LOW FIELD MAGNETS WITH HIGH TEMPERATURE SUPERCONDUCTORS FOR AN UPGRADE OF CESR*#

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Abstract

An upgrade to the CESR electron-positron storage ring is being considered in which the single ring machine is replaced with two rings capable of storing high currents to provide high luminosity symmetric electron-positron collisions. This paper considers the implementation of the two rings using dual bore quadrupoles fabricated with high temperature superconductors (HTS). The use of HTS provides the required high current density needed to achieve the small (81 mm) inter-beam spacing, with a simpler and more efficient cryogenic system than would be required with conventional low-temperature superconductors. Concepts for the quadrupole magnetic and cryostat design are discussed. A concept for dipole magnets using Nb_3Sn, integrated with a warm beam tube vacuum system, is also discussed.

1 MOTIVATION FOR THE DUAL-BORE SUPERCONDUCTING QUADRUPOLE

The requirement for closely-spaced dual bore quadrupoles in the two ring symmetric collider[1] arises from the desire to minimize, as much as possible, the separation of the beams in the two rings. In the current design , the two beams share all the dipoles in the ring. The width of the dipoles, and consequently their cost and complexity, is thus minimized by keeping the beam centerlines relatively close together. The limited space available in the existing tunnel for the new rings provides an additional motivation to keep the overall dipole and quadrupole cross section small. Furthermore, the difficulties of beam separation as the beams emerge from the interaction region is minimized with a small beam separation. The goal for the beam-to-beam separation in the current ring design, 81 mm, requires a sufficiently high current density that a normal-conducting solution would have prohibitively large operating costs. Thus a superconducting coil design is the only practical and affordable choice.

2 DUAL-BORE QUADRUPOLE DESIGN

2.1. Requirements

Table I presents the general requirements. Fig. 1 shows a layout of a design of a dual-bore quadrupole which satisfies these requirements, using a high temperature superconducting coil.

Table I: Dual-bore quadrupole requirements

Parameter	Requirement
Length	380 mm
Field gradient	10 T m^{-1}
Good field diameter	54 mm
Field quality @ r=27 mm	$<4x10^{-4}$, all harmonics
Bore-to-bore separation	81 mm

2.2 Conductor and coil

The conductor parameters are given in Table II.

Table II: Quadrupole conductor parameters

Parameter	Requirement
Conductor material	BSCCO 2223 or 2212
Coil inner diameter	70 mm
Coil cross section	4mm x 16mm
Engineering current density	8500 A cm^{-2}
Operating temperature	25-30^{o} K
Peak field in coil in "bad" direction	0.34 T
Tolerance on coil cross section dimensions	+/- 0.1 mm

The conductor material is currently available in the form of tapes, roughly 3-4 mm wide by 0.1-0.2 mm thick. The tapes would be wound into a coil of the shape shown in Fig. 1. The operating temperature is chosen to place the peak field below the irreversibility line for BSCCO, so that sufficient critical current density is assured. In order to satisfy the field quality requirements, the coil must be of the saddle-coil form. Extensive studies were made of the possibility of using a flat racetrack coil, but no solution was found which satisfied both the geometric constraints associated with the 81 mm bore-to-bore separation, and the field quality requirement.

The principal issue in the fabrication of a saddle coil is related to the strain produced while winding the coil ends. The bending radius in the end is about 20 mm; in addition, there is a strain produced by the twist required to form a saddle coil. Tapes made from the oxide superconductors degrade rapidly with bending strains in excess of a few tenths of a percent. For this reason, it will probably be necessary to fabricate the coils using a wind-and-react approach. If sufficiently thin multifilamentary tape is available, a react-and-wind coil would be possible.

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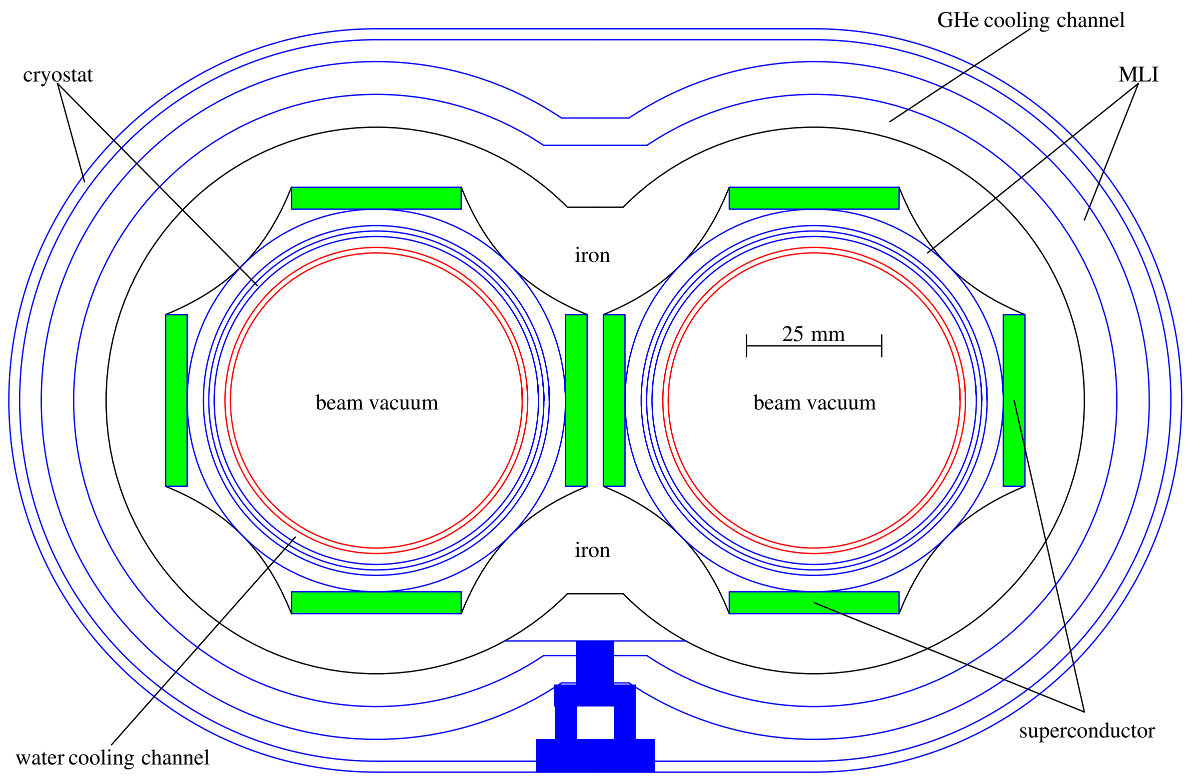

Fig. 1: Layout of the dual-bore superconducting quadrupole

2.3 Iron design

The pole tip shape shown in Fig. 1 is hyperbolic. The combination of a rectangular coil, and a hyperbolic iron pole tip, produces excellent field quality [2]. The outer radius of the iron, 50 mm, is chosen to ensure that the iron is not driven into saturation.

The septum between the two quadrupole bores is 2 mm thick. This is sufficient to allow the quadrupoles to be operated with up to 10% difference in current, without affecting the field quality (within the specifications).

2.4. Cryostat

The cryostat is illustrated in Fig. 1. The 54 mm diameter copper beam vacuum tube is warm and water-cooled, to handle the synchrotron radiation from the beam. Within the cryovacuum, the superconductor is thermally shielded from the inner bore of the cryostat with 3 mm of standard multilayer insulation. The superconductor is conduction cooled, using gaseous helium at 25^{o}K which passes through a plenum around the outside of the cold iron. Between this plenum and the outer housing of the cryostat, there is another layer of multilayer insulation, 6 mm in thickness. No nitrogen shields are foreseen. The magnet is supported near both ends with two low-heat-leak supports, as shown in Fig. 1 The total heat leak for the quadrupole from 25^{o}K to room temperature is estimated at about 1.6 W.

3 DIPOLE DESIGN

3.1 Requirements

Table III presents the general requirements for the dipole. Fig. 2 shows a layout of the design of a warm iron dipole which satisfies these requirements, using a Nb_3Sn single-turn superconducting coil.

Table III: Dipole requirements

Parameter	Requirement
Length	3200 mm
Field	0.24T
Good field diameter	54 mm
Field quality @ r=27 mm	<4x10^{-4}, all harmonics
Gap dimensions	70mm x 281mm

3.2 Conductor, coil and cryostat

The conductor parameters are given in Table IV.

Table IV: Dipole conductor parameters

Parameter	Requirement
Conductor material	Nb_3Sn
Coil width	270 mm
Coil cross section	8mm x 8mm
Engineering current density	11,700 A cm^{-2}
Operating temperature	10-15^{o} K
Peak field in coil	0.42 T

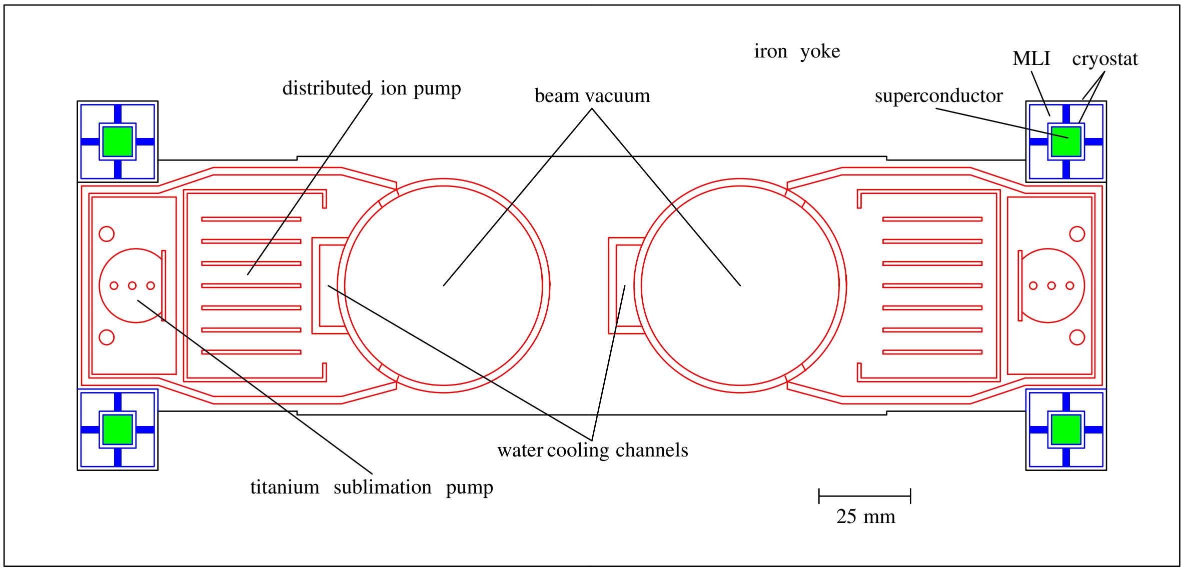

Fig. 2: Layout of the superconducting dipole

The choice of Nb_3Sn for the conductor is motivated by several considerations. This material is (currently) considerably less expensive than BSCCO. Although it must be operated at a lower temperature than BSCCO, it is still substantially more cryogenically efficient than NbTi.

As shown in Fig. 2, the conductors are of the cable-in-conduit form, with each conductor encased in its own mini-cryostat. The cables carry 7500 A in a single turn. The conduits are envisioned to run in series from one dipole to the next, carrying both current and GHe cooling. Within each cryostat, the single conductor, encased in a sheath to contain the GHe cooling, is surrounded by 4 mm of MLI and supported from the cryostat walls with ceramic spacers. The total heat leak is estimated to be about 4 W per dipole.

At the ends of each magnet, the cryostats carrying opposite currents must be brought together, to limit stray fields, and routed past the quadrupoles. Since the bending radius required is quite large, issues related to the strain sensitivity of Nb_3Sn should not be serious.

The pole tips are shaped to achieve the required field uniformity specified in Table III. The width of the return yoke iron is 20 mm; this is sufficient to prevent saturation.

3.4 Beam vacuum

Fig. 2 shows a possible design for a vacuum chamber. The circular cross section required in the dual aperture quadrupoles is maintained in the dipole magnets to minimize the coupling impedance. To maintain a beam-gas lifetime of 3 hours at an ultimate photodesorption coefficient of 2×10^{-6}, the average linear pumping speed in the storage ring arcs must be 230 l s^{-1} m^{-1}. Pumping is provided by a distributed sputter ion pump, and by a distributed Ti sublimation pump which provides faster pumping at low pressures. The conductance of the pump slots is well in excess of that needed to maintain the necessary linear pumping speed.

An alternative pumping scheme is the use of a linear cryopump, consisting of a pipe containing He liquid or gas at a temperature near or less than 10 K, surrounded by several layers of slotted radiation shields. One such design has a calculated speed of 560 l s^{-1} m^{-1} (pump only) and a heat leak of 0.125 W m^{-1}. A practical difficulty with such a cryopump is the release of adsorbed gases should it become necessary to allow the cryopump to warm for maintenance or repair.

4 CONCLUSION

Two superconducting magnet concepts have been described. These concepts are options for main arc quadrupoles and dipoles for a new two ring symmetric 5.2 GeV electron-positron collider. The quadrupole magnet utilizes currently available high temperature superconducting tape (BSCCO), and has a relatively simple cryostat. The dipole magnet is driven by small cross section Nb_3Sn cable-in-conduit, and has an integrated distributed pumping system to handle the photodesorbed gas from the beam's synchrotron radiation. Both magnets use gaseous helium cooling, and can operate at temperatures well above 4^oK, offering the promise of a relatively simple and inexpensive cryogenic system for the whole machine.

5 REFERENCES

[1]. D. Rubin, G. Dugan, A. Mikhailichenko, J. Rogers, "Dual Aperture High Luminosity Collider at Cornell", contribution 6B10 to this conference

[2]. A. Mikhailichenko, D. Rubin, "Concentric Ring Colliding Beam Machine with Dual Aperture Quadrupoles", CLNS 96/420 (Cornell University)