Description of rope-lay cable requirement for CTH helical coil

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Summary of request

Advise on whether or not NEEWC rope-laid copper cable can be supplied with internal 3/16" I.D. Teflon (or other suitable polymer) tube for cooling.

If the above is not feasible, advise on whether or not rectangular cross-section cable can be supplied with one shaped edge.

Advise if cable could be fabricated (a) from heavier gauge wire than 36 ga. to reduce possible fraying & improve copper packing fraction; (b) with lower winding pitch; i.e. less twist, to improve effective electric conductivity; and (c) without the nylon serve to reduce accumulation of chips & dirt during our coil fabrication.

Cable description:	Rope-laid stranded copper cable, alloy 102 (OFHC)
Cross-section:	Rectangular; 0.56 ± 0.01″ x 0.76 ± 0.01″
Length:	40 m (131 ft.)
Min. quantity:	40, excluding prototype and extras.

Overview

The main magnet coil of the Compact Toroidal Hybrid (CTH) device consists of a continuous helical coil wrapped around a donut-shaped vacuum vessel. The coil is wound into a helical trough formed by ten cast aluminum coil frames that are bolted together to surround the vacuum vessel. The CTH core is shown in Fig. 1.

The conductor for the helical coil will be insulated and laid into the trough. The trough will be covered, and the coil mold will be filled with epoxy using a vacuum-impregnation technique. To facilitate the fabrication of the helical coil, we hope to use flexible copper rope instead of hollow (or solid) drawn copper tubing with a rectangular cross-section. The potential issues associated with the use of the flexible rope-lay conductor are:

1. Cooling of the large coil pack
2. Increased effective resistance of the rope conductor compared to the same length of drawn copper tube.

This document describes our application, and should provide the basis for designing and selecting a custom cable for the CTH coil.

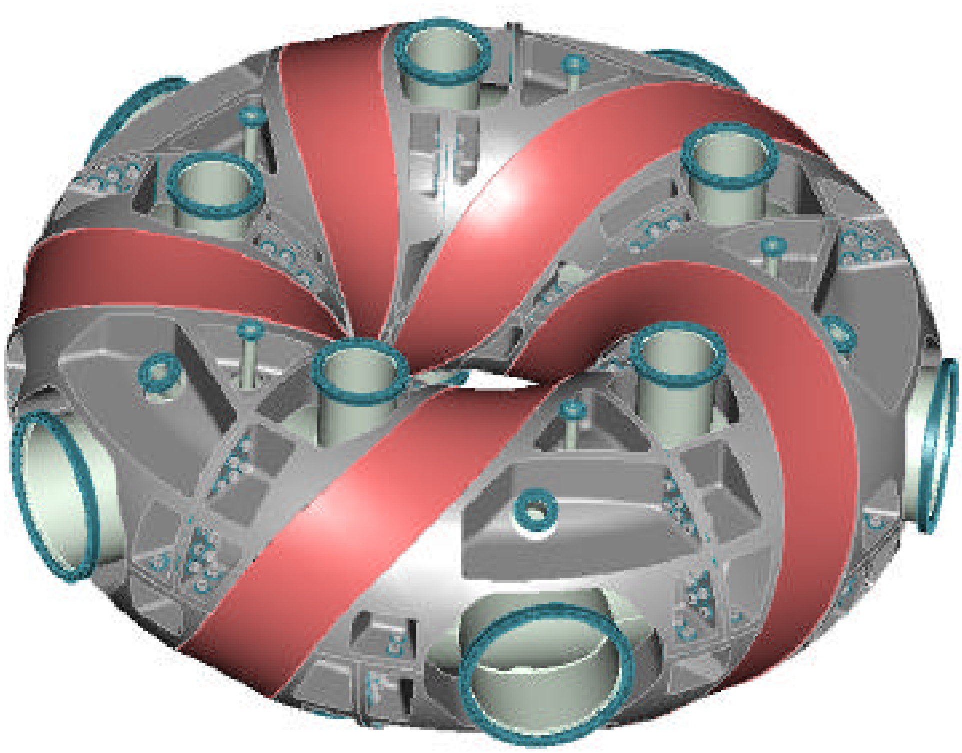

Fig. 1 Core of the CTH experiment. The helical magnet coil (red) is wound into the trough of the helical coil frame (grey) enclosing the vacuum vessel (pale green). The outer diameter of the donut is approximately 2 m.

Requirements

The maximum helical coil current is 600 kA-turns. The coil consists of 96 turns (6250 A/conductor), and is divided into 8 pancakes of 12 turns each. The coil is wound into a trough 0.265 m wide x 0.132 m high, as shown in Fig. 2. The pancakes are oriented vertically, with the crossover between pancake halves located at the bottom of the trough. The total number of individual conductors is 40 (8 pancakes x 5 periods) Each conductor is 40 m long, for a total of 1600 m. The maximum resistive voltage available to drive the requisite current is 900V.

The expected duty cycle of the coil is approximately 0.3%, or 1 second near full current every 5 minutes. Calculations of conduction cooling of the coil pack to the aluminum coil frame indicate that the epoxy insulation overly limits the cooling efficiency; without internal cooling, heat conduction is insufficient to keep the coil below its maximum desired operating temperature of 50°C over the course of several hours of operation. With internal cooling, we estimate 8-9 gallons per minute will be required.

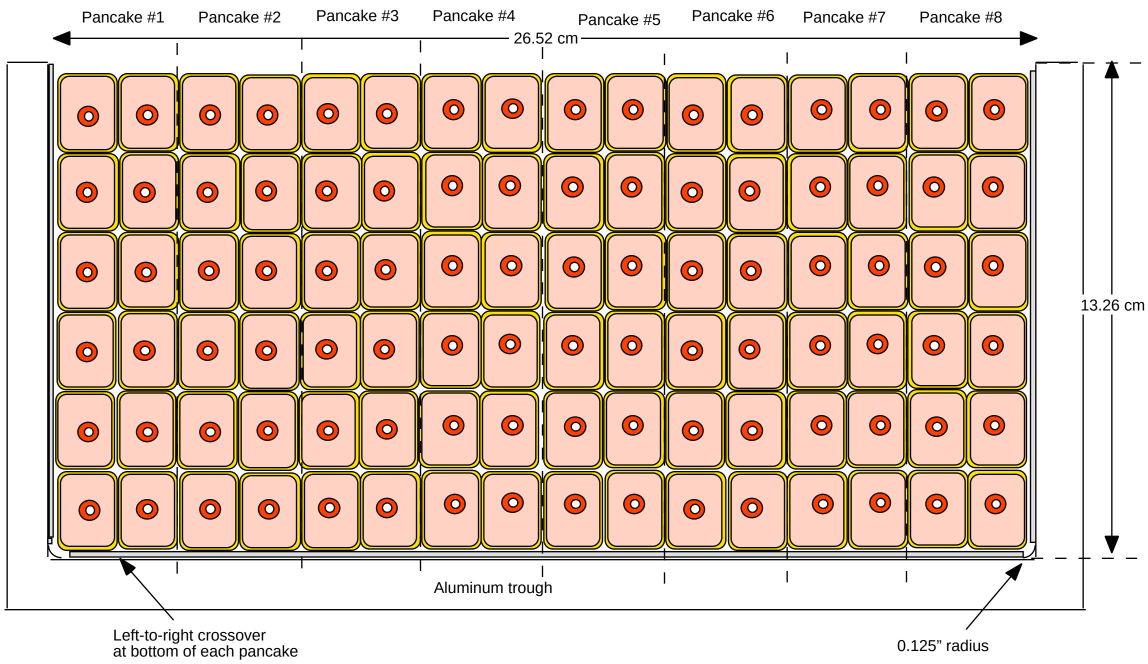

Fig. 2 Cross-section of coil pack in rectangular trough. The pancakes are wound from bottom to top.

Electrical Tests of NEEWC Rope

Approximately one year ago, NEEWC supplied Oak Ridge National Laboratory with a test run of copper rope with a rectangular cross-section in exploratory studies for the NCSX fusion project located at Princeton Plasma Physics Laboratory. The dimensions of the rope were 1.2 cm x 1.6 cm. Oak Ridge supplied us with a length of this rope, and we used it to make electrical resistivity measurements and epoxy-potting tests. We found the rope to have an electrical resistance 43% higher than that of what we would expect of solid OFHC copper alloy 102 of the same dimensions. The difference can be ascribed to the lower density of the rope (approximately 80% of solid) and the remainder to the twist of the strands in the rope. We conjecture that current flows primarily along the strands (which are longer than the cable itself), and not down the axis of the cable. While this possibility seemed surprising to us, it may perhaps be explained by lubricant from the braiding process remaining on the strands and providing electrical insulation between strands.

We have designed a helical coil using our measurements of the rope's resistivity, and concluded that the use of the rope is acceptable for our application provided cooling can be effected within the coil pack itself. Nonetheless, our space limitations and the increased conductor resistivity are pushing us to our voltage limit. Therefore, we hope that in following up our request for a custom cable design, NEEWC will consider means by which conductor cross-section and conductivity can be maximized.

Coil pack with internal cooling

The estimated coolant flow of 8-9 GPM can be achieved through 40 tubes (one per conductor) using tubing with 1/8” ID or larger. To provide cooling within the coil we envision two general methods:

1. Embed a teflon (or other plastic) tube within the rope during winding, and prevent it from being crushed when the rope is compressed into a rectangular shape. We have identified a standard Teflon ETFE (Tefzel) tube of 3/16” O.D. and 0.140” I.D. that should be suitable for our purpose. The temperature limit of Tefzel is 150°C, and the maximum temperature of the coil is expected to be 80 - 85°C during the epoxy cure process. If this proves feasible, the desired cross-section is 0.56 ± 0.01˝ x 0.76 ± 0.01˝ with 3/16˝O.D. cooling tube in the center. The corners of the cable should not be rounded more than .02" radius.

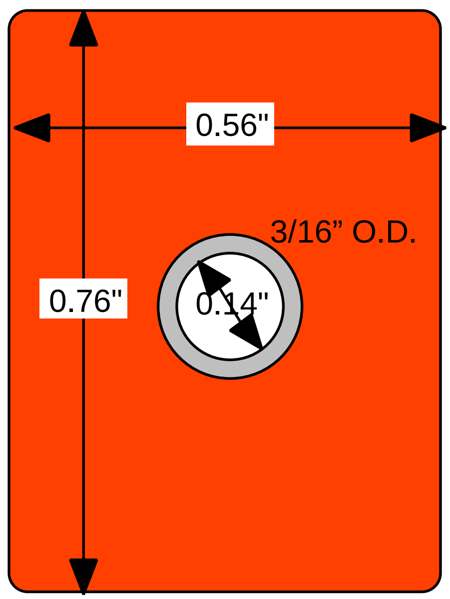

Fig.3 Preferred option for copper conductor with embedded cooling tube.

2. Fabricate a cable with one mitered corner, as shown in the sketch below. We would then insert a cooling tube within the triangular vacancy during the winding of the coil pack. We have assumed that only simple miters can be made, but clearly other shapes (partial rounds) might leave more space for copper conductor.

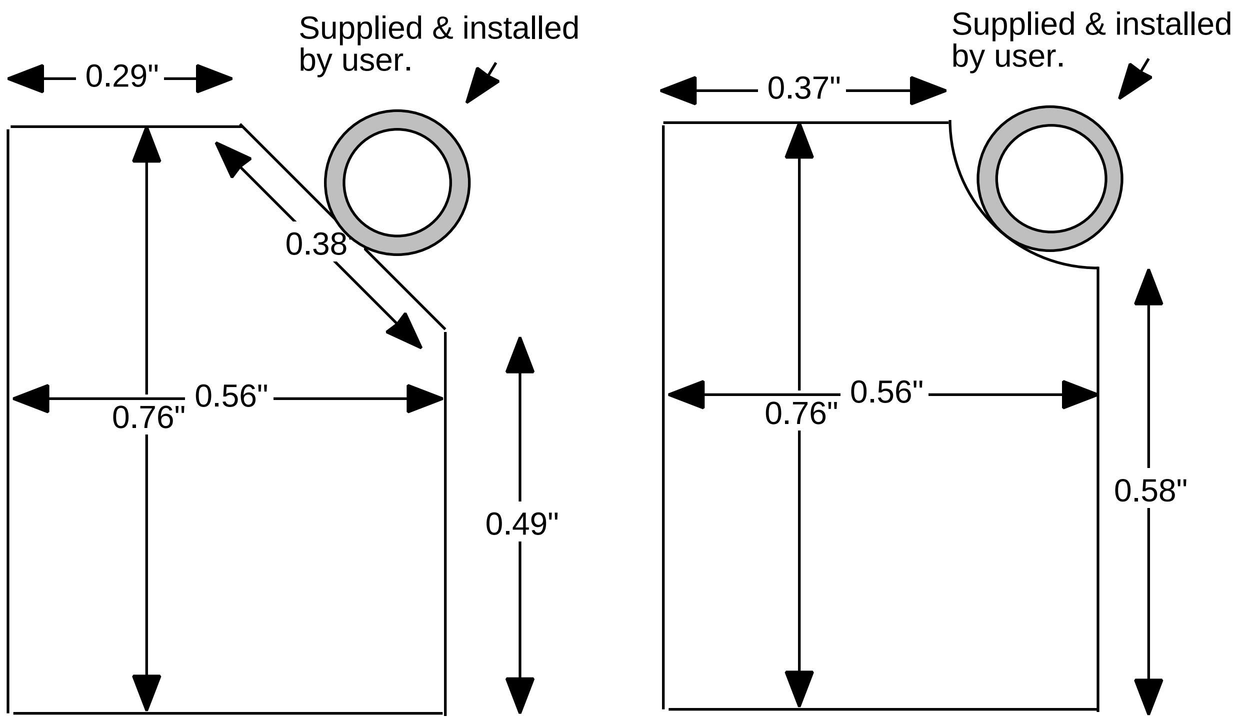

Fig. 4 (Left) Rectangular coil with one mitered corner to allow installation of cooling tube during coil fabrication. (Right) alternate concept of mitered corner to permit greater utilization of copper cross-section.

The first option of a rectangular cable with enclosed cooling tube should lead to a higher copper cross-section, and requires less work from us during assembly; this is preferable to us if the cable can be fabricated with reasonable cost-effectiveness. We hope you will advise us on the two options, or suggest possibilities we haven't considered.

Additional Requirements & Questions

1. We have noticed from the copper rope sample that because of the direction in which the strands are wound, the conductor twists more easily in one direction than another. The helical nature of the coil as shown in Fig. 1 lends itself to a particular winding direction of the rope-lay conductor; specifically, opposite to that of the cable sample we have. We believe that the winding polarity that fits our direction is one in which

the strands go from lower left to upper right as one looks down at the cable. We would consult with you to ensure we have specified the proper winding direction.

2. The cable sample we have is fabricated from 36 gauge wire. To prevent fraying (which could lead to internal shorts within the coil pack), we request a heavier gauge wire to be used. We will consult with you as to whether 32 or 34 gauge would be appropriate.

3. The winding pitch of the wire within the rope apparently leads to increased effective resistance of the cable. To what extent can the pitch of the winding be reduced without sacrificing the properties of the rope? If the pitch can be reduced, more strands can be used for a given cross-sectional area, and the effective resistance per length should go down. Once we receive the rope, we intend to immediately wind it with fiberglass tape in preparation for putting the cable into the helical trough; the rope will be flexed only during coil fabrication, and will be rigidly encapsulated in epoxy afterwards.

4. We would like the rope fabricated without the nylon serve unless it is important to the fabrication process.