

# SC QUADRUPOLE FOR CRYMODULE FOR ERL/ILC

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## Abstract

We are considering SC quadrupole where the field formed not only by the current distributions, but with the poles also. This delivers good quality field in all aperture allowing compact and inexpensive design. This type of quadrupole designed for Cornell ERL could be recommended for ILC also.

## INTRODUCTION

CLASSE is studying the feasibility of building the Energy Recovery Linac (ERL)[1]. The ERL will include ~70 new made cryomodules each equipped with the focusing units. Each focusing unit contains one SC quadrupole and a SC dipole corrector unit located one after one in the same vessel.

There are several publications describing the SC quad design for TESLA and for ILC, which could be useful for implementation in ERL. Design of [3] repeats earlier design described in [2]. However neither of these publications contains the field through-the-lens-integrals as function of transverse offset. Meanwhile 3D field behavior is crucial for the low emittance beams, which are ILC and ERL. On the other hand it is clear that the field generation with the poles requires enlarged aperture and careful profiling to compensate finite width of pole.

So we have chosen a different approach for SC lens design, which allows, theoretically, a good-field region coinciding with the entire aperture (100%) available for the beam [4], [5]. Coils for this type of lens is single layered and could be manufactured with minimal efforts [6].

## DESIGN

Cold mass includes: Laminations assembled into solid yoke, coils wound with SC wire, brackets for coils to hold them attached to the yoke. Cold mass held in the helium vessel and cryostat wrapped by mu-metal.

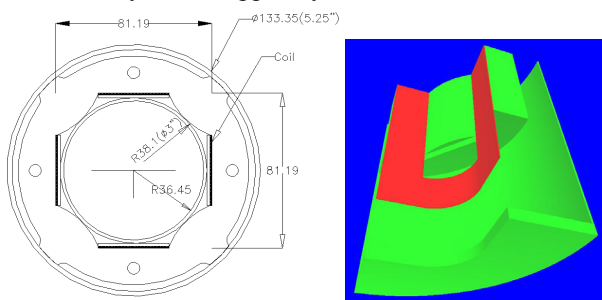


Figure 1: The concept of Quadrupole, at the left. At the right: 1/8 of 3D model as it appears in MERMAID.

Numerical calculations made with MERMAID successfully used for design of CESR-C wigglers for

taking into account real properties of Steel 1010 made yoke at liquid Helium temperatures.

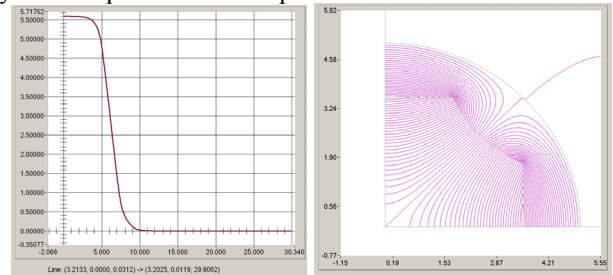


Figure 2: At the left: Field dependence on longitudinal coordinate, kG; transverse off-set is 3.21-cm; Iron is ±5 cm long. At the right: the field lines.

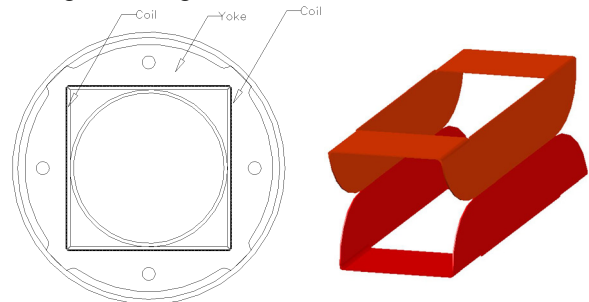


Figure 3: The concept of Dipole, at the left. At the right: the set of saddle-type coils for one coordinate.

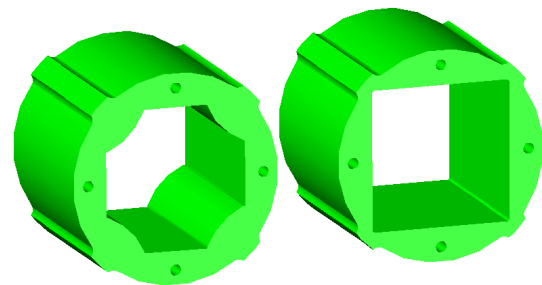


Figure 4: The yoke packages assembled and welded. Total length of each package is 100±0.1 mm.

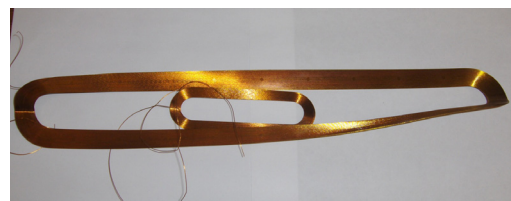


Figure 5: Example of the single-layer coils fabricated at Cornell [6].

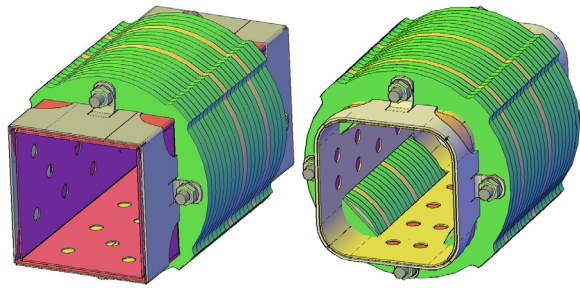


Figure 6: The Dipole corrector (at the left) and quadrupole (at the right) assembled.

Table 1: Parameters of the SC Dipole Corrector Magnet

Inner diameter of corrector	76.2	mm
Outer diameter of corrector	127	mm
Maximal working current**	22	A
Field at working current	0.065	T
Magnetic length	140	mm
Number of turns per side	95	
Wire diameter (bare/insul.)	0.33/0.41	mm
Copper to SC ratio	2:1.66	
Filament diameter	20	μm
Twist pitch	25.4	mm
Insulation to ground	50	Volt
Insulation turn to turn	10	Volt
Iron yoke length	100	mm
Coil length	186	mm
Total length of dipole	186	mm
Stored energy at 20 A	1.4	J
Self inductance	0.007	H
Integrated b1 at 20 A	0.935	T·cm
Integrated b3/b1; 20 A; 30 mm	3.2x10 <sup>-3</sup>	
Integrated b5/b1; 20 A; 30 mm	1.7x10 <sup>-3</sup>	
Coil peak field	0.7	T
Saturation at 20 A (integrated)	0.15	%

for one Direction

\*SC dipole for orthogonal direction has identical parameters

\*\*Maximal current allowable by the wire ~120A

Laminations are made from low carbon Steel 1010 with laminations not thicker, than 0.4mm. The laminations are to be individually insulated. Total packing coefficient should be not less than 90% . At the edges a thick lamination or end plate (of ~5mm thick) are required. All laminations should be line-welded at the outside in four locations (along the entire package).

The SC wire is 0.30 mm bare, wrapped by Kapton insulation and covered by Bondal (or its analog), final Ø 0.41mm.

Table 2: Parameters of SC Quadrupole Magnet

Iron yoke inner diameter	76.2 (3")	mm
Iron yoke outer diameter	127	mm
Maximal current	110	A
Maximal gradient	15.46	T/m
Magnetic length @ x=1cm; with magnetic screen	120.0	mm
Number of turns	84/pole	
Wire diam. (bare/insul)	0.33/0.41	mm
Copper to SC ratio	2:1.66	
Filament diameter	20	μm
Twist pitch	25.4	mm
Insulation to ground	50	Volt
Turn to turn insulation	10	Volt
Iron yoke length	100	mm
Coil length	147	mm
Total length of the lens	147	mm
Stored energy at 100 A	45	J
Self inductance	0.009	H
Integr. Grad. at 100 A	2.21	T
Integr. Δb/b2; 100 A, 2cm	4 x10 <sup>-5</sup>	
Integr. Δb/b2; 100 A, 3cm	5 x10 <sup>-4</sup>	
Coil peak field	0.76	T
Gradient at 5 A	0.00437	T/m
Saturation at 100 A	0.17	%

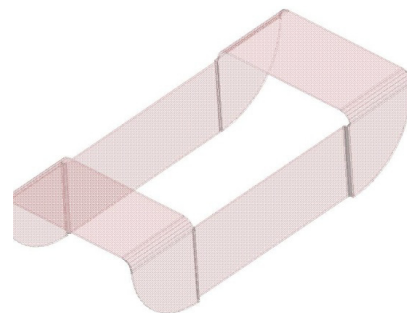


Figure 7: One of Dipole coil.

The Dipole coil is would flat as a single-layer and then bent as necessary. The coils are flexible, so they can be bent easily. The exact position of the coils in the region outside the Iron is not critical. It is important, however, that the coils have no gap in between them and the iron in the region inside the Iron (flat wall of wires), Fig. 1.

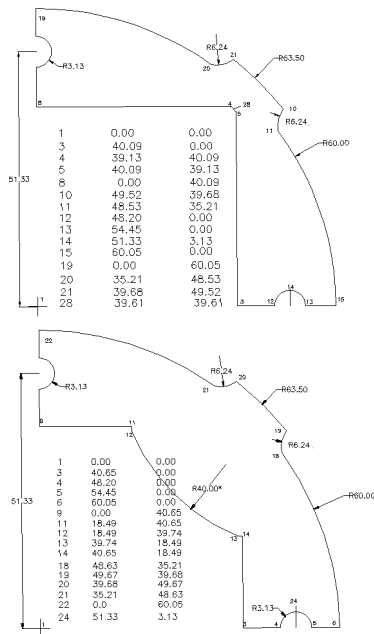


Figure 8: Dimensions for the Dipole (top) and Quadrupole (bottom) Yokes. Tolerances for inner dimensions are ±0.01mm.

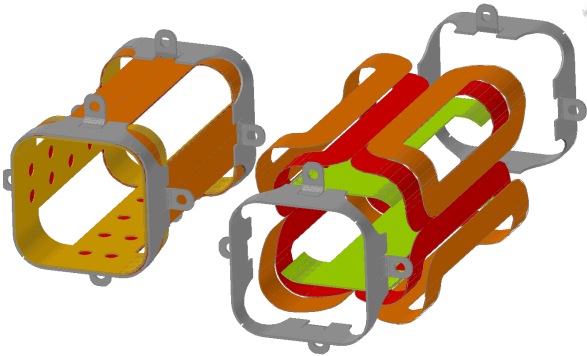


Figure 9: The Quadrupole coils assembly.

The coils are attached to the yoke with epoxy in a central region allowing expansion in both sides. Before that the Yoke covered by Kapton tape having thickness 1mil. Additional Copper or Stainless steel thin plates (0.793mm; or 1/32”) press the coils Round holes in the yoke can be used for attachment of fixtures holding the coils; additional threaded holes can be made in the end plates as required.

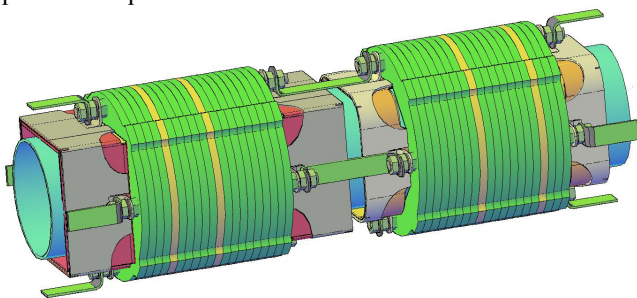


Figure 10: Dipole and quadrupole assembled. Tube OD is Ø3”.

### INSTALLATION IN A CRYOMODULE

Dipole and quadrupole installed in a separate vessel, attached to SRF section with 4 5/8 flanges at the end side of SRF cryomodule.

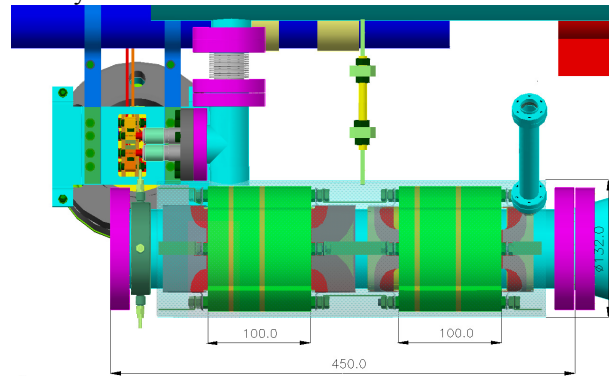


Figure 11: The focusing device inside view; semi-transparent wall. Dimensions are given in mm.

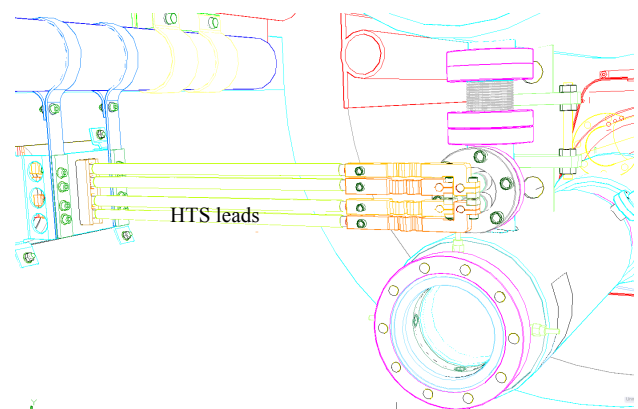


Figure 12: The Focusing device fully assembled. Large flange has O.D. 4 5/8 in. Other flanges are 2 3/4 in. HTS leads are shown also.

### REFERENCES

- [1] ILC and ERL Baseline documents available at corresponding websites.
- [2] A.Koski, R.Randemann, S.Wolf, ”Superconducting Magnet Package for TESLA Test Facility”, IEEE Transactions on Magnetics, Vol. 32,No4, July 1996, pp 2155-2158.
- [3] V.S.Kashikhin, N.Andreev, M.J.Lamm, M.L.Lopes, J.C.Tompkins, A.V.Zlobin, ”Design and Manufacturing Main Linac Superconducting Quadrupole for ILC at FERMILAB”, IEEE Transactions on Magnetics, Vol. 18, No 2, June 2008, pp 155-158.
- [4] A. Mikhailichenko, “3D Fields. Representation and Measurements”, (Cornell U., LNS), CBN-95-16, 1995. 42pp.
- [5] A.Mikhailichenko, “SC Ouadrupole and Dipole”, CBN 10-1, Cornell, 2010.
- [6] A.Mikhailichenko, T.Moore, ”Simple Procedure for SC Coils Winding”, Presented on PAC2001, June 18-22, Chicago, IL, Proceedings, pp. 3645-3647.