Development of Quadrupole for the SIS300

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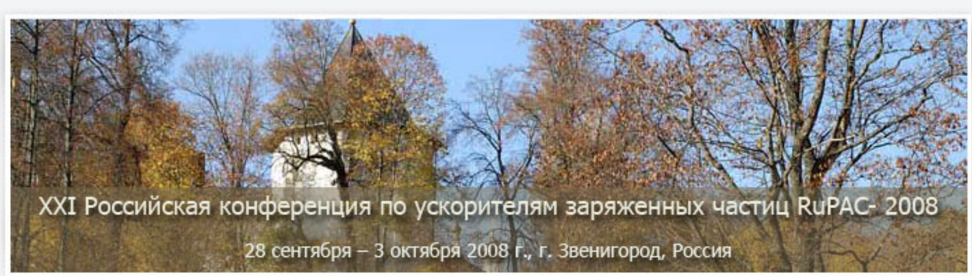
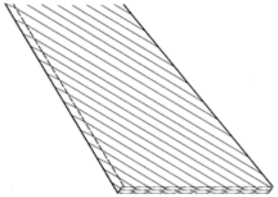


Introduction

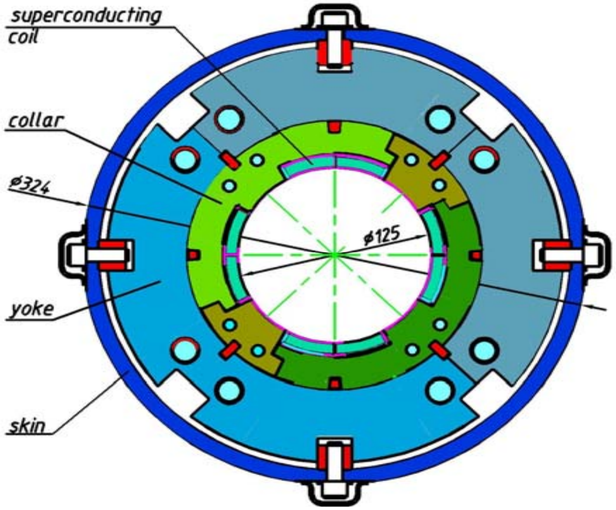
- Russia expressed interest in participation in international project FAIR. In compliance with this, IHEP proposes to get involved in development and mass production of main quadrupoles for the SIS 300 ring. A series of studies have shown that the best benefit to use UNK technology. In the frame of spade-work IHEP did geometry optimization of the quadrupole both cross section and end parts. Characteristics of the mechanic, the protection system and losses in the magnet are also considered here.
- Main quadrupole requirements are as follows: the central gradient is equal to 45 T/m; the inner beam pipe diameter is 105 mm; the field ramp rate is 10 T/m/s; the injection field is 10 T/m. The temperature margin has to be at least 1 K.

Main Parameters of the quadrupole for SIS 300

Conductor



First 2D section was optimized (appropriate number blocs turns, good field radius)



cross- section

Wire: **(like dipole of SIS 300)**

Strand diameter: 0.825 mm;
Filament diameter: 3.5e-3 mm;
Filament twist pitch: 5 mm;
Cu/SC ratio: 1.4;
Radius over filament boundary: 0.35 mm;
Ni or Cr coating ;
critical current density at 5T, 4.2 K, 2700 A/mm2

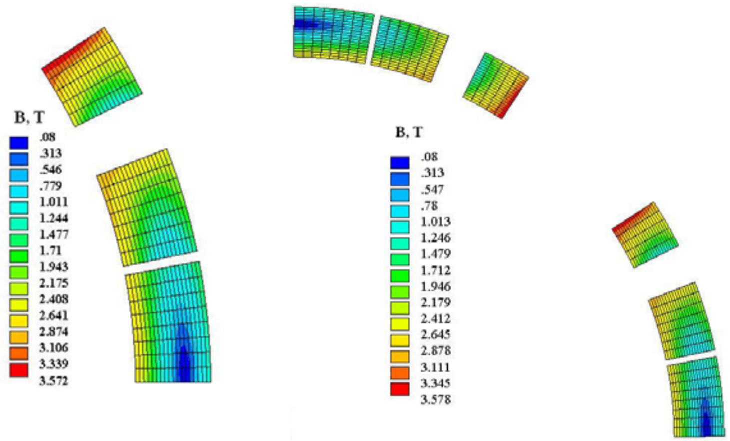
Cable:

Rutherford-Type ;
19 Wires;
The cable will be fully keystone with a width of 8.45 mm and an average height of 1.56 mm (with insulation). The cable will be insulated by polyimide tape in three layers. The radial thickness of the insulation after assembly and cooldown is 100 µm and azimuth thickness is 72 µm ;
Crossover resistance R_c: 10-20 mOm;
Adjacent resistance R_a: 10-20 mOm.

Main geometric parameters of the quadrupole

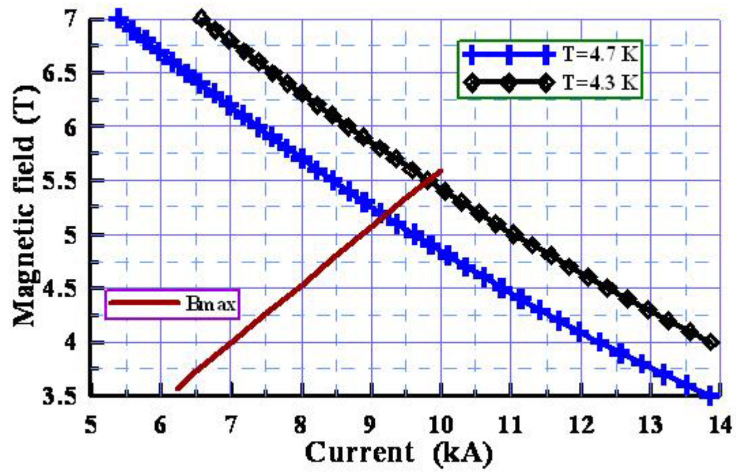
Coil inner diameter, mm	125
Effective length, m	1
Number of layers	1
Number of turns	8,7,5
Collar width, mm	22
Iron yoke width, mm	82

Magnet Characteristics



1/8 cross- section **1/4 cross- section**

Distribution of magnetic field in the coil at operating current



Dependences of maximal field in coil on operating current and critical current of cable on magnetic field

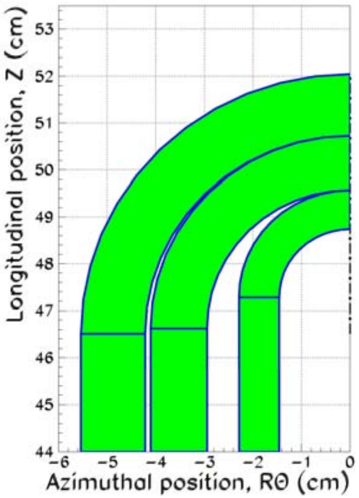
Main parameters of the quadrupole

Operating current, kA	6.22
Gradient, T/m	45
Max magnetic field, T	3.6 T
Quadrupole critical temperature, K	6.45
Stored energy, kJ/m	47.45
Total magnetic force, kN/m	210

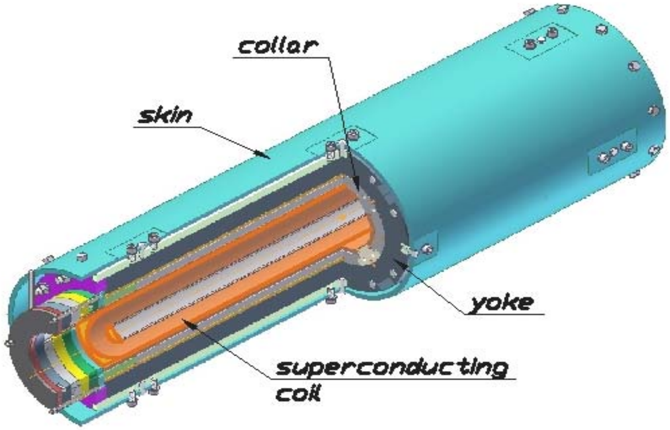
Ratio operating current to critical is about 0.6

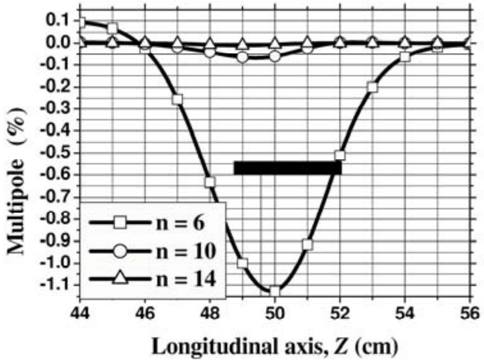
3D geometry

3D geometry was considered with a point of view of integral field optimization. Edge multipoles in quadrupole are suppressed by central field multipoles. Geometric shape of the end parts is similar to those of the UNK magnet. Such geometry (without spacers) gives very compact length of the end parts and allows increasing the effective length of the quadrupole.



Involutes of the end parts



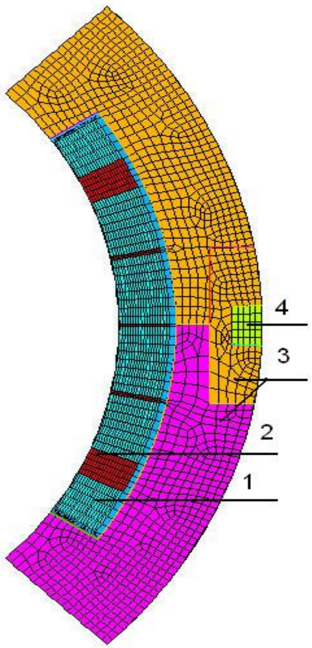


Distribution of lower field multipoles along longitudinal axis

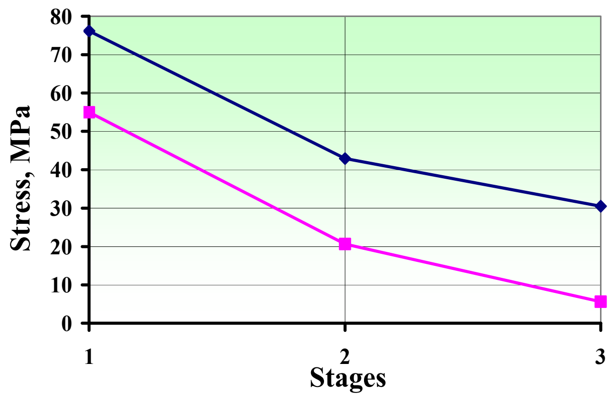
$b_n^{int} = 0, \quad n = 6, 10, 14;$

Mechanical Analysis of quadrupole

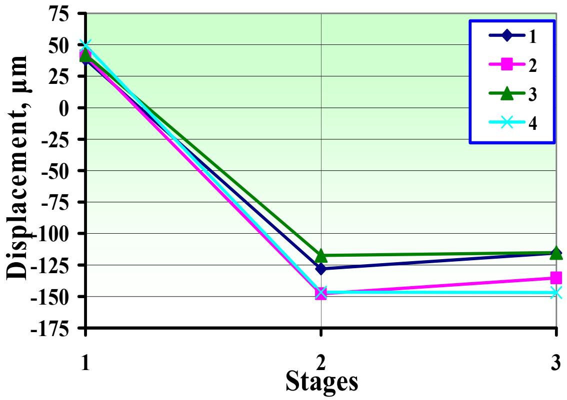
Ponderomotive forces in the quadrupole do not exceed 200 kN/m. Calculations showed that collars with wide 10 mm easy support against the radial component of the ponderomotive force. Wide of collars 22 mm were chosen for technological reasons.



FEM model: 1 - coil, 2 - inter-turn spacers, 3 - collars, 4 – key.



The change of minimal and maximal pre-stress in pole of the superconducting coil during stages (collaring, cooling, excitation)



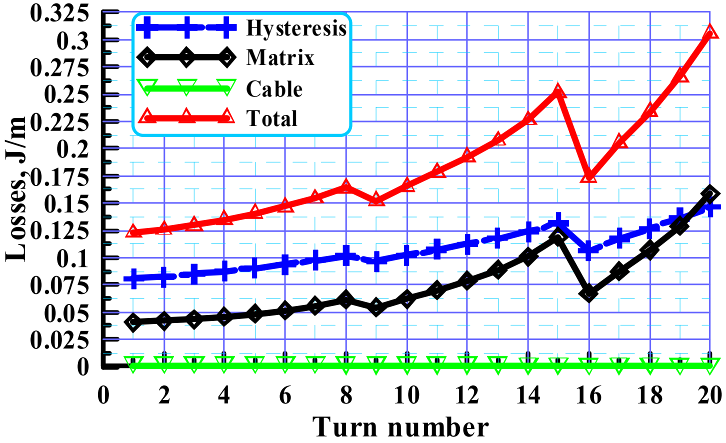
The change of radial displacements of points of pole (1, 2) and median (3, 4) turns located on inner (1, 3) and outer (2, 4) radius of coil during stages (collaring, cooling and excitation)

AC Losses

AC losses in the coil were calculated for the standard triangle cycle for the SIS 300: B_{min} = 10 T/m, B_{max} = 45 T/m, $\Delta t/2$ = 3.5 sec.

Components of AC losses per cycle in the coil

Hysteresis (do to persistent currents) : 11.2 J/m;
Matrix (do to coupling currents between filaments) : 4.9 J/m ;
Cable (do to coupling currents between strands) : 0.1 J/m ;
Total : 16.2 J/m ;



Distribution of AC losses per cycle over turns. The turns are counted off from the median plane

AC losses per cycle in the iron yoke

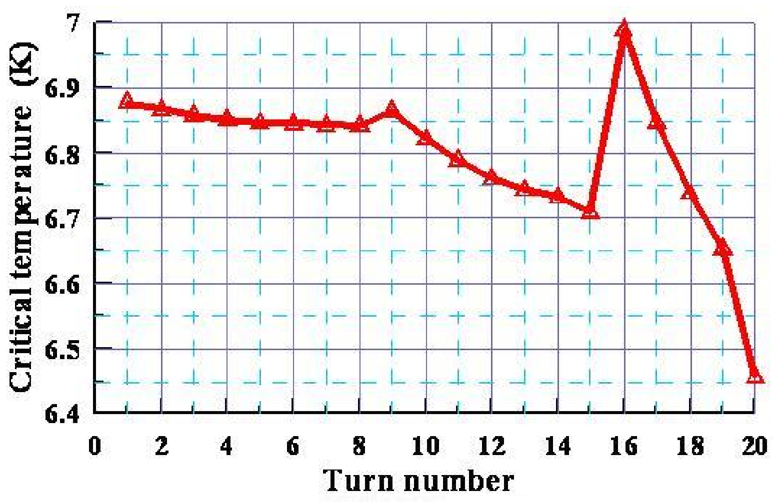
Eddy current losses in the iron yoke are a negligible component because thickness of the laminated plates is only 0.5 mm

Hysteresis losses per cycle (M250-50)-0.4 J/m

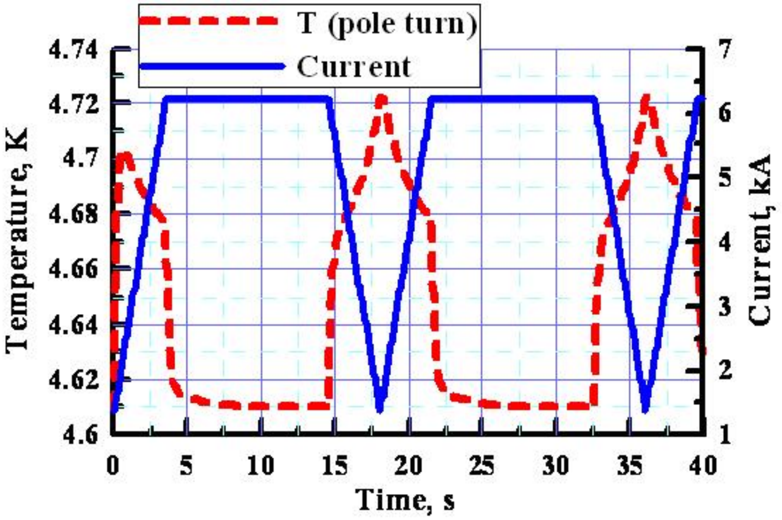
So the total losses in the coil and yoke are either 16.6 J/m

Temperature margin and Cooling

Temperature margin of magnet is minimal difference between critical and operating temperatures in turns of coil. The critical temperature and operating temperature are not homogenous over turns and their magnitudes vary in time during accelerator cycles. So it is necessary to determine the operating and minimal critical temperatures in each *k*-th turns during accelerator cycles



Critical temperatures in turns of quadrupole

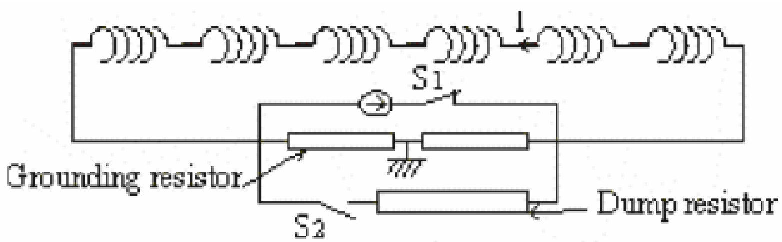


Change temperature in the pole turn of quadrupole and current during SIS 300 cycles

Temperature margin of the magnet is about 1.7 K.

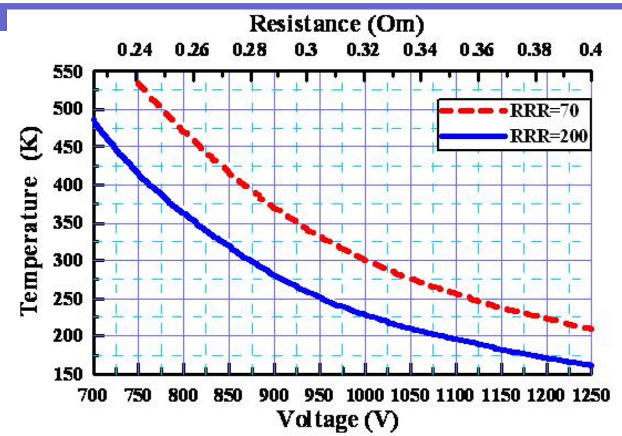
Quench Protection

The quench protection scheme must be designed so that the maximum voltage to ground does not exceed 1000 V and maximum temperature of the coil is less than 350 K. The simplest and most reliable quench protection scheme for a string of magnets is based on the use of dump resistors. We assumed in further calculations that the SIS 300 ring will be divided by two strings with 43 quadrupoles in each.

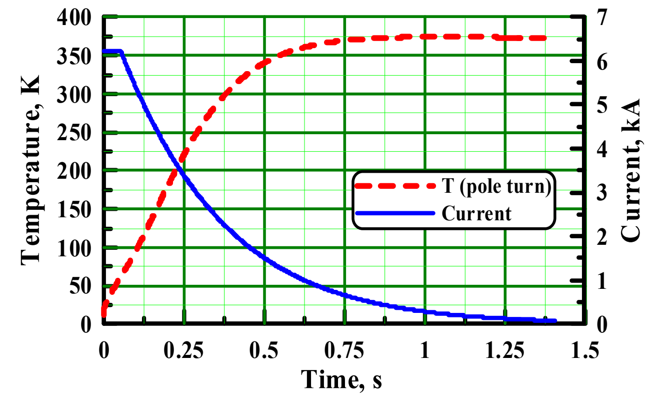


Protection scheme with one dump resistor

The quench protection scheme completely satisfies the quench protection requirements through use of a dump resistor with resistance of 0.3 Ω



Maximum temperature in the coil as function of dump resistor resistance and voltage to ground for RRR = 70 and 200



Time evolution of temperature during quench

Conclusion

- Design of quadrupole for the SIS 300 was developed by IHEP.
- Fully keystone 19-strand Rutherford cable is chosen for the quadrupole. SC coil has compact length of the end parts that increases the effective length of the magnet.
- AC losses of quadrupole cold mass in the SIS 300 operating cycle are small.
- Ratio operating current to critical is about 0.6.
- Temperature margin of the magnet is about 1.7 K.
- Quench protection scheme for a string of SIS300 quadrupole can use dump resistors.