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Nb_3Sn Quadrupole Coil in MQXB Collar

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Introduction

Fermilab is planning to start a development of large-aperture quadrupole magnets for the future LHC luminosity upgrade. It is anticipated to develop 90-mm 200 T/m Nb_3Sn quadrupoles that will eventually replace the present 70-mm 200 T/m NbTi quadrupoles developed and being fabricated by KEK (MQXA) and by Fermilab (MQXB). Several magnet designs with 90 mm aperture and nominal field gradient of 210 T/m based on the Nb_3Sn strands have already been developed [1,2].

In order to accelerate the initial steps of the short model R&D program it is planned to start with 70 mm bore models that would use the MQXB mechanical structure and the iron yoke with Nb_3Sn coils. Using the available stainless steel collars along with the assembly tooling could significantly reduce the model development and manufacturing time as well as the program cost.

This note describes the optimized design of the Nb3Sn coil that match the MQXB mechanical structure. The calculated magnet parameters are also reported

1. Coil optimization

The main constrain for the coil design is that it should match the geometry of the MQXB collar [3]. Additional constrain adopted here is that the 70-mm coil design has to use the Nb_3Sn cable engineered for the baseline 90 mm magnet. This approach allows starting the development and optimization of the final quadrupole cable at the earliest stage of the R&D program.

The coil has been optimized using the ROXIE code [4] with constant permeability of the iron yoke of 3000 and the yoke inner radius of 92.564 mm corresponding to the MQXB yoke inner radius. The insulated turns of the inner layer were aligned on the inner mandrel surface with the radius of 35.00 mm and the turns of the outer layer were aligned on the outer mandrel with the radius of 66.58 mm (assuming the ground insulation thickness of 0.57 mm).

Figure 1 presents one octant of the optimized coil cross-section within the MQXB collar. In order to accommodate the maximum number of turns and achieve the best field quality, the cable insulation thickness (per side) was reduced from 0.180 mm to 0.170 mm. All the rest cable parameters remained unchanged and summarized in Table 1.

The thickness of the ground insulation between the collar pole and the pole turns was the same as in MQXB design. The second block of the outer layer has been eliminated without noticeable degradation of the field quality. Since the polar angle of the outer pole turn does not match the collar angle, the tapered wedge was used. The thickness of the interlayer insulation, predetermined by the radii of the mandrels and the cable size was 0.61 mm.

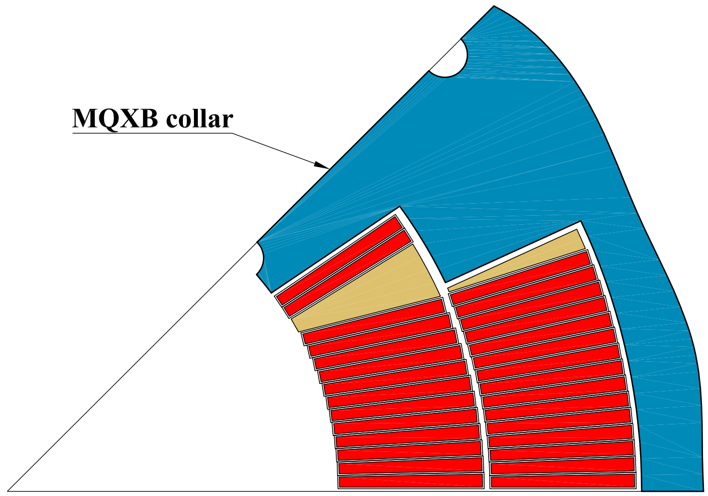

Figure 1. Arrangement of the Nb_3Sn coil within the MQXB collar.

Table 1. Cable parameters.

Parameter	Unit	Value
Number of strands	-	42
Strand diameter	mm	0.700
Bare width	mm	15.138
Bare inner edge thickness	mm	1.080
Bare outer edge thickness	mm	1.391
Cabling angle	degree	14.5
Keystone angle	degree	1.180
Average packing factor	%	89.0
Inner edge compression	%	23.0
Outer edge compression	%	0.64
Width compression	%	0.00
Radial insulation thickness	mm	0.170
Azimuthal insulation thickness	mm	0.170
Copper to non-copper ratio	-	1.2

The field quality for the optimized coil cross-section is presented in Table 2 and Figure 2. There is ~0.5 units of b_{10} component that could not be eliminated for the given collar and cable designs. It is acceptable at this stage since the main goal of this quadrupole model is an investigation of the suitable fabrication technologies and magnet mechanical and quench performances rather than tuning the field quality. Final tuning of systematic b_6 component will be done by varying the midplane insulation thickness later, after analysis of the collar and iron yoke magnetization effects, and other systematic components.

Table 2. Field harmonics at 17 mm radius.

Harmonic	10^{-4}
b_6	0.0070
b_{10}	-0.4910
b_{14}	-0.0061

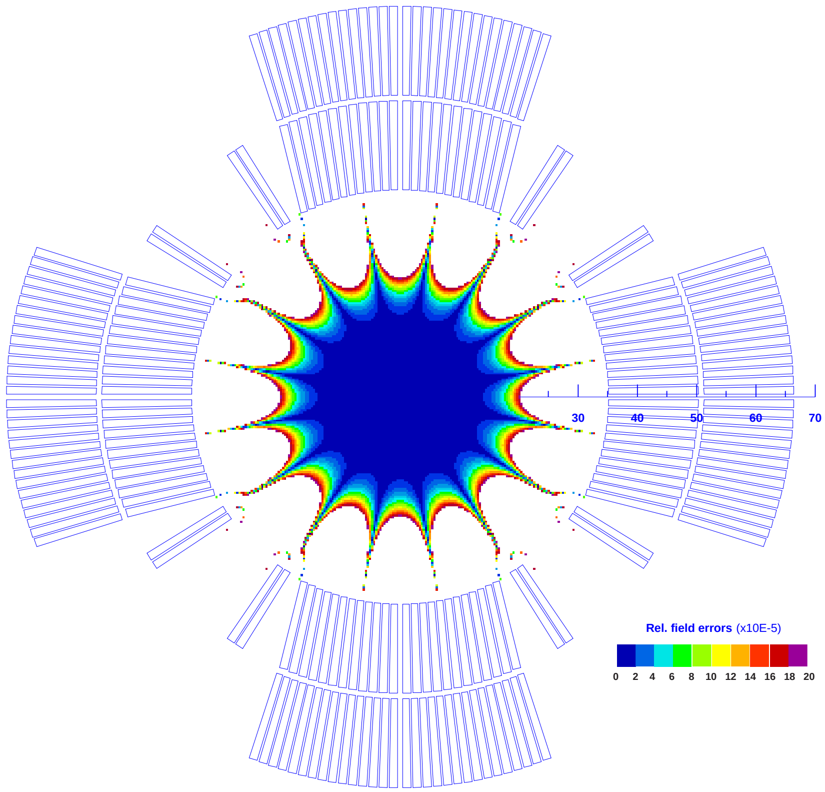

Figure 2. Field quality in the coil cross-section.

2. Magnet parameters

The major magnet parameters are summarized in Table 3. The quench parameters were determined for the critical current density in the coil (non-copper) of 2000 A/mm^2 at 12 T field. The maximum calculated field gradient for this design is about 290 T/m. The maximum gradient and quench current are 16% higher than in the MQXB magnet. The stored energy and Lorentz forces are 29% larger. Due to a smaller number of turns, the inductance is 9% smaller than for the MQXB. The iron yoke and the skin have to be involved in providing the adequate coil support.

Table 3. Quadrupole magnet parameters.

Parameter		Value
Aperture, mm		70
Turns per octant		29
Quench gradient G, T/m		292.5
Quench current I, kA		16.430
G/I, T/m/kA		17.801
Quench stored energy, kJ/m		413.9
Inductance, mH/m		3.07
Quench forces per first coil octant, MN/m	F_x	1.56
	F_y	-2.03

References:

[1] T. Sen, J.Strait, A.V. Zlobin, “Second Generation High Gradient Quadrupoles for the LHC Interaction Regions”, Proceedings of the 2001 Particle Accelerator Conference, Chicago, pp.3421-3423.

[2] A.V. Zlobin et al., “Nb3Sn Low-beta Quadrupoles for the LHC IR Upgrade (R&D program proposal”, TD note TD-02-007, February 27, 2002.

[3] FNAL drawings: 5520-ME-369190, 5520-MC-369189.

[4] S. Russenschuck, “ROXIE – the Routine for the Optimization of magnets X-sections, Inverse field computation and coil End design”, Proceedings of the First International ROXIE Users Meeting and Workshop, CERN, Geneva, Switzerland, 1998, CERN-99-01, pp.1-5.