accelerator centers was developed in last ten years. Two superconducting magnetic systems of Electron Lens for the Tevatron accelerator (USA) were developed, manufactured and successfully brought into operation. 42 cryogenic electrical feed boxes of various types for Large Hadron Collider (Switzerland) were developed, produced and put into commission. Results of the development of fast-cycling superconducting magnets for the FAIR project (European Research Centre of Ions and Antiprotons, Germany) are discussed. Description of the largest in Russia cryogenic system for cooling with superfluid helium of superconducting RF separator for the new beam channel of the U-70 accelerator (Russia) is presented. Design and test results of current leads as well as a dipole magnet on basis of High Temperature Superconductor are reviewed.

ITRODUCTION

In 1967 the 70 GeV proton machine of Institute for High Energy Physics (IHEP) has been commissioned. Experiments at high energies always required of cryogenic techniques (liquid hydrogen and deuterium targets, bubble chambers, cryogenic detectors). Special cryogenic plant and workshop were developed at IHEP.

RESULTS OF ACTIVITY

New generation of high energy proton accelerators is based on superconducting (SC) magnets. In the early eighties of the last century the special cryogenic and superconducting facilities have been created at IHEP in frame of UNK project (Fig.1 – 5). In collaboration with Bochvar's institute SC NbTi wire of 0.85 mm diameter with 8910 of 6 micron filaments was developed. More than 100 SC magnet models and 25 full scale 6 m dipoles (Fig. 6) and four quadrupoles were developed, produced and tested at IHEP [1] - [2]. The main characteristics of the magnets are presented in Table 1.

Figure 1: Machine for SC cable production. Nmax=28 strands of 0.3-1 mm diameter, V=1.5 m/min.

Figure 2: Machine for 6 m length SC coil winding.

Figure 3: Presses for collaring and curing of SC coil. 3800 tons, L = 7m, h = 0.67m.

Figure 4: Test facility for study of 1 m length SC magnets. 180 l/h boiling helium.

Figure 5: Test facility for study of 6 m length SC magnets and string of magnets. 120 g/s forced helium flow.

Table 1: The main characteristics of UNK SC magnets

Parameters	Dipole	Quad
Magnetic field, T	5.11	
Field gradient, T/m		97.4
Operating current, kA	5.25	5.25
Field ramp rate, T/sec	0.11	
Number of layers	2	2
Strand number in cable	19	19
AC losses, W	5.5	2
Stored energy, kJ	570	180
Inductance, mH	45	13
Coil inner diameter, mm	80	80
Length of the coil, mm	5800	3100
Length of the cryostat, mm	6420	4165
Mass of magnet, kg	6000	1600

Figure 6: UNK SC dipole magnet.

Cooperation with international scientific accelerator centers was developed in last ten years. In frame of collaboration with DESY, Germany in 1997 IHEP produced cryogenic helium vacuum heat exchanger for cooling 10g/s helium flow from 300 to 2 K temperature [3] shown in Fig. 7.

Figure 7: Cryogenic helium vacuum heat exchanger. 10g/s helium flow, 300-2 K temperature range.

In 1999 – 2000 and 2002 – 2003 two SC magnetic systems of Tevetron Electron Lens for Fermilab, USA were developed and produced. These systems were placed at TEVATRON accelerator (Fig.8) and operate up to date.
The system consists of seven SC and ten copper magnets [4]. Main SC solenoid - 6.5 T nominal magnetic field, 2.5m length, 152 mm coil inner diameter. The solenoid coil was wound by the Rutherford type cable from 10 SC wires of 0.85 mm diameter. Turn number of the solenoid is 7238 and nominal current – 1800 A. Six SC steering dipoles were placed over the solenoid. Two dipoles of 1840 mm length were arranged in centre and four dipoles of 250 mm length in end parts of the solenoid. The central dipole produced 0.2 T magnetic field at 50 A current and end dipole – 0.8 T at 200 A. All dipoles were

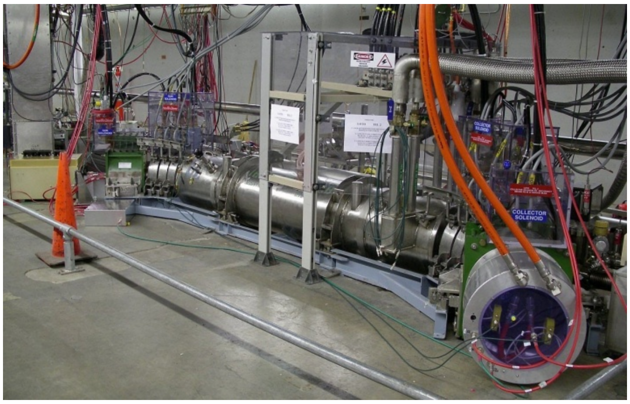
Figure 8: SC magnetic system of Tevetron Electron Lens.

wound by cable transposed from 8 SC wires of 0.3mm diameter.

The system has gun and collector solenoids with 250 mm inner diameter, 474 mm outer diameter, 300 mm length which produce 0.4 T magnetic field in aperture. Copper corrector coils are inside these solenoids. Three bending electron beam solenoids with 390 mm inner diameter, 500 mm outer diameter, 72 mm length are between cryostat and gun solenoid and the same between cryostat and collector solenoid. Turn number and nominal current of the solenoid are 48 and 357 A. Gun, collector and bending solenoids are produced from copper cable with 8.25×8.25 mm^2 cross-section with 5.5 mm diameter hole for water cooling.

At the same time activity for application of high temperature superconductor (HTS) for accelerator equipment production in collaboration with Bochvar's institute was begun. In 1998 – 2000 first in Russia 600 A HTS current leads on basis of Bi2223 were developed and successfully tested in frame of contract with CERN, Switzerland [5]. First current lead had 33 HTS tapes with Ag+10%at.Au matrix, second - 16 HTS tapes and third current leads – 14 HTS tapes with Ag+1%at.Au matrix (Fig.9).

These current leads consist of resistive part cooled by 20 K helium gas and HTS part cooled by helium vapor. The resistive part consists of 2300 copper wires of 0.13 mm diameter which are placed into stainless tube of 11 mm inner diameter and 500 mm length. HTS part is 400mm length. The third current leads had characteristics qualified LHC: Heat leak to liquid helium is 0.08W at 600A current; resistance of HTS – resistive contact equals 220 nohm, resistance of HTS – NbTi wire contact - 6nohm; helium flow cooled resistive part – 0.04 g/s; pressure drop of the helium flow – 5 kPa.


Figure 9: 600 A HTS current leads.

In 2004 – 2007 years 42 Cryogenic Electrical Feed Boxes of various types for powering of SC magnets of Large Hadron Collider (Switzerland) were developed, produced and put into commission [6]. These boxes have 2600 HTS current leads with operating current from 25 to 12500A. DFBA type box is shown in Fig. 10.


Figure 10: DFBA Cryogenic Electrical Feed Box for LHC.

The next step in application of HTS is development of first in Russian HTS dipole in 2000 – 2001 [7]. The dipole has 280x345 mm^2 cross section and 590 mm length (Fig. 11). 1 T magnetic field was reached at 25 A current and 65 K temperature in 21×70 mm^2 aperture of the dipole. "Racetrack" type coil was wound by 3.8×0.25 mm^2 HTS tape which consists of Bi2223 filaments in silver matrix. The coil was placed into yoke from electric steel.

Figure 11: HTS dipole magnet.

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 [8]. Design refrigeration capacity of the cryogenic system is 250 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.12), cryogenic transfer line with distribution box, pumping group. 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. 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.

Figure 12: Cryogenic plant and large helium heat exchanger of superfluid refrigerator system of 21 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.

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. Special design of SC wire and cable with stainless steel core was developed for this dipole. 6.9 T magnetic field in aperture of the dipole was reached and the magnetic field value did not reduced up to 1.1 T/s ramp rate [9]. Combination of these dipole parameters is unique in world practice. The dipole is shown in Fig. 13and its parameters are presented in Table 2.

Figure13: SIS300 SC high field fast cycling dipole model.

Table 2: 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
AC losses (calc.), W/m	4.7
In the coil	3.4
In the iron yoke	1.3
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

Prototype of SIS300 fast cycling quadrupole will be produced till end of this year (Fig. 14) and tested in 2011. Design parameters of the quadrupole are 45 T/m central gradient of magnetic field, 10T/m/s ramp rate, 125 mm inner diameter and 1 m effective length [10]. Bochvar's institute developed pilot batch of SC wire of 0.825 mm diameter, 6 km length, 3 mcm diameter SC filaments and 8 mm twist pitch.

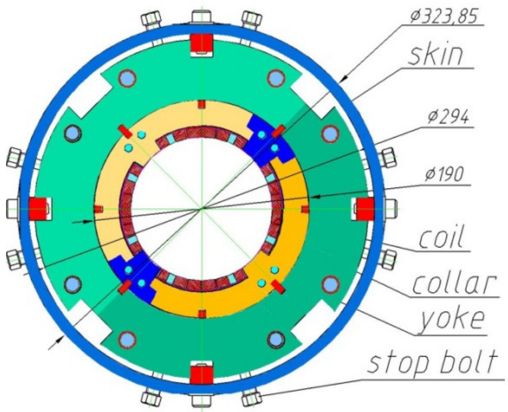

Figure 14: Cross – section of SIS300 fast cycling quadrupole prototype.

At present prototypes of SIS300 fast cycling corrector magnets are developed [10]. 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 2011 production 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 [11]. 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.

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

IHEP plan to use experience getting during production of LHC cryogenic electrical feed boxes for development and production of cryogenic electrical feed boxes and cryogenic holders for XFEL project, Germany. At present drawing development of the cryogenic equipment is begun.

CONCLUSION

IHEP has meaningful experience and equipment for development and production of accelerator magnets on basis of Low Temperature Superconductors and High Temperature Superconductors as well as cryogenic system for cooling superconducting devices and systems.

At present IHEP develops superconducting high field fast cycling magnets and cryogenic system for cooling these magnets.

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