

Direct Wind Slim Quadrupoles for an LHC Upgrade*

P. Wanderer[#] and B. Parker, Brookhaven National Lab, Upton, NY, 11973, U.S.A.

Abstract

Slim quadrupoles, located inside ATLAS and CMS, have recently been discussed as a new option for an upgrade to the LHC luminosity. Locations inside the experiments where such magnets might be located have been identified. This paper outlines how such magnets could be made using the “direct wind” technology at BNL.

INTRODUCTION

Slim quadrupoles have been recently introduced as a new option for an LHC upgrade [1]. Two slim quadrupoles, each of modest aperture and gradient, starting about 13 m from the IP, would modify the β function, reducing the aperture required for new triplet quadrupoles Q1, Q2, Q3. These magnets would have to be placed inside the ATLAS and CMS detectors, a major challenge. Initial studies indicate that it may be possible to mount slim quadrupoles inside the experiments without major redesigns of the detectors. BNL has developed a CAD/CAM method of making superconducting magnets over a number of years. Quadrupoles with aperture and gradient needed for slim quadrupoles could be made using this “direct wind” method.

SLIM QUADRUPOLES

The slim quadrupoles, called SQ1 and SQ2, modify the β function at their location so that β is the same at the entrance and exit of the SQ’s and, thus, lower at Q1. The preliminary solution presented in Ref. [1] has the effect of reducing β^* from the nominal value of 0.55 m to 0.22 m. The parameters of the slim quadrupoles are given in Table I.

Table 1: Slim Quadrupole Specifications

Magnet	Length	Gradient	Diameter
SQ1	~ 3 m	~ 118 T/m	>32 mm
SQ2	~ 3.5 m	~ 163 T/m	> 35 mm

At the CARE-HHH workshop LUMI-06 [2], presentations made by representatives of ATLAS and CMS indicated that locations for such magnets inside the experiments could be found. For ATLAS, the magnets would be located in a region now occupied by forward shielding [3]. The available region is 5.65 m long (about 1 m shorter than the nominal lengths of the two magnets), extends to a radius of 1.47 m, and begins at $z = 12.95$ m.

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[#]wanderer@bnl.gov

The region is nearly field-free. Two constraints were cited: the performance of the original shielding needed to be maintained and the SQ’s will need to be removed every time the experiment is opened. The overview drawing of CMS showed locations where it may also be possible to locate slim quads.

DIRECT WIND MAGNETS

The direct wind technology has been used to make superconducting IR magnets which have operated for several years in HERA [5] and magnets now in Beijing awaiting final tests prior to installation in BEPC II. The most recent of these magnets are being made for the ILC R&D program [6]. The design of the QD0 final focus quadrupole calls for a gradient of 140 T/m, with a 20 mm beam aperture, a length of ~ 2 m, and operating in a 3 T background field. Short versions of this magnet have been made and successfully tested with good results for both operating field and field quality [7]. These tests, and others, indicate that the aperture and gradient needed for slim quads are within reach of the direct wind technology. The coil designed for the ILC contains a winding in series with the main coil to nearly cancel the field external to the magnet (Fig. 1). If a self-canceling winding is included in the slim quads, the stray field may not be a problem for the LHC experiments.

The direct wind magnets are wound on a CAD/CAM facility using a 1 mm-diameter round, seven-strand Nb-Ti cable. The cable is insulated with Kapton® film that has a polyimide adhesive on the outside. The direct wind machine places the insulated cable against a cylindrical surface coated with B-stage epoxy and focuses ultrasound energy at the point where the cable and cylinder meet (Fig. 2). This melts the epoxies. The winding is done at a speed that permits the epoxies to set while the position of the cable is still constrained by the winding head. The cable is wound using a novel, “serpentine,” method so that only a single length of conductor is needed to wind all poles at a given radius [8]. This allows for accurate pole-to-pole location, a prerequisite for good field quality. Gaps between blocks of conductor are filled with G10 and a filled epoxy. The winding is then overwrapped with S-glass under tension, coated with epoxy, and cured. Layers of S-glass and epoxy are integrated into the coil to provide the needed support against Lorentz forces.

SLIM MAGNET ISSUES

Many issues beyond the optics design must be considered. These might be divided into: installation into the experiments, alignment, radiation lifetime, and beam heating. An overview of these issues for Q0 was presented at LUMI06 [9]. In addition to this overview, several other items are worth noting.

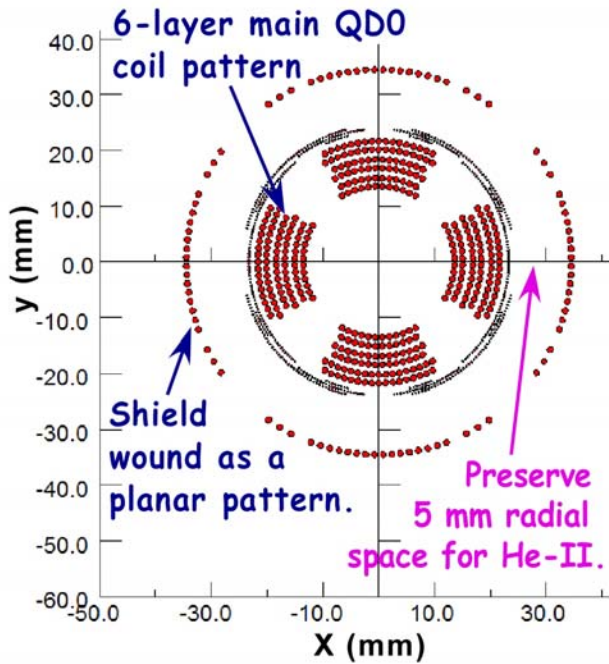


Figure 1: Actively shielded QD0 coil for the ILC 14mrad crossing angle. The inner and outer coils are wound on separate tubes (not shown) with a 5 mm space left inside the outer support tube for He II cooling. Running both coils at ~ 700 A gives 148 T/m from the inner coil and 8 T/m from the outer coil, for a net gradient of 140 T/m.

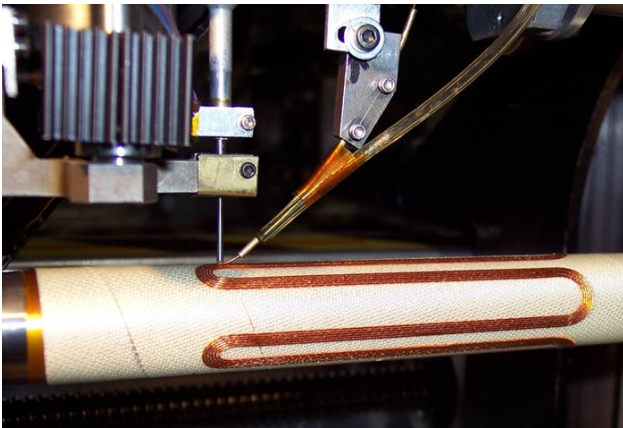


Figure 2: The direct wind machine in operation. The ultrasound energy comes through the vertical tube. The cable is fed from right to left at 45° .

Installation into the experiments requires careful study to determine how to mount the magnets and provide services such as cryogenics. One approach to this work would be to include studies of mounting and services as part of the upgrade proposals being developed by ATLAS and CMS. CMS plans to have its upgrade proposal ready by the end of 2007. The ATLAS schedule calls for a technical design report early in 2010.

Alignment of direct wind magnets will be studied as part of the ILC R&D at BNL to measure and control vibrations to the level of 10s of nm.

The issue of magnet lifetime due to radiation damage will require studies to determine the radiation dose received by the coil and studies to determine whether replacements for the most radiation-sensitive materials in the coil can be found. A modest program to identify radiation-resistant materials and use them to construct test coils of the nominal aperture and gradient would be quite helpful in determining whether slim quads could be made using direct wind methods.

Studies of the sensitivity to beam heating will be made as part of the ILC R&D program when the quench threshold will be measured by the use of localized heaters embedded in the winding.

CONCLUSION

An initial look at the direct wind technology indicates that further investigation into its application for making slim quadrupoles for an LHC upgrade is warranted.

REFERENCES

- [1] E. Laface, R. Ostojic, W. Scandale, D. Tommasini, and C. Santoni, "Interaction Region with Slim Quads," Proc. EPAC 2006, Edinburgh, Scotland, July 2006, <http://www.jacow.org>
- [2] CARE-HHH-APD LHC-LUMI-06 Workshop, October 16-20, 2006, Valencia, Spain. Talks are at <http://indico.cern.ch/conferenceOtherViews.py?view=standard&confId=4777>
- [3] P. Grafstrom, talk at LUMI-06, "ATLAS Perspective of Upgrade."
- [4] J. Nash, talk at LUMI-06, "CMS Perspective of Upgrade".
- [5] P. Wanderer et al., "Completion of Superconducting Magnet Production by BNL for the HERA Luminosity Upgrade," IEEE Trans. Appl. Supercond. Vol. 12, No. 1, pp. 305-308, March 2002.
- [6] B. Parker et al., "Compact Superconducting Final Focus Magnet Options for the ILC," Proc. PAC05, Knoxville, TN, USA, May 2005, p. 1569, <http://www.jacow.org>
- [7] B. Parker, "Recent Progress Designing Compact Superconducting Final Focus Magnets for the ILC," Proc. Nanobeam 2005, Kyoto, Japan, Oct. 2005, <http://atfweb.kek.jp/nanobeam/files/proc//proc-WG2d-01.pdf>
- [8] B. Parker and E. Escallier, "Serpentine Coil Topology for BNL Direct Wind Superconducting Magnets," Proc. PAC05, Knoxville, TN, USA, May 2005, p. 737, <http://www.jacow.org>
- [9] P. Limon, talk at LUMI-06, "Integrability of Q0 in Experiment."