SUPERCONDUCTING MAGNETS FOR A FINAL FOCUS UPGRADE OF ATF2*

B. Parker#, M. Anerella, J. Escallier, P. He, A. Jain, A. Marone, BNL, Upton, NY 11973, U.S.A
C. Hauviller, CERN, Geneva, Switzerland
B. Bolzon, A. Jeremie, IN2P3-LAPP, Annecy-le-Vieux, France
T. Tauchi, K. Tsuchiya, J. Urakawa, KEK, Tsukuba-shi, Ibaraki-ken 305-0801, Japan
P.A. Coe, D. Urner, University of Oxford, Oxford OX1 3NP, England
A. Seryi, SLAC, Menlo Park, CA 94025, U.S.A.

Abstract

The Accelerator Test Facility 2 (ATF2) at KEK is a scaled version of the final focus (FF) design proposed for a future linear collider (LC). A primary ATF2 goal is to experimentally verify the FF technology needed to obtain very small, stable beam spots at an LC interaction point [1]. Initially the ATF2 FF is made using conventional (warm) quadrupole and sextupole magnets. We intend to upgrade the ATF2 FF by replacing conventional magnets with new superconducting ones that use the same technology proposed for the International Linear Collider (ILC) baseline FF magnets [2]. With this upgrade we can investigate smaller interaction point beta-functions and study superconducting magnet vibration stability in an accelerator environment. Our ATF2 magnet cryostat design incorporates features to facilitate monitoring of the cold mass movement via interferometric techniques. The status and future plans for the ATF2 superconducting magnet upgrade are reported here.

ATF2 UPGRADE COIL DESIGN

ATF2 upgrade magnet production follows closely that envisioned for the ILC FF magnets by using the same BNL direct wind magnet technology [2-4]. With direct wind we bind multilayer, multi-function coils, of seven-strand round superconducting cable or single-strand wire, to a coil support tube and stabilize these coil windings against Lorenz forces via layers of compression wrap. The conductor is positioned on the tube under computer control using a general purpose winding machine.

For the ATF2 upgrade we need to produce quadrupole and sextupole coil packages as indicated in Figure 1. Both coil packages will be wound using 1 mm diameter round cable on a common support tube. Each coil package will also have single-wire correction layers (dipole and skew-dipole coils in the quadrupole package and skew-sextupole, quadrupole and skew-quadrupole in the sextupole package) in order to give these coils a similar degree of freedom for magnetic center offset and field rotation adjustment as found in the ILC FF Baseline [2]. For a given coil package the effective magnetic length of all coils are the same by design. Compared to the ILC ATF2 has much lower beam energy and larger emittance. So ATF2 FF magnets are much shorter, lower-gradient but larger in diameter than for the ILC. We avoid some ILC FF complications due to housing ILC FF extraction line and anti-solenoid magnets in a common cryostat [2,4] since these coils are not needed for ATF2.

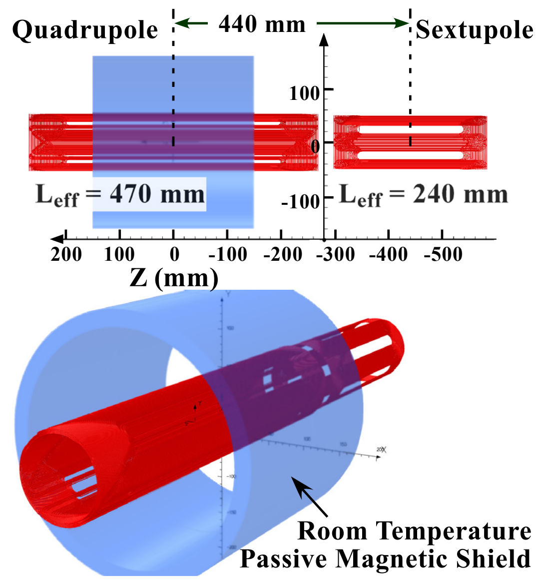

Figure 1: ATF2 Coil Layout Schematic.

In order to reduce our production costs the ATF2 quadrupole coil package will also be made without an active shield. However, we are still interested in using a magnetically sensitive device, namely a geophone, to determine the mechanical stability of the ATF2 FF magnet (for a cross check to an interferometer as

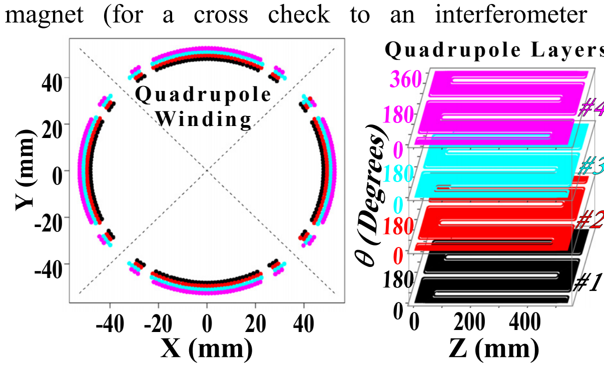

Figure 2: ATF2 Quadrupole Winding Schematic.

*This manuscript has been authored by Brookhaven Science Associates, LLC under Contract No. DE-AC02-98CH1-886 with U.S. Department of Energy. The United States Government retains, and the publisher, by accepting article for publication, acknowledges, a world-wide license to publish or reproduce published form of this manuscript, or allow others to do so, for the United States Government purposes.
#PARKER@BNL.GOV

discussed later). So we will provide a region of reduced field outside the cryostat by using a room temperature passive magnetic shield that is centered on the quadrupole as shown in Figure 1. Due to the shield's large diameter, it brings only a minor increase in transfer function and has a negligible affect on field harmonics. The sextupole external field falls sufficiently swiftly with increasing radius as not to be an issue.

A coil winding layout schematic for the main ATF2 quadrupole coil is shown in Figure 2. The coil is comprised of four Serpentine style quadrupole layers laid down in two coil sets [5]. With this arrangement we perform field harmonic (warm) measurements after winding the first coil set and then can make small harmonic adjustments by modifying the winding pattern of the second coil set. The design harmonics for the quadrupole coil are smaller than one unit (a part in 10^4) in magnitude relative to the fundamental at a reference radius of 25 mm. The FF magnets are at the highest-beta (Twiss function) locations in the ATF2 beam line so our goal is to have their field quality as good as is practical in order to minimize impact of errors on the FF spot size. With the above procedure we expect to have good field quality within the entire warm beam tube bore.

Presently the main sextupole coil is envisioned to be wound as a single, two-layer, Serpentine coil set. So there is no corresponding opportunity to make harmonic corrections during its production; however, it would be straightforward to remove the sextupole coil set and restart winding in the event that an unforeseen issue arose with its field quality.

ATF2 UPGRADE CRYOSTAT DESIGN

A fundamental consideration for the ATF2 upgrade magnet cryostat design is that there is no preexisting cryogenics supply at ATF2. We must balance the amount of new cryogenic infrastructure that will be needed at ATF2 against maintaining a close link to testing an "ILC like" cryogenic system configuration. The way we see to handle this is to test the ATF2 magnet in two stages. First we test using pressurized superfluid helium at 1.9K (parameters for ILC FF) at BNL followed later by operation at 4.2K at ATF2. During BNL testing we make measurements of the vibration stability of the magnet system, gain experience with an 1.9K ILC like cryogenic system and develop measurement and stabilization techniques that are applicable to future testing of the full length ILC FF magnet prototype. For this work we can take advantage of the service cryostat that is being built for long prototype testing. This service cryostat contains a heat exchanger needed to cool the pressurized He-II in the magnet cryostat and has current and instrumentation leads for connecting to external power supplies and monitoring equipment. The service cryostat provides a convenient interface for connecting to the BNL cryogenic test system. Actually the service cryostat is itself an ILC system component that we want to test with an eye to seeing if it is a possible vibration source.

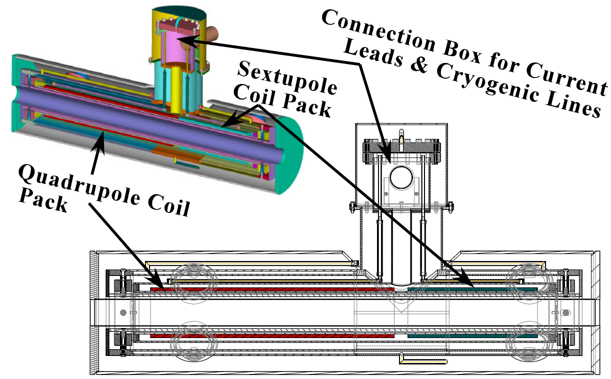

Figure 3: ATF2 Magnet Cryostat Overview.

This service cryostat is however not as useful at ATF2 and since the service cryostat will be needed at BNL anyway for later ILC full length testing, we decided in the second stage, i.e. ATF2 operation, to only cool the magnet to 4.2K via a more limited combination of cryocoolers and temporary helium dewars. Design work on the ATF2 magnet cryostat has proceeded with these two quite different modes of operation firmly in mind. Following is a snapshot of the ongoing ATF2 cryostat design work with many details still left to be worked out.

Figure 3 shows an overview of the ATF2 upgrade magnet cryostat design and Figure 4 shows a close up view of the inner cryostat structure. The inner support philosophy of the ATF2 cryostat follows that of the ILC cryostat for the most part as closely as possible; however, the ATF2 magnet will have a warm beam pipe with an inner heat shield between the beam pipe and cold mass rather than the ILC cold beam pipe. The intent is to reduce the heat leak to the ATF2 cold mass as much as possible to minimize the cryogenic system requirements at ATF2 and secondarily to simplify the vacuum interface to the rest of the ATF2 beam line diagnostics. The ATF2 magnet warm beam tube inner diameter of 57.2 mm was chosen to be larger than the existing ATF2 FF quadrupoles (present QD0 is 50 mm and QF1 is 40 mm). This opens new possibilities for beam studies under different optics scenarios, such as reducing β* at the

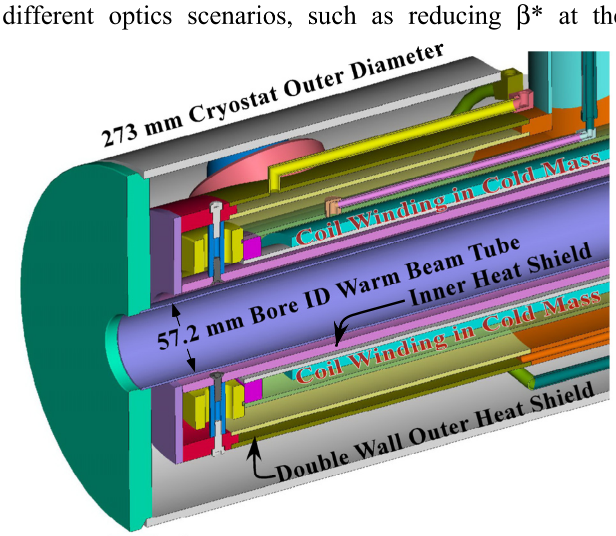

Figure 4: ATF2 Magnet Cryostat Radial Build Up Detail.

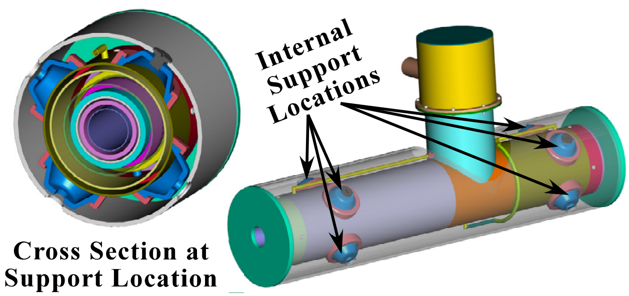

Figure 5: ATF2 Magnet Cryostat Internal Support Detail.

interaction point or lengthening the distance to the interaction point, without incurring added beam related background. Although the larger bore and added intermediate heat shield do increase the coil radius, the ATF2 upgrade magnet can reasonably be operated at three times the nominal QD0 quadrupole gradient yielding a generous operational range and flexibility.

In the ATF2 cryostat design we take care, both in routing cryogenic lines and in the placement of an intermediate lead connection wiring box, to preserve the dual temperature operation modes for BNL 1.9K testing and ATF2 4.2K operation. The heat shield is designed to be run at 5K when the cold mass is 1.9K or it can be held at 90K if the cold mass is cooled by 4.2K helium.

Figure 5 shows the ATF2 cryostat internal support structure and outer heat shield in greater detail. Eight supports, four near each end, lock the outer heat shield to the main cryostat vessel while the cold mass is attached to the heat shield via an extended thermal path at both ends (note the four supports near the sextupole end are slotted in order to accommodate differential longitudinal contraction). With this support design the cold mass is fixed to the cryostat vessel with less than half a watt heat leak to the cold mass through the support structure for ILC style 1.9K operation and four watts to 4.2K in the ATF2 run mode when the heat shield is operated at 90K.

Design work is underway to provide optical access for laser beams through the cryostat vessel and heat shield to reach targets attached to the cold mass. These targets would be used to directly monitor the cold mass movement via a MONALISA-like interferometric measurement system [6,7]. With the ATF2 magnet we want to clarify the extent to which cold mass motion is correlated with movement of the cryostat vessel as a whole. The present support structure design completely constrains the cold mass so our expectation is that the cold mass should move in concert with the outer cryostat vessel. Since it is obviously much easier to monitor motion of the outer cryostat, this is an important hypothesis we want to test using the ATF2 R&D cryostat.

The optics of the ILC and ATF2 FF make the interaction point much more sensitive to vertical motion than horizontal motion. So the present plan for monitoring the cold mass is to provide laser access to the bottom of the cold mass at both ends of the cryostat. Ideally the laser path should be completely in vacuum; however, we very much want to avoid directly connecting the external laser and cryostat insulating vacuums. One way to achieve this with minimal impact on measurement precision could be to fit the cryostat with Brewster windows, i.e. windows tilted at Brewster's angle that completely pass one light polarization state [8]. This option as well as the degree to which the ATF2 cryostat shall be passively isolated and/or actively stabilized remain for future study.

SUMMARY AND FUTURE PLANS

The design for the ATF2 upgrade magnet coils is now done and pending results from a future production readiness review we anticipate starting to wind ATF2 coils in 2009. Design work on the ATF2 cryostat is currently quite active and is planned to be completed in 2010 in parallel with procurement of some long lead time items needed for the service cryostat. ATF2 magnet production and testing then continues through the first quarter of fiscal year 2012 with the magnet available for ATF2 operation later in 2012. Note that we are aware that gaining approval to operate a new cryogenic system in accord with Japanese regulations is in itself a significant task and a dialogue in this area has now started.

More work is needed to flesh out both stages of ATF2 magnet testing alluded to earlier. With 1.9K ILC style helium superfluid operation only possible at BNL, we should ensure that the vibration/stability measurement program is as complete as possible before the magnet is shipped to ATF2. Recently the ILC and CLIC projects started to collaborate in areas of common interest and FF stability is a special concern for CLIC. While even a simple measurement of ATF2 cold mass stability could have some utility, we are unlikely to reach a level of measurement sensitivity of interest to CLIC without expending greater effort on active stabilization. Discussion will continue on how best to leverage 1.9K ILC system testing at BNL to gain information relevant to both CLIC and the ILC

REFERENCES

[1] ATF2 Proposal Volume 1, CERN-AB-2005-035 and ATF2 Proposal Volume 2, CERN-AB-2006-004.

[2] ILC Reference Design Report, ILC-Report-2007-01.

[3] B. Parker, *et.al.*, "Compact Superconducting Final Focus Magnet Options for the ILC," PAC05, Knoxville, U.S.A. (2005).

[4] B. Parker, *et.al.*, "The Superconducting Magnets of the ILC Beam Delivery System," PAC07, Albuquerque, U.S.A. (2007).

[5] B. Parker and J. Escallier, "Serpentine Coil Topology for BNL Direct Wind Superconducting Magnets," PAC05, Knoxville, U.S.A. (2005).

[6] P.A. Coe, D. Urner, A. Reichold, "The Stabilisation of Final Focus System," Pramana 69 pp1173-40 (2007).

[7] M.S. Warden, P.A. Coe, D. Urner, A. Reichold, "Nanometre Precision Interferometric Stability Monitoring Systems for Key Accelerator Components," EPAC08, Genoa, Italy (2008).

[8] http://en.wikipedia.org/wiki/Brewster%27s_angle