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SC AND HTS - RELATED ACTIVITY at IHEP

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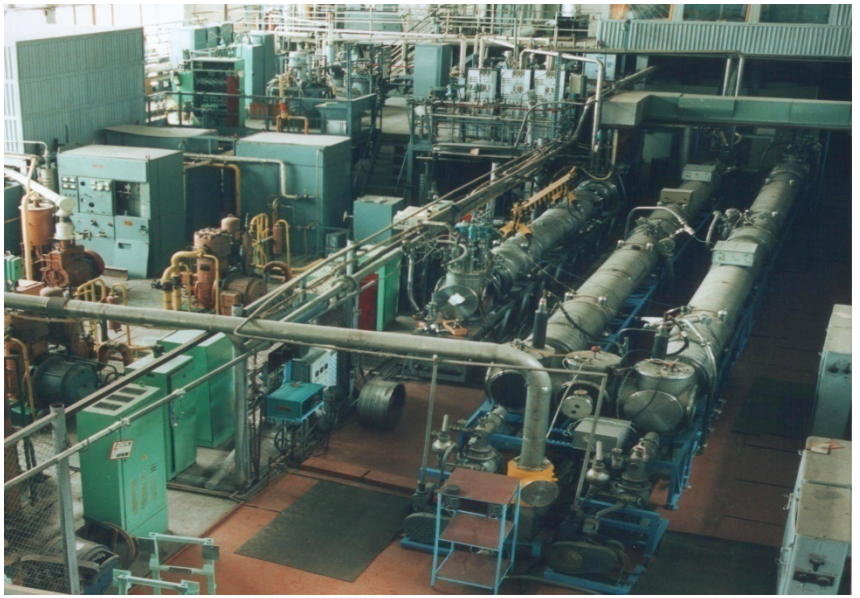
Equipment for production and test of superconducting magnets at IHEP



More than 100 SC magnet models and pilot batch consisting of 25 full scale 6m dipoles as well as 4 quadrupoles were developed and produced at IHEP

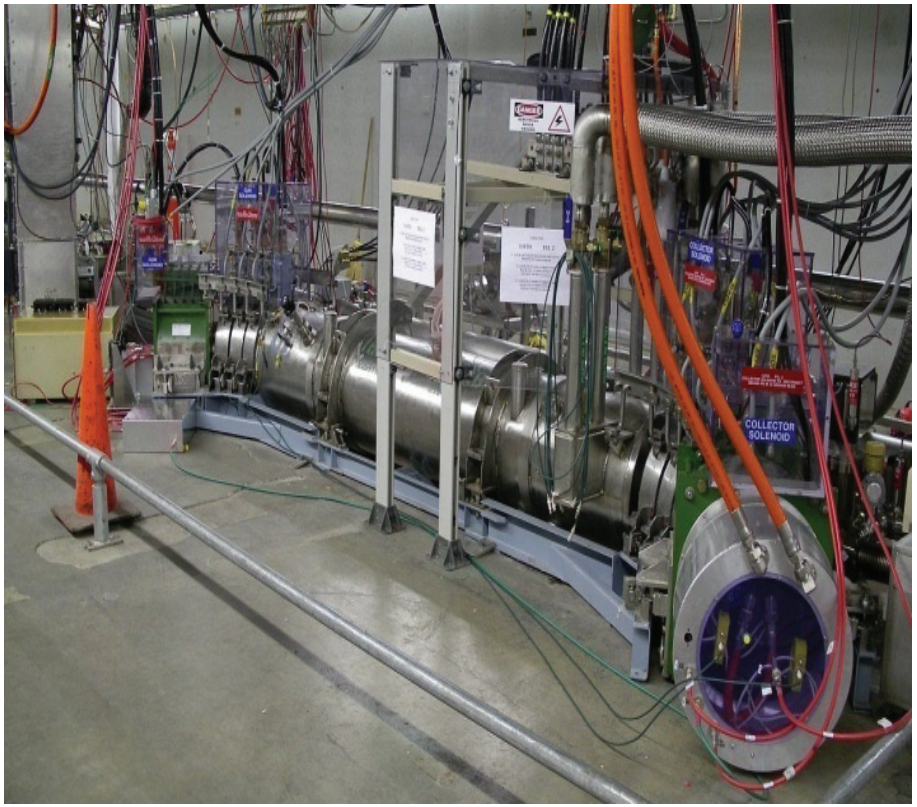
UNK superconducting dipole

UNK superconducting magnets

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

Tevatron Electron Lens (TEL)

Two SC magnetic systems of Electron Lens were produced and operated at TEVATRON, Fermilab, USA



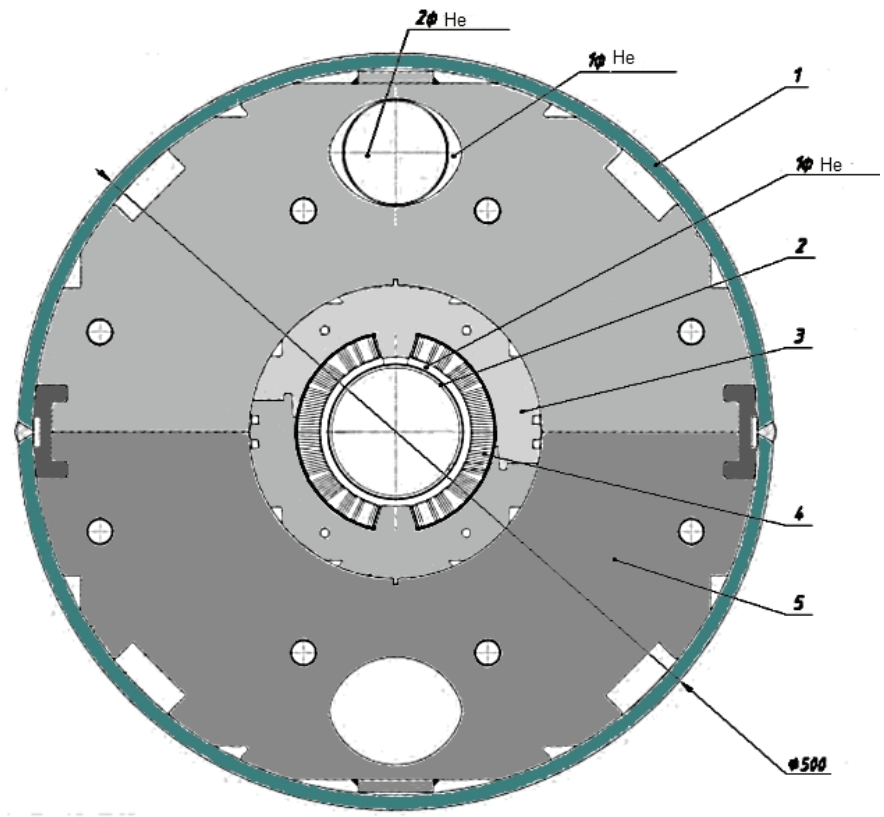
Parameters of TEL SC magnetic system

Magnet	B, T	I, A	D_{in}, mm	L, mm
SC solenoid	6.5	1800	152	2500
SC central dipole	0.2	50	200	1940
SC end dipole	0.8	200	200	250
Gun, collector solenoid	0.4	357	250	300
Bending solenoid	0.19	357	390	72

Cable of fast cycling high field superconducting magnets

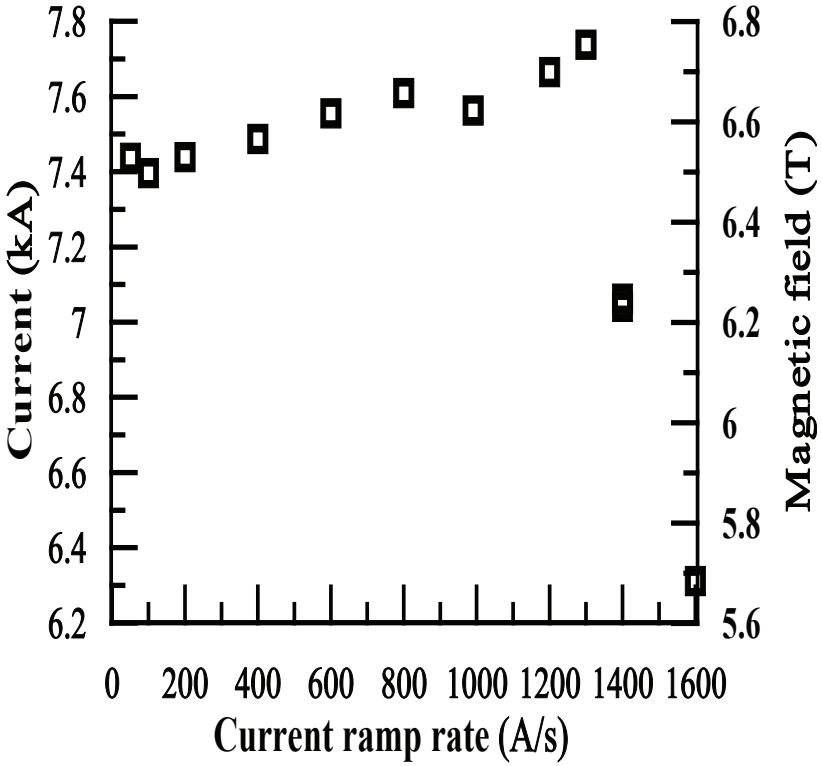
Parameter	Dipole	Quad
Number of SC strands	36	19
Diameter of SC wires, mm	0,825	0,825
Diameter of NbTi filaments, μm	4,4	3
Twist pitch of NbTi filament, mm	5	8
Copper / NbTi ratio	1,8	1,3
Critical current (5T, 4.2 K), A	520	590
Cable width, mm	15,1	8,25
Cable middle thickness, mm	1,48	1,45
Pitch of strands, mm	100	72
SC wire coating	Sn+5%Ag, 0.5 μm	
Cable of stainless core thickness, μm	25	
Contact resistance between SC wires Rc (Ra), mΩ	>20 (0.2)	500 (0.1)
Thermal treatment of cable	190℃, 30 min	

SIS300 superconducting high field fast cycling dipole model



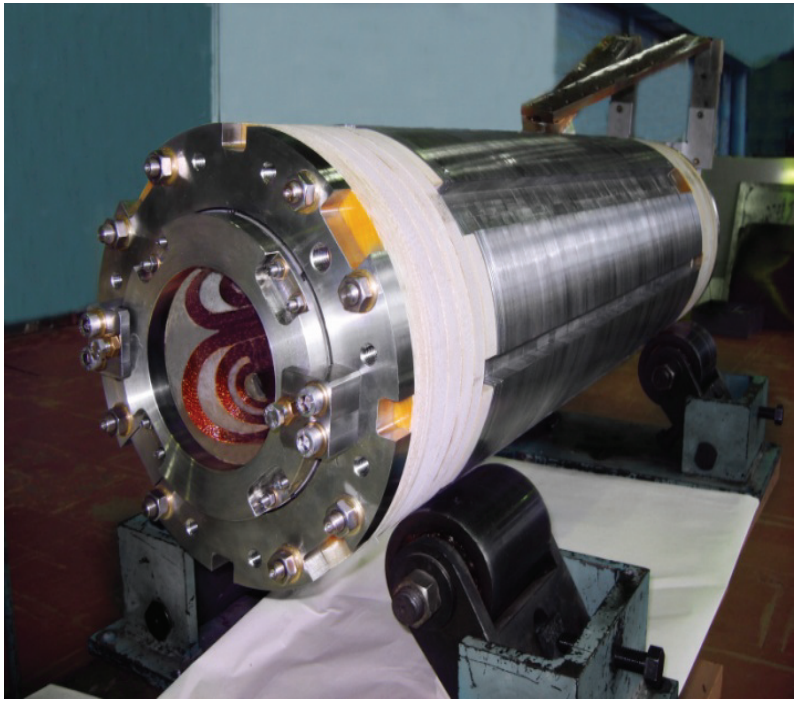
Dipole magnet	SIS300	UNK
Magnetic field, T	6	5.1
Operating current, kA	6.72	5.22
Field ramp rate, T/s	1	0.11
Number of layers	2	2
Cable strand number	36	19
AC losses, W/m	4.7	0.95
In coil, W/m	3.4	0.6
In iron yoke, W/m	1.3	0.35
Stored energy, kJ	260	570
Inductance, mH	11.7	45
Coil inner diameter, mm	100	80
Length of SC coil, m	1	5.8
Mass of magnet, ton	1.8	6

Test results of SIS300 dipole model



Dipole has unique parameters in world practice:
6.8 T magnetic field up to 1.2 T/s ramp rate

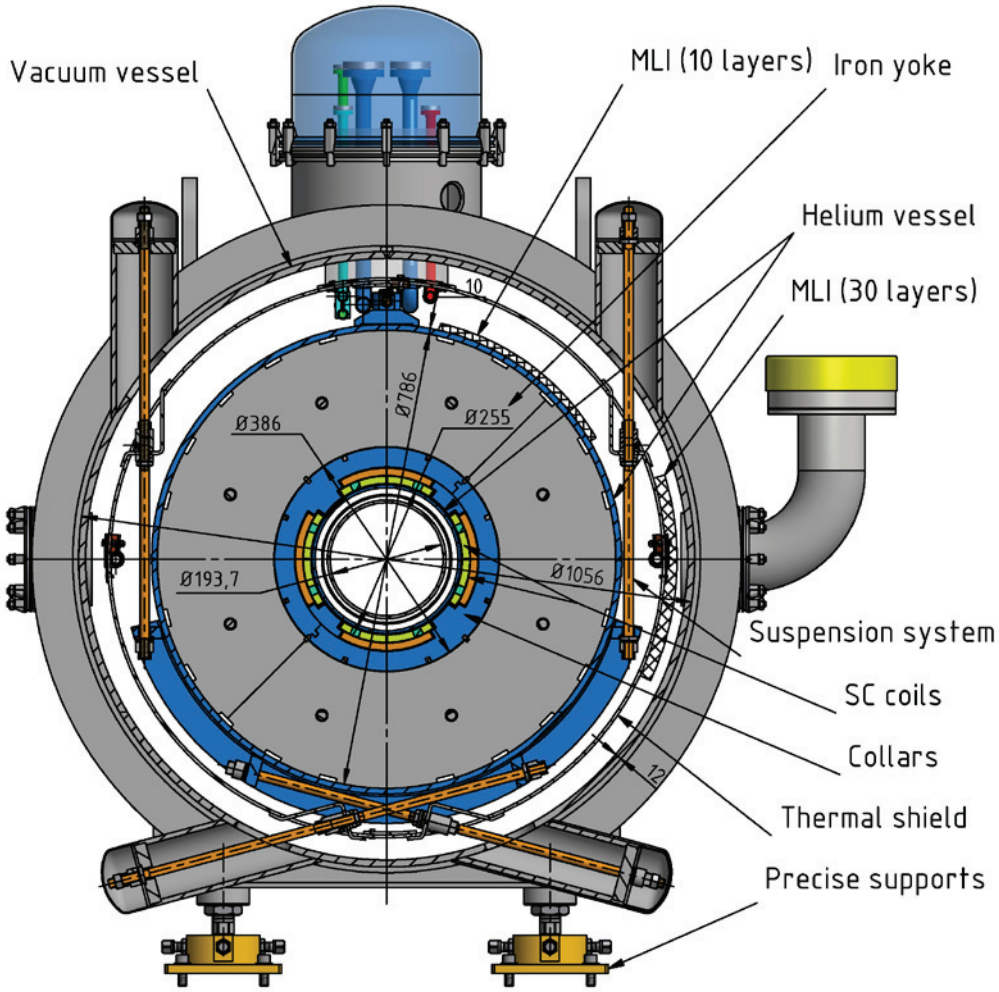
SIS300 fast cycling quadrupole prototype



Quadrupole magnet	SIS300	UNK
Field gradient, T/m	45	97
Operating current, kA	6.26	5.22
Ramp rate, T/m/s	10	2
AC losses, W/m	1	0.67
Coil inner diameter, mm	125	80
Length of SC coil, m	1	3.1
Number of layers	1	2
Cable strand number	19	19
Strand diameter, mm	0.825	0.85

Quench current was higher than 8.5 kA (40% current margin) up to 5 kA/s (2.8 T/s) ramp rate.

Large-aperture high-gradient quadrupole for Plasma Experiments within the FAIR Project



Design of a wide-aperture high gradient quadrupole for final focus system of the HEDgeHOB beam line has been developed.

Parameter	Value
Central gradient, T/m	38
Coil inner diameter, mm	260
Length of SC coil, m	1.89
Maximal field, T	5.9
Operating current, kA	5.7
Stored energy, kJ	1078
Inductance, mH	64

600 A HTS current leads

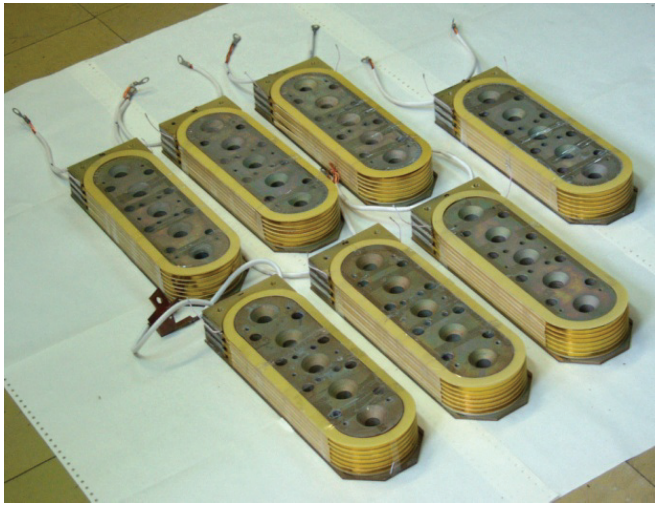
First in Russia HTS current leads and dipole on the Bi2223 basis were developed and successfully tested

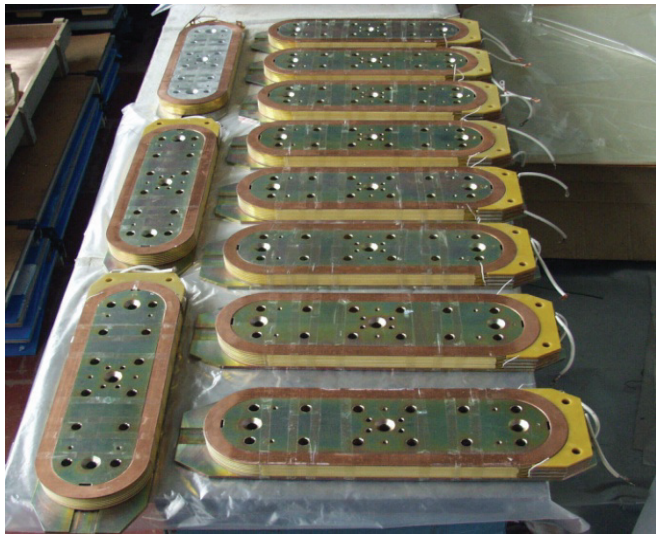
Nominal current	600 A
Heat load to liquid helium at 600 A	0.08 W
HTS	Bi-2223
Material of matrix	Ag+1at.%Au
HTS tape dimension	4.6*0.25 mm^2
Number of HTS tapes	14
Length of HTS tapes	400 mm
Resistive part length	500 mm
Diameter of copper wires	0.13 mm
Tube inner diameter	11 mm
Packaging density	35 %

HTS dipole magnet on Bi2223 basis

Magnetic field	0.5 T
Nominal current	25 A
Operating temperature	77 K
Aperture	21*70 mm^2
Magnet dimension	280*345*590 mm^2
Inductance	0.85 H
Turn number	712
HTS	Bi2223
HTS tape dimension	3.8*0.25 mm^2

The HTS coils of rotor of SC 200 kW motor and SC 1 MVA generator





Parameter	Motor 200 kW	Generator 1 MVA
Cross section insulated "AMSC"2G HTS tape, mm^2	4.93×(0.32 – 0.40)	
HTS tape critical current (1 μV/cm, 77 K, self field), A	94 - 116	
Length coil, mm	334	587
Width coil, mm	114	187
Number of layers	6	6
Number of turns in the coil	188-205	381-393
Critical current (1 μV/cm), A	46- 53	42- 47
Inductance, mH	45- 51	42- 43
Weight of coil with pole, kg	13	51
Number of coils	6	10

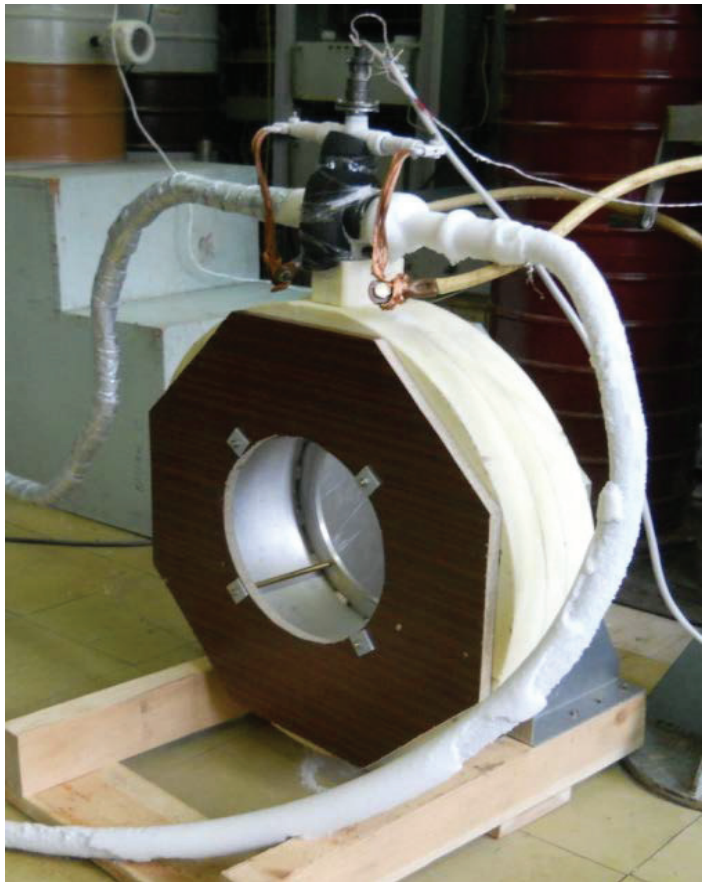
Insulation of 2G HTS tape

Setup for insulation of 2G HTS tape at IHEP

“SuperOx” HTS tape

Parameter	Value
Substrate	Hastelloy C276
Silver coating	1.5 μm
Copper coating	20 μm per side
Min critical current (77 K, self-field)	400 A
Bare tape cross section	12 ×0.1 mm^2
Insulation	20 μm polyimide film
Insulation thickness per side	40 μm

Annular 2G HTS excitation coils for 1 MVA superconducting synchronous generator



Parameter	Value
Cross section bare "SuperOx" 2G HTS tape, mm^2	12.0×0.15
HTS tape min critical current (1 μV/cm, 77 K, self field), A	300
HTS coil axial thickness, mm	25
HTS coil inner diameter, mm	490
HTS coil outer diameter, mm	557
Number of layers	2
Number of turns in the coil	306
Max operating current, A	115
Inductance, H	0.4
Coil and cryostat weight, kg	28

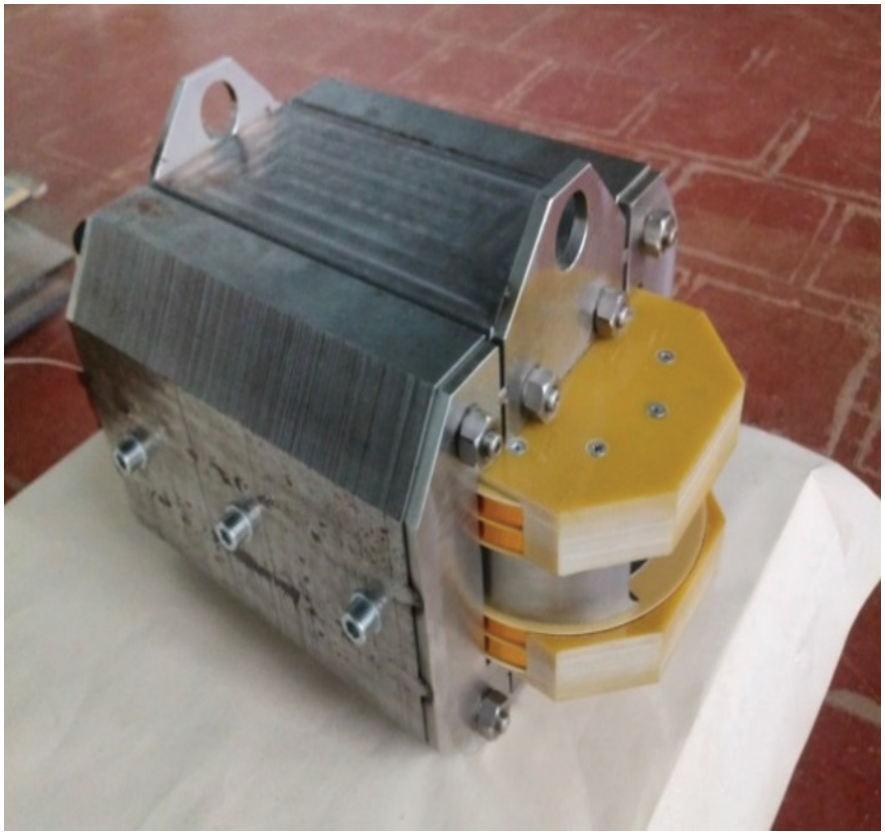
Test results (78 K, 1 μV/cm) :

Coil#1: Critical current / Axial magnetic field – 116 A / 0.25T

Coil#2: Critical current / Axial magnetic field – 126 A / 0.27T

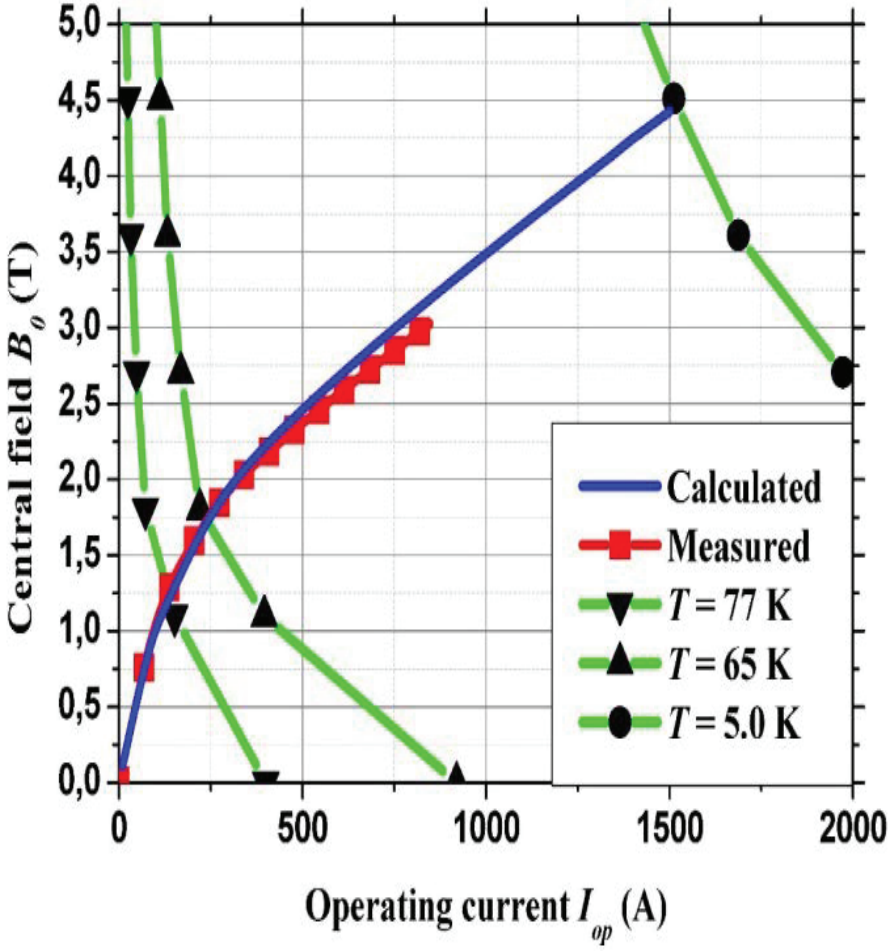
Dipole magnet on basis of second generation HTS

Dipole on the basis of second generation HTS has been designed fabricated and successfully tested



Parameter	Value
Nominal magnetic field in aperture, T	1
Operating current, A	100
Number of coils	2
Number of layers in coil	2
Number of turns in coil	180
Total number of turns	360
Magnet length, mm	425
Coil length, mm	418
Yoke length, mm	250
Aperture dimensions, mm^2	40×80
Magnet mass, kg	103

2G HTS dipole test results



- **At 77 K: 113 A critical current, 1.12 T central field.**
- **At 65 K: 228 A critical current , 1.66 T central field.**
- **In liquid helium bath, the maximum injected current of 847 A was limited by the power supply, central field was 3.0 T.**

Conclusion

- In frame of UNK project more than 100 SC magnet models and pilot batch consisting of 25 full scale 6 m dipoles as well as 4 quadrupoles were produced and tested at IHEP.
- Two SC magnetic systems of Electron Lens were produced and operated at TEVETRON, Fermilab, USA.
- High field fast cycling magnets with unique parameters in a world practice for the SIS300 accelerator and design of wide-aperture high gradient quadrupole for Plasma Experiments within the FAIR project, Germany were developed.
- First in Russian HTS current leads and dipole on Bi2223 basis were manufactured and successfully tested.
- IHEP developed equipment and technology of 2G HTS tape insulation.
- 2G HTS racetrack and annular coils for electrical machines were produced and tested at IHEP.
- Dipole on basis of second generation HTS has been designed, fabricated and successfully tested. At 77 K the central field of 1.12 T and 1.66 T at 65 K was reached.