Conceptual Design of Nb_3Sn Magnets for the Muon Collider Ring*

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ABSTRACT

This paper describes a method for building Nb_3Sn magnets that could be useful for the muon collider. Designs for both dipole and quadrupole magnets are included.

I. INTRODUCTION

High field magnets are advantageous in the collider ring of a muon collider[1]. The luminosity is directly proportional to the field level in its dipole magnets, and its intersection region quads need the maximum possible gradient to focus the beam at the collision point. In addition, the magnets of the collider ring must operate in the face of heating caused by the still substantial radiation escaping the shielding in the machine. Required apertures are large; the combination of large apertures and high fields means that large Lorentz forces are generated. However, the magnets do not need to ramp during machine operation. A possible solution to these requirements is a cos θ coil design made only with Nb_3Sn superconductor and stainless steel components.

II. CONCEPTUAL DESIGNS

A. Dipole Magnet

Fig. 1 shows a conceptual drawing of the proposed dipole

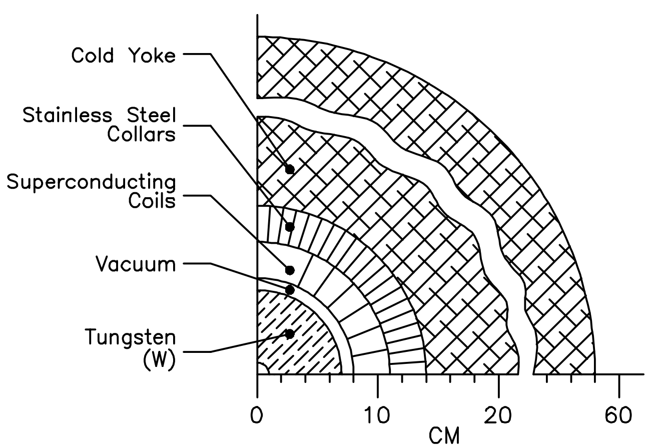

Figure 1: A quarter-section view of a dipole magnet for the muon collider ring.

magnet for the arcs of the collider ring. The requirement that most of the energy from the muon decay products be contained dictates the large center tungsten shield, which in turn determines the coil and overall magnet size. Even with this amount of shielding, several watts/meter of heat will still have to be removed in the cryogenic system. In addition, the coolant (not specified) circulating through the tungsten must remove several kilowatts/meter of heat.

The design has wind-and-react coils made with Nb_3Sn Rutherford cable wrapped with thin stainless tape as "insulation"[2]. Aside from the superconductor, only stainless steel parts are used to build the coils, e.g. for the coil wedges and end parts. Two layers of coils are assembled and collared with stainless collars, then encased in a stainless welded tube. This tube is in turn welded to stainless end plates, which contain the end forces when the magnet is powered. The assembly is then placed in an oven programmed to provide the required temperature and time cycle to react the Nb_3Sn. Since the structure is all stainless steel save the cable itself, it can tolerate the high reaction temperature without component damage and without the buildup of dangerous thermal stresses. The cable differential expansion relative to stainless is accommodated in the cable itself, which necessarily has 5-10% voids.

In this design, the Nb_3Sn is completely encased in a strong mechanical structure before reaction and not released thereafter. Thus, there is no possibility of damage to the filaments once the Nb_3Sn compound forms in the reaction process. Upon cooldown to cryogenic temperature, much of the coil prestress will be lost but the structure is designed to provide adequate mechanical support to eliminate stick-slip motion that could lead to training quenches.

The finite turn-to-turn electrical conductivity of this design will allow eddy currents while ramping but the muon collider magnets only operate DC. The magnitude of these eddy currents, though not consequential in the muon collider, are of significant interest and their effect on field quality must be measured. Quenches spread quickly, thereby minimizing local voltages and heating. The large forces in these high field, large aperture magnets require that new methods to support the coil turns must be developed; several options are under consideration.

B. IR Quadrupole Magnet

High gradients are important to achieving small spot size at the final focus but are difficult to achieve because the required apertures are large. Fig. 2 shows a conceptual drawing of a quadrupole magnet that accommodates these conflicting requirements. The principle of coil construction is the

* Work performed under the auspices of the US Department of Energy

same as for the dipole magnets discussed above. Shielding against muon decay products is done differently, however, in order that the coil apertures not become too large. The decay products from upstream muon decays are absorbed in thick absorbers at the entrance of the magnet. A lesser amount of shielding is provided around the beam tube. Detailed calculations of decay showers must be done to determine the optimum thickness of these shields. Only the superconducting coil and its support structure are operated at cryogenic temperature in this design. Calculations and measurements of the heating in 17 m SSC magnets[3] indicate that with cross-flow cooling, a heat input to the 40 mm diameter SSC magnet coil of 2.4 W/m would result in a coil temperature rise of only 0.14 K. It is estimated that at least 30 W/m of heat could be tolerated in this coil structure. A high heat load would not be acceptable in the entire machine but could be managed for the limited number of insertion magnets.

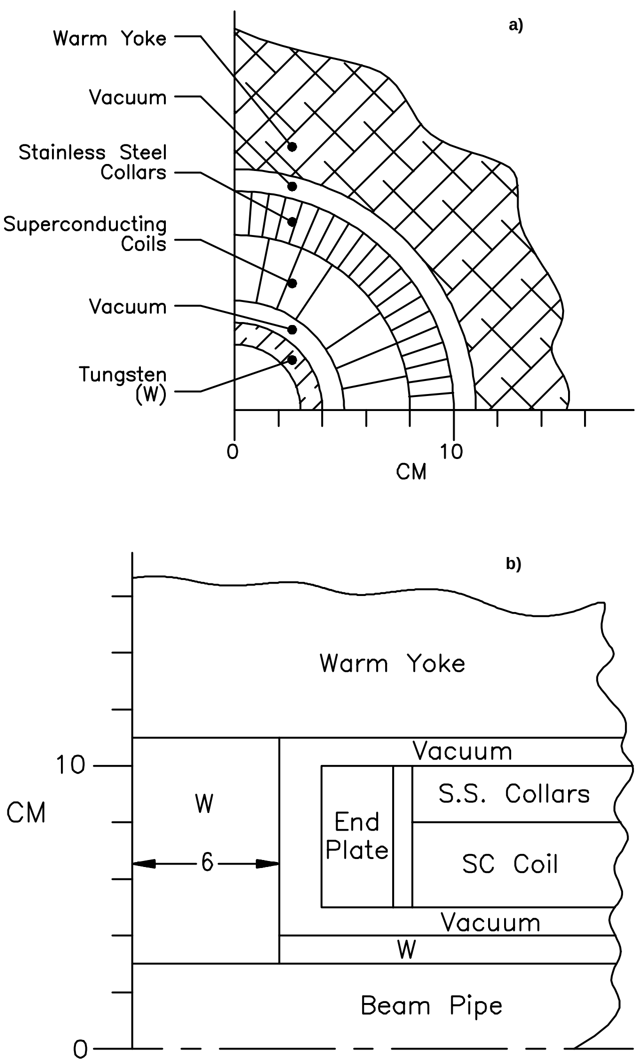

Figure 2: A quarter-section view (a) and an elevation view (b) of a quadrupole magnet for the IR region of the muon collider.

III. PARAMETERS

The 4.2 K performance of currently available superconductors[4] is shown in Fig. 3. At high fields, Nb_3Sn has a substantial advantage over NbTi: it has a critical current J_c of 1000 A/mm^2 at 14 T whereas NbTi reaches this level already at 8 T. Further, its high critical temperature T_c of 18 K compared to 9 K for NbTi makes it more forgiving of temperature excursions caused by radiation heating, exactly what is desirable in the muon collider. The data from Fig. 3 are used to calculate the achievable magnetic fields in the proposed designs.

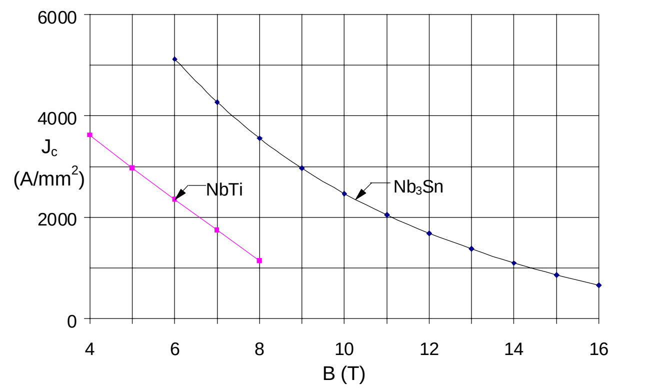

Figure 3: Critical current vs. field for Nb_3Sn and NbTi superconductors at 4.2 K.

Table I gives the parameters of the superconductor strand and cable used in the calculations.

Table I: Superconductor parameters.

		Inner	Outer
Strand diameter	mm	0.75	0.70
Quad (Dipole) Cu/SC ratio		1.5 (1.3)	1.8 (1.5)
Cable thickness, narrow edge	mm	1.5	1.4
Cable width	mm	15	15.4
Num of strands		40	44

Table II gives the parameters of the dipole and quadrupole magnets that could be achieved with the specified superconductor. With the designs that are described, it would be possible to reach higher fields with improved superconductor.

Table II**:** Typical parameters for Nb_3Sn dipole and quadrupole magnets. Operating temperature = 4.2 K. Infinite permeability iron is assumed.

		Dipole	Quad
Coil aperture	mm	160	100
Num of turns, inner coil		55	17
Num of turns, outer coil		71	24
Quench field (at pole)	T	12.5	10.3
Quench gradient	T/m	---	206
Quench current	kA	10.3	14.9
Quench, J_{SC}, inner	A/mm^2	1335	2105
Quench, J_{Cu}, inner	A/mm^2	1027	1403
Quench, J_{SC}, outer	A/mm^2	1514	2460
Quench, J_{Cu}, outer	A/mm^2	1010	1367
Yoke aperture	mm	280	220

IV. SUMMARY

Magnets producing high fields are important for the collider ring of the muon collider. The designs described here appear able to reach these high fields. They are feasible because there is no need to ramp the field in a short time---the magnets operate in a DC mode. Even higher fields than those listed appear attainable in these designs with improved superconductor.

[1] R. Palmer et al, “Muon Collider Design”, BNL 62949 (March 1996)
[2] Robert Palmer suggested the use of stainless steel foil for cable insulation in this application.
[3] R. Shutt & M. Rehak, “Cross-Flow Cooling for SSC Magnets”, Brookhaven SSC Technical Note 104 (September 1993)
[4] The data for Nb_3Sn come from: J. C. McKinnell, et.al., IEEE Trans. Appl. Supercond. , Vol. 5, No. 2, p. 1768 (1995); the data for NbTi are the measured performance of cable used in the RHIC 130 mm quadrupoles