DEVELOPMENT OF QUADRUPOLE FOR THE SIS300

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Abstract

The synchrotron SIS 300, developed for the Facility for Antiproton an Ion Research (FAIR) project at GSI, will use fast-cycling quadrupole magnets with 45-T/m central gradient; 10-T/m/sec ramp rate, 105-mm aperture, 1-m effective length. The coil consists of 1 layer, which is divided by 3 blocks in one octant. Collars are self-supporting mechanical structure. Integral multipoles are suppressed by central field harmonics in one of them and central and edge field multipoles are suppressed independently in the second one. Thermal and mechanical characteristics of the magnet are presented too. Variants of protection system parameters for the SIS 300 quadrupoles are discussed.

INTRODUCTION

Russia expressed interest in participation in international project FAIR [1]. 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. Some 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 (G_0) 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 region of good field quality is r_0 = 40 mm and the effective length of the magnet is 1 m. The temperature margin has to be at least 1 K. It is possible to use two normalizations for determination of multipoles: either quadrupole normalization $B_0 = G_0 r_0$ = 1.8 T or dipole normalization B_0 = 4.5 T. Alterations of lower multipoles of the integral field at r_0 should be less then 2×10^{-4} in dipole normalization. Furthermore, as a rule, quadrupole normalization will be used since it is stronger. Additional requirements are: minimal geometric length; simple and reliable design; decrease of AC losses in the magnet.

MAGNET DESIGN

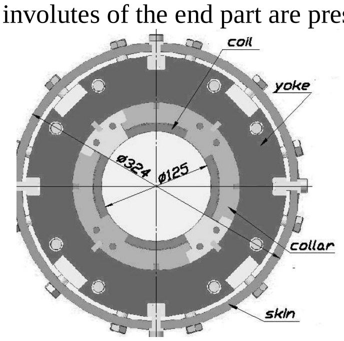
The main characteristics of strands [2] (like dipole of SIS 300) are: 0.825-mm strand diameter; 3.5-µm filament diameter; a 5-mm filament twist pitch, a Cu/superconductor ratio of 1.4, a critical current density of J_c = 2.7 kA/mm^2 (at 5 T, 4.2 K). Ratio of ρ_{300}/ρ_{10} is more than 70. Numerical simulations showed that it is enough to have a cable with 19 strands in order to meet given requirements for the quadrupole. Such type of cable will be fully keystone. 19 strands fully keystone cable was used for the UNK magnets [3], this magnets had compact design and good reliabilities.

The width of cable is 8.45 mm and an average height of 1.56 mm (with insulation). The radial thickness of the insulation (polyimide tape in three layers) after assembly is 100 µm and azimuth thickness is 72 µm. Superconducting strands will have Ni or Cr coating (without stainless core) it allows decreasing cable losses [4] and to have compact shape of the end parts is similar to those of the UNK magnet[5]. Without stainless core in cable we will have lesser stability but owing to helium in cable will keep sufficient stability of the magnet for nominal current [6]. It is estimated that the cable will have contact crossover and adjacent resistance about 10 - 20 mΩ [6].

All magnetic characteristics of quadrupole were calculated with help of computer programs MULTIC [7] and HARM-3D [8].

The coil consists of one layer. From the midplane to pole there are 3 blocks with 8, 7 and 5 turns. So it is possible to suppress lower multipoles b_6, b_{10} and b_{14}. Operating current is 6.22 kA. The inner diameter of the coil is 125 mm, inner diameter of the iron yoke is 190 mm. The main parameters of 2D geometry are given in [9].

3D geometry was considered with a point of view of integral field optimization. Edge multipoles in quadrupole are suppressed by central field multipoles. The optimized geometry has suppressed integral field multipoles for n = 6, 10, 14. Geometric shape of the end parts is similar to those of the UNK magnet [5]. Such geometry (without spacers) gives very compact length of the end parts and allows increasing the effective length of the quadrupole. General view of the quadrupole cross section and involutes of the end part are presented in Fig. 1.



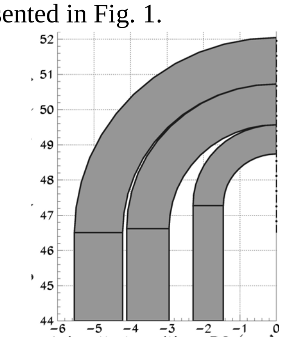


Figure 1: General view of the quadrupole cross section (left) and involutes of the end part (right).

Fig. 2 and Fig. 3 present longitudinal distribution of edge field multipole b_2, b_6, b_{10} and b_{14}. Multipoles are given at dipole normalization.

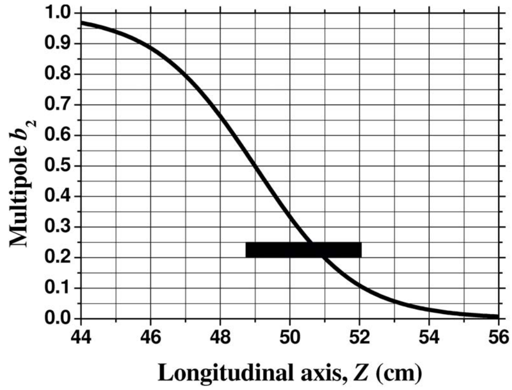


Figure 2: Multipole b_2 along longitudinal axis.

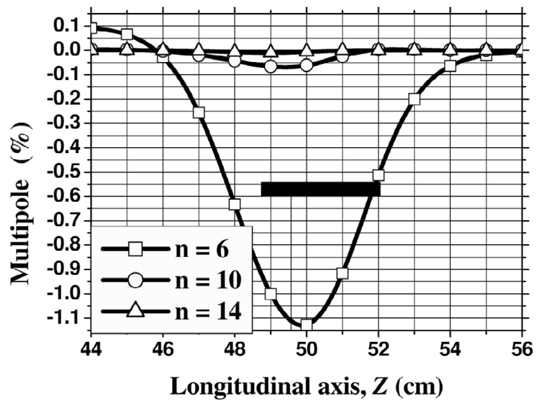


Figure 3: Multipoles b_6 b_{10}, b_{14} along longitudinal axis.

Fig. 4 presents for dependences of maximal field (B_{max}) in coil on operating current and critical current (I_c) of cable on magnetic field for different temperature. From Fig. 4 can see that for the quadrupole I/I_c is about 0.6.

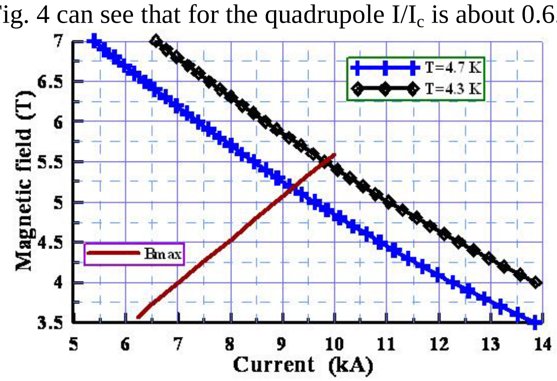


Figure 4: Dependences of maximal field in coil on operating current and critical current of cable on magnetic field.

MECHANICAL DESIGN

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. Maximum distortion of the coil in the radial direction would not exceed 30 μm after powering. Collars must be made of austenitic steel with magnetic susceptibility not exceeding 0.003. This value must be independent from field and time. One of such materials is Nitronic 40. After assembling of collar have to create preload in the coil about 70 MPa. This preload drops down to 30 MPa after cooldown and then decreases down to 15 MPa after powering.

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. The components of losses in the coil are (J/m): hysteresis - 11.2; matrix - 4.9; cable - 0.1; total losses in the coil are 16.2. Eddy current losses in the iron yoke are a negligible component because thickness of the laminated plates is only 0.5 mm, so losses in the iron yoke consist of only hysteresis losses that can be calculated by $w = aB_{\max}^{b}\left(B_{\max} - B_{\min}\right)$, [mJ/kg] [2]. Here (a, b) = (4.476, 1.750) for M250-50 steel and (10.507, 2.360) for 2212 steel. Numerical calculations give 0.4 J/m (M250-50) and 1.0 J/m (2212). So the total losses in the magnet are either 16.6 J/m for M250-50 steel or 17.2 J/m for 2212 steel.

TEMPERATURE MARGIN AND COOLING

Temperature margin of magnet is minimal difference between critical and operating temperatures in turns of coil [10]. Fig. 5 shows the critical temperatures of turns. Turns counting counter clockwise from the median plane to pole. There is minimal critical temperature in the pole turns of coil.

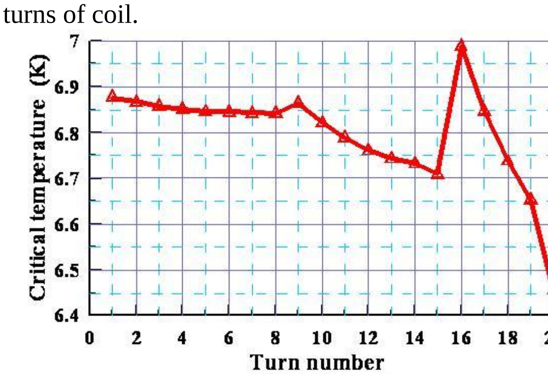


Figure 5: Critical temperatures in turns.

The heat loads on the magnet, originating from the AC loss and beam heating must be removed efficiently. The two main issues are heat transfer from the cable to the helium, affecting the temperature margin of the superconductor, and the operating conditions, that need to be optimized. We assumed in further calculations that the SIS 300 ring will be divided by two strings with 43 quadrupoles in each. Inlet temperature of helium in the last magnet of the string is determined by both cryogenic conditions and heat load in the magnet and is equal to 4.6 K. Fig. 6 shows the time history of temperature in pole turn and current at magnet. From Fig. 5 and 6 can see that temperature margin of the quadrupole is 1.7 K.

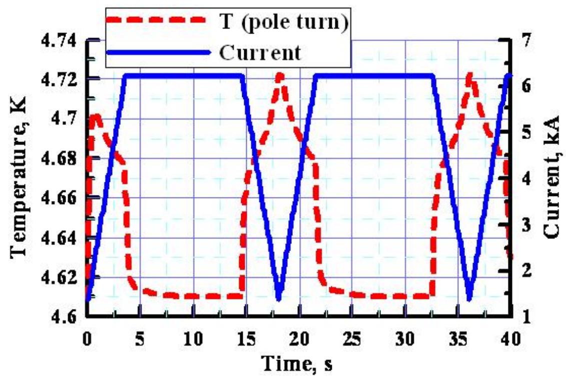


Figure 6: Change temperature in the last turn of magnet and current during SIS 300 cycles.

QUENCH PROTECTION

The quench protection scheme must be designed so that the maximum voltage to ground (U_{max}) 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. The study of the quench process in one string of quadrupoles with dump resistor was performed with a help of the computer code QUEN [11]. It was assumed that the origin of quench is in the pole turn of the coil (where maximum magnetic field is found) and threshold voltage is 0.2 V after quench detection. The power supply is switched off with 20 ms time delay after the quench detection. The maximum voltage on the dump resistor is reached at the moment, when the resistor is connected: $\Delta U_{\mathrm{dump}} = R_{dump} \times I$. If the ground is fixed in the middle of the dump resistor the voltage to ground during quench will be between $[-\Delta U_{\mathrm{dump}}/2,\ \Delta U_{\mathrm{dump}}/2]$ and the maximum voltage to ground will be $U_{max} = \Delta U_{\mathrm{dump}}/2$. Fig. 7 demonstrates dependence of the maximum temperature of the coil during quench on value of resistance of the dump resistor and maximum voltage to ground for RRR of the matrix of cable of 70 and 200.

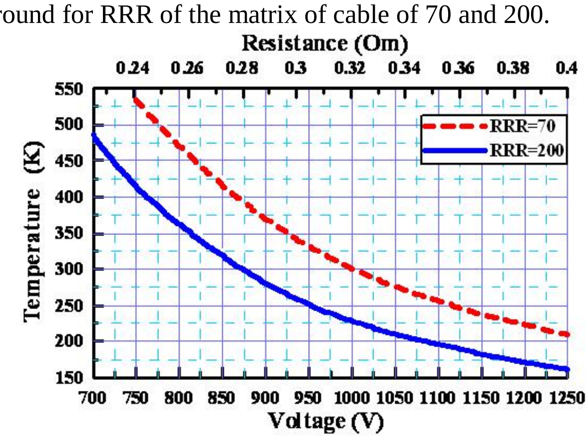


Figure 7: Maximum temperature in the coil as function of dump resistor resistance and voltage to ground for RRR = 70 (dotted line) and 200 (solid line).

As seen from Fig. 7, the quench protection scheme completely satisfies the quench protection requirements through use of a dump resistor with resistance of 0.3 Ω.

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.

REFERENCES

[1] http://www.gsi.de/fair/reports/btr.html

[2] L. Tkachenko et al., "Magnetic and Thermal Characteristics of a Dipole Magnet for the SIS 300" ASC-2006, Seattle, USA, 2006, p.p.1161-1164.

[3] A.I. Ageev et al., "Results on Testing Pilot Industrial Batch of SC Magnets for the UNK" Proc. of EPAC'1992, Berlin, Germany, March 1992, p.p. 1411-1413..

[4] L. Tkachenko et al., "Methods for Reducing Cable Losses in Fast-Cycling Dipoles for the SIS300 Ring" EPAC 2004, Lucerne, Switzerland, 2004, p.p.1750-1752.

[5] V.I. Balbekov, L.M. Tkachenko. "Optimization of the End Parts of the UNK SC dipoles". Preprint 82-167, Serpukhov, 1982 (in Russian),

[6] V. Zubko et al. "Simulation of electromagnetic and thermal processes in Rutherford superconducting cables during the initiation of a quench". EUCAS 2007, September, 2007.

[7] L.M. Tkachenko. "Code Package MULTIC for Calculation of Magnetic Field with an Arbitrary Configuration". IHEP preprint 92-28, 1992, (in Russian).

[8] S.V. Purtov and L.M. Tkachenko. "HARM-3D - a Code to Calculate Magnetic Characteristics of SC Magnets". MT-15, Beijing, China, 1997, Beijing, China, Vol. 1, p.p. 1335-1338.

[9] L. Tkachenko et al., "Quadrupole Geometry for the SIS 300" ASC-2008, USA, 2008.

[10] V. Zubko et al., "Stability of Fast-Cycling Dipole for THE SIS300 Ring", Proc. of EPAC-2004, Lucerne, Switzerland, 2004.

[11] I. Bogdanov et al. "Study of Quench Process in Fast-Cycling Dipole for the SIS300 Ring". EPAC 2004. Lucerne, Switzerland, 2004, p.p.1744-1746.