Title

Design and Fabrication of Racetrack Coil Accelerator Magnets

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DESIGN AND FABRICATION OF RACETRACK COIL ACCELERATOR MAGNETS*

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Abstract

Most accelerator magnets for applications in the field range up to 9 T utilize NbTi superconductor and a cosine theta coil design. For fields above 9 T, it is necessary to use Nb_3Sn or other strain sensitive materials, and other coil geometries that are more compatible with these materials must be considered. This paper describes our recent efforts to design a series of racetrack coil magnets that will provide experimental verification of this alternative magnet design for a dual aperture dipole magnet wit the goal of reaching a field level of 15 T, will be described. The experimental program, which consists of a series of steps leading to a high field accelerator quality magnet, will be presented. Fabrication of a racetrack dipole magnet utilizing Nb_3Sn superconductor and a wind and react approach will be presented.

1 INTRODUCTION

The ongoing program for the development and utilization of brittle superconductors for accelerator magnets at LBNL has recently been focused on coils with a simple racetrack geometry. High field, low cost magnets are the most likely option for significantly lowering the overall cost of a new high energy collider. In particular, we are concentrating on the development of the common coil approach [1,2] for its potential simplicity of construction and consequent cost effectiveness. The design concept, shown schematically in Figure 1, consists of a pair of racetrack coils shared between two apertures, producing fields in opposite directions.

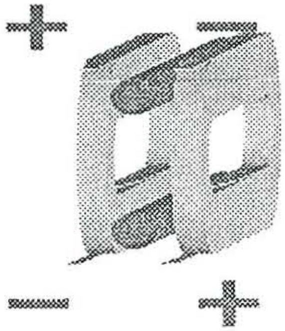

Figure 1: Common Coil Geometry

The ultimate goal of the program is the development of accelerator quality dipoles with fields up to 15 T. This will be approached by building a few lower field magnets to demonstrate the feasibility of the design, develop fabrication techniques and understand relevant performance parameters. Success will also depend on the parallel development of high quality, low cost superconductor.

2 DESIGN

2.1 Conductor and Cable

Using 0.808 mm diameter strand manufactured by Teledyne Wah Chang Albany (TWCA) for the ITER project, which has a J_c of about 610 A/mm^2 at 12 T and 4.2 K, this magnet is expected to achieve a bore field of approximately 7 T. Thirty strands are wound into a Rutherford style cable with a rectangular cross section, 1.45 X 12.34 mm. The cable is insulated with a nominal 0.13 mm thick sleeve of woven S-2 glass. To reduce carbon deposits during reaction, the factory sizing is baked out and replaced with a palmitic acid sizing which leaves a minimal carbon residue.

2.2 Coil Module Design

The basic component of this design is the coil module, which consists of a double-layer coil contained in a support structure. The coil module components are shown in Figure 2.

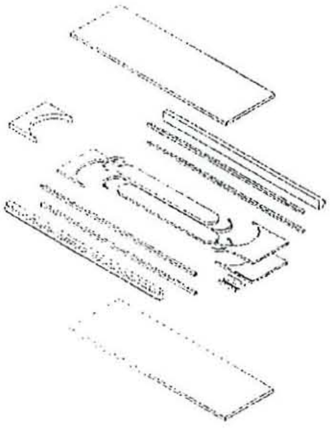

Figure 2: Coil Module Components for a 2-Layer Racetrack Coil

The preliminary design is for a 40 mm aperture magnet with emphasis on maintaining the simplicity of the racetrack geometry. The major parameters optimized were bore spacing, coil aspect ratio, high field to bore field ratio and inductance with relatively low priority on field quality initially. Table 1 summarizes the coil parameters.

Table 1: Coil Parameters

Bore Diameter	40 mm
Coil length (straight section)	50 cm
Number of turns	40
Coil configuration	2 –layer racetrack
Bore spacing	150mm
Coil Radius	40mm

2.3 Structural Support

The magnet's structural support is designed for modular coil assembly, Figure 3. End forces and vertical forces (forces in the plane of the racetrack coils) are supported within the coil module. A vertical prestress of 50 MPa is applied through 50 mm thick aluminum-bronze rails running the full magnet length in the coil package and an end preload of 50 MPa is applied using a series of setscrews loaded against the end shoes. To apply horizontal prestress and structural support, the coil packages are sandwiched between stainless steel clamping bars pulled together by aluminum tension rods. The horizontal preload is 16 MPa at room temperature and increases to 30 MPa at liquid helium temperatures. When fully preloaded, the magnet coil will not separate from the island when it is energized. Integration of vertical and end structural support into a coil package decouples the support elements in each direction. Preload can be adjusted independently in each orthogonal direction and different coil packages can be swapped into the external horizontal support framework.

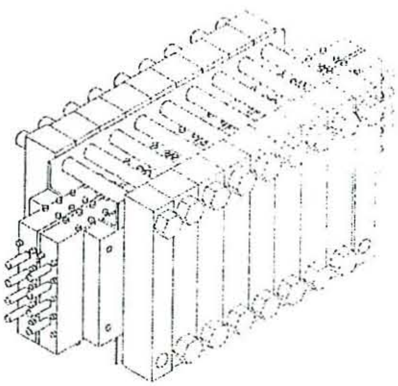

Figure 3: Coil Module Support Structure

3 FABRICATION

3.1 Coil Winding

The double-layer coils are wound around a center island (pole piece) on a flat plate with a ramp between layers to avoid internal splices. All metal parts which will be in contact with the coil are made from aluminum-bronze in order to survive the high temperature heat treatment and because of it's relatively high heat transfer coefficient compared to other materials such as stainless steel. During the winding process, strips of stainless steel foil are wrapped around the cable in strategic locations to provide voltage taps. All metal parts are insulated with 0.086 mm thick strips of mica paper to augment the electrical integrity of the coil. A 10 mm spacer is inserted after the 6th turn to reduce the field in the coil end.

3.2 Reaction

After winding, the coil straight section is compressed to a predetermined size by adding spacer bars and side rails, bolted into upper and lower plates. The ideal coil size is determined by 10-stack measurements of insulated cable. It is important to minimize the amount of epoxy between the coil layers and thus control the mechanical properties of the composite coil. Optimal compression is achieved at a pressure between 14 and 20 MPa. End shoes are then added and the leads are carefully supported in their final positions. The pole piece is made in two parts with a gap to allow for differential thermal contraction of the conductor and components during reaction. The lead-end shoe and pole piece section are fixed in place, while the return end of the coil is allowed to move. The coil is placed in a stainless steel retort under an Argon atmosphere and reacted according to the manufacturer's recommended reaction cycle, which lasts approximately two weeks.

3.3 Instrumentation

Following reaction, a pair of NbTi cables are spliced to the fragile Nb_3Sn leads. The splice regions are eventually safely contained in the impregnated coil package. Four capacitance gauges are then inserted in each coil layer. One in the pole piece gap, one between the pole piece and inner turn, another between the outer turn and side rail and one between the return-end shoe and the outer turn. Finally, a 0.13 mm laminated sheet of Kapton, stainless steel and copper, containing the heater strips and readout traces for the voltage taps is added to each layer, followed by a 0.13 mm sheet of glass cloth.

3.4 Epoxy Impregnation

The reacted coil is strain sensitive and must be reinforced with a glass fiber and epoxy matrix. The epoxy needs to have low viscosity in order to penetrate the glass fiber between the coils, good mechanical properties at cryogenic temperatures and a relatively long pot life.

CTD-101 [3] is a good choice for this application and has been used successfully in the past [4]. Similar parts made of aluminum-bronze, designed to closely fit the post-reaction dimensions of the coil replace the stainless steel side rails and plates used during reaction. A strip of mica paper is added between the outer turn of the coil and the surfaces of the side rails and end-shoes for electrical insulation and to provide a shear plane, intended to prevent stick-slip motion under Lorentz loading. In addition, the plates, side-rails and end-shoes are mold released. The completed package is then vacuum impregnated, providing a robust module for insertion into the outer support structure. All surfaces in contact with the coil remain after potting, providing good surface matching and reducing the necessity for high part tolerances, another potential cost saving feature of this design.

3.5 Final Assembly

Prior to impregnation, a 0.5 mm shim is inserted between the side support rail and the top and bottom plates. The coil size, and thus the vertical preload on the coil can easily be adjusted by reducing the thickness of the shim and retightening the side bolts. The coil packages and support structure components are stacked and aligned via pins. The nuts on the aluminum tension rods are then tightened to obtain the desired preload.

4 FUTURE PROGRAM

This magnet represents the first in a series of magnets with the goal to produce a device of similar design with a field of 14 – 15 T within two years. It will be completed and tested in early August. Test plans include a series of preload studies, making use of the simple support structure design. Experience gained will be used to modify the existing design to accommodate higher fields.

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