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Design of a Sample Holder for Measurements of Nb_3Sn Cable Critical Current Under Transverse Loading Conditions

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Introduction

A critical predictor of performance for a Nb_3Sn magnet design is the ability of the conductor to carry high transport current while under significant transverse loading resulting from Lorentz forces acting on the conductor. Conversely, it is beneficial to design a magnet mechanical structure that minimizes such forces, so that degradation of the current-carrying capacity of the conductor is limited. Important to this effort is an understanding of the effect of applied transverse pressure on the critical current (I_c) of a cable sample.

Measurements have been performed[1] at the National High Magnetic Field Laboratory (NHMFL) in Florida to quantify the effects of transverse pressure on I_c for Nb_3Sn and HTC conductors. The technique employed[2] utilizes a He gas pressurized piston to apply pressure to a section of cable under test. The maximum load that can be applied is 530kN, while the contact surface of the piston has a diameter of 122mm.

Candidate cables for a common coil react-and-wind Nb3Sn dipole magnet[3] are to be evaluated for their critical current performance and its' degradation due to applied axial and transverse strain. A fixture to hold samples of such cables in the required orientation in the test facility, while providing adequate restraint, with the concurrent ability to transfer a controlled transverse stress to the cable, has been designed. Additionally, this fixture has been designed to be compatible with the Brookhaven National Laboratory (BNL) cable test facility, so that measurements of cable critical current can also be performed there. Measurements at BNL are performed with a uniform transverse pressure applied to the cable via the sample holder cover plate and restraining bolts, rather than an active system.

Sample Holder Design

General

The sample test holder is designed to securely hold cable samples in place while transverse stresses up to 290 MPa can be applied to the cable broad face. This holder consists of a stainless steel "U" channel base containing two insulated Nb_3Sn cables in a groove running along its length. The cables are spliced together in a copper case at the lower end to provide a continuous current path, and are soldered to Cu bus plates at the upper end where the connections to the test system current supply are made. Additional insulated Nb_3Sn cables, that are not electrically part of the circuit, surround the Nb_3Sn cable samples under test, one above and one below the active Nb_3Sn pair. These additional cables are used to replicate the mechanical environment found in the magnet coil. The cable samples are vacuum impregnated with epoxy in situ in order to provide additional cable support and again reproduce the magnet coil mechanical environment.

The sample holder is 1220 mm long overall, with an active sample length of 970 mm. The holder is 60.5 mm wide and the thickness of the body is 26 mm. These dimensions represent the largest allowable sample holder that can be accommodated by either the NHMFL or BNL facilities. A pressure bar, with a rectangular protrusion (pressure "dog") that contacts the loading piston, rests on the cable surface and is held in place by the cover plate. The pressure dog extends ~0.5 mm past this cover plate, and is the same width as the cable sample to be tested. To accommodate thinner cables, additional pressure bars can be manufactured, or a shim added between the cover plate and pressure bar. In the event that it is desired to study the effects of loading the thin edge of the cables on critical current, a U channel with a deeper groove that will hold the cables when rotated by 90° can be fabricated. The cover plate is bolted to the U channel using 9.5 mm diameter socket head screws spaced on 24 mm centers, along both sides of the cover plate. The pressure bar is attached to the cover plate using #10-32 screws, to prevent tilting of the pressure bar during operation, and hence, application of a non-uniform pressure. The pressure "dog" is likewise attached to the pressure bar using two #10 screws.

The sample holder is oriented and restrained in the magnet bore by wedge-shaped brackets mounted to its exterior, which serve to reproducibly position the sample holder with respect to the background magnetic field, and restrain it from motion induced by torque on the sample during testing. These brackets are designed to be adjustable so that vertical alignment in the magnet bore can be tuned, and also so that they can be removed when the sample holder is in use at BNL.

Pressure Transfer

A pressure bar, held in place with a G-10 cover plate that runs the length of the fixture, applies transverse pressure to the cable sample, by means of a pressure "dog" that contacts the He-gas driven ram that is part of the NHMFL test facility. The outer end of this gas ram can be operated with internal pressures of up to 10 MPa at 4.2 K before the helium solidifies. This pressure is applied to the outer edge of a 305 mm diameter piston, yielding a maximum force of 707 kN. Utilizing a 75% safety factor, 530 kN of force is available to be applied to the inner piston, which is 122 mm in diameter. The dimensions of the pressure dog are 150 mm x 15 mm; however since the ram diameter (inner piston) is less than the pressure dog length, the effective area is given by the ram diameter and pressure dog width (122 x 15 = 1830mm^2). This gives a maximum available applied transverse pressure of about 290 MPa. This is, of course, quite a bit larger than the maximum required for cable studies (about 100 MPa), and testing will be limited to pressures below about 100 MPa. A capacitative pressure transducer of dimensions 80 mm x 15 mm is built into the sample holder underneath the center of the pressure plate, in order to provide a measurement of the stress applied to the cable sample during testing. This transducer can be calibrated for operation up to 75 MPa, at both 300 K and 4.2 K. Pressure sensitive film (Fuji film) will be used in room temperature tests of the assembly to check loading uniformity.

Lateral Cable Restraint

Reproducible and accurate test results require that the cable samples be supported against mechanical motion that would induce a quench. This is accomplished by restraining the cables very securely in the fixture. A set of lateral shims, 4.8 mm thick and 8.5 mm high, running the length of the fixture, can be adjusted using screws to tighten the shims against the cable package. A lateral travel of about 1.75 mm can be achieved by adjusting these shims; therefore cables of up to 16.75mm width can be accommodated. This system was chosen in lieu of solid shims that would need to be inserted with significant pressure in order to restrain the cable. It was felt that this could lead to localized cable degradation. The use of one adjustable and one fixed shim would possibly result in an off-center alignment of the cable sample, so this too was rejected. The present design minimizes the static loading applied to the cable and provides sufficient restraint while minimizing the epoxy volume. The cables will initially be supported by adjusting the shims snugly and uniformly against the cable sides. Then, additional restraint is provided by epoxy impregnation of the cables within the fixture, forcing epoxy to flow (under vacuum) along the length of the fixture. To this end, temporary end pieces with impregnation ports have been designed for vacuum impregnation. These end pieces are removed after impregnation and before testing. To facilitate disassembly later, the various components of the fixture will be coated with mold-release, and gaps sealed with RTV silicone sealant.

Current Lead Attachment & Splices

At the lower end of the fixture, the two Nb_3Sn cable samples are spliced together to provide a continuous current path. The two Nb_3Sn 'filler' cables ("dummies") stop short of the splice location, and the Nb_3Sn cables, with insulation removed, are sheathed in a Cu box about 125 mm in length. The splicing operation is performed in situ in this Cu box, which provides a stable thermal and mechanical environment for the splice. The cover plate of the Cu box is attached using #4-40 socket head cap screws spaced at 12.5 mm intervals along the two sides of the top surface of the box. The U channel is widened to accommodate the larger dimensions of the splice box, which is insulated from the fixture by wrapping with Kapton® tape before insertion.

At the upper end of the fixture, the Nb_3Sn dummy cables are terminated and the Nb_3Sn cables to be tested extend into a Cu bus plate, to which they are soldered, along with short NbTi cable segments used to fill the splice cavity (in the BNL configuration, these NbTi cables are longer, and used to mate with the power leads of the test facility). This plate is designed so that the NbTi "rope" current leads of the NHMFL test facility can be connected to the sample holder by clamping them between the Cu bus plate and G-10 bus cover, using Indium foil to improve electrical contact. The G-10 cover plate extends past the Cu bus plates and covers part of the underside of the U channel, to which it is bolted. This provides additional mechanical support to the Nb_3Sn cables where they exit the U channel, as without this overlap the Cu bus plates are linked to the sample holder body only by the Nb_3Sn cables. Since the sample holder will experience a torque (~22N-m) due to the vector cross-product of the sample current and background field, this additional mechanical support is needed to prevent excessive strains on the test cables, and premature quenching. The Cu bus plates are insulated from the other sections of the sample holder using 125 μm thick Kapton® tape. All of the splices are performed "on the bench" before inserting the cables (and Cu splice box and bus plates) into the U channel sample holder. This operation requires great care in order to minimize any strains imparted to the cables.

Instrumentation

Voltage taps spaced 200 mm and 250 mm apart surround the section of the cable underneath the pressure plate, and are used to monitor sample voltages during I_c testing. A total of two pairs are used per sample. The voltage tap leads are Tefzel coated Kapton® insulated wire as used in model magnet fabrication. The lead wires are twisted together and routed through the "U" channel via grooves and holes drilled perpendicular to the longitudinal axis. The wires are then led along the outer edge of the fixture to the top, where a connector is installed that will mate to the facility DAQ system. The wires from the top Nb_3Sn sample are routed out the right side of the holder, while those of the bottom sample are routed out the left side (as viewed looking toward the top of the sample holder).

A capacitative pressure transducer with active dimensions 80 mm x 15 mm x 0.5 mm is installed in the bottom of the "U" channel in a groove machined for this purpose. The gauge is centered longitudinally with respect to the pressure 'dog'. The gauge is held in place using Kapton® tape and RTV adhesive. The gauge's lead wires are routed to the outside of the sample holder in a fashion similar to that of the voltage taps, through the same hole used by the voltage tap wires for the top Nb_3Sn sample. A mating connector (Hypertronics® Type LDMSTH, Mod D, male 17 pin, 2-unit) is then installed at the top of the fixture for connection to the DAQ system.

Modifications for use at BNL

It is envisioned that cable I_c measurements may also be performed at the Brookhaven National Laboratory, using their standard cable test facility[4]. These measurements will focus primarily on the effects of induced strain, resulting from reaction of the cable in the coiled state, on the cable I_c performance when tested in the unwound (flat) condition. At this facility, variable transverse pressures are not available - the cable is to be fully mechanically supported by clamping the sample holder cover plate to the U channel using the 9.5 mm socket head screws in conjunction with the appropriate shim to yield the desired cable clamping stress. For this purpose, a different cover plate (made of stainless steel instead of G-10) without the cutout for the pressure dog has been designed. The length of the sample holder itself (U channel and cover plate) has been chosen to accommodate the bore length of the background field magnet at BNL, resulting in a longer sample holder than would be needed solely for use at NHMFL.

The power supply connection scheme at the BNL facility differs from that at NHMFL, whereby the cable samples are directly soldered to leads in the test facility. Therefore, when samples are to be tested at BNL, the Nb_3Sn sample cables will be soldered to long NbTi "lead" cables in a groove in the Cu bus plates designed for this purpose (instead of the short NbTi cables used as fillers when the sample holder is to be used at NHMFL). These leads will extend past the end of the Cu bus blocks for a distance of about 50 cm, to allow connection to the BNL power supply leads.

Alignment of the sample holder within the background field magnet at BNL is accomplished by using a specially designed "nosepiece" on the sample holder that fits into a mating plate at the top and bottom of the magnet bore tube. Special shims have been designed for use with the present sample holder, to accommodate these parts (supplied by BNL).

References

1.) D. Dietderich, R. Scanlan, R. Walsh, J. Miller *"Critical Current of Superconducting Rutherford Cable in High Magnetic Fields with Transverse Pressure"*, IEEE Trans. Appl. Superconductivity, Vol. 9. No.2 June 1999

2.) P. Bauer, D. Dietderich, *"Critical Current Measurements of Superconducting Cables at the National High Magnetic Field Laboratory* - *Documentation/User Guide Version,1.0"*, Fermilab TD-99-039, Batavia, USA., 1999.

3.) G. Ambrosio, N. Andreev, E. Barzi, P. Bauer, D. Dietderich, K. Ewald, J. Ozelis, G. Sabbi, *"Study of the React and Wind Technique for a* NB_3Sn *Common Coil Dipole"*, IEEE Trans. Appl. Superconductivity, MT-16, FL, USA.,1999

4.) M. Garber, W.B. Sampson, *"Quality Control Testing of Cables for Accelerator Magnets"*, Supercollider 1, Plenum, New York, 1989

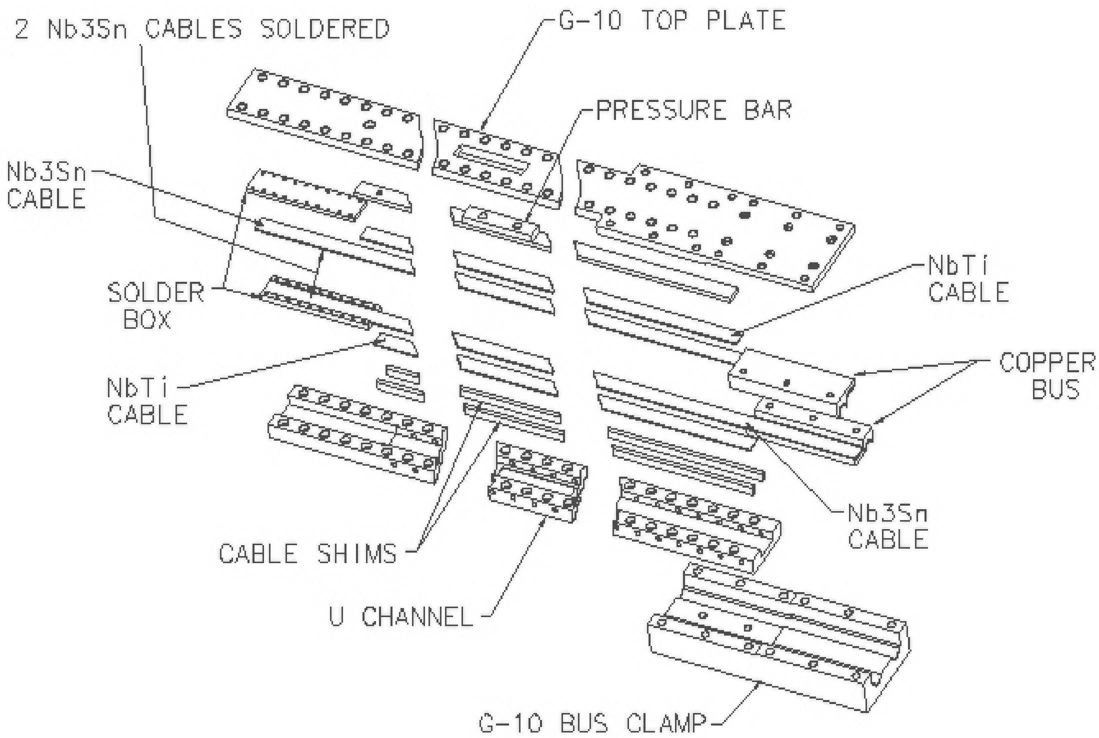

Fig. 1.) Exploded view of sample holder, showing samples, Cu splice box and lead attachments

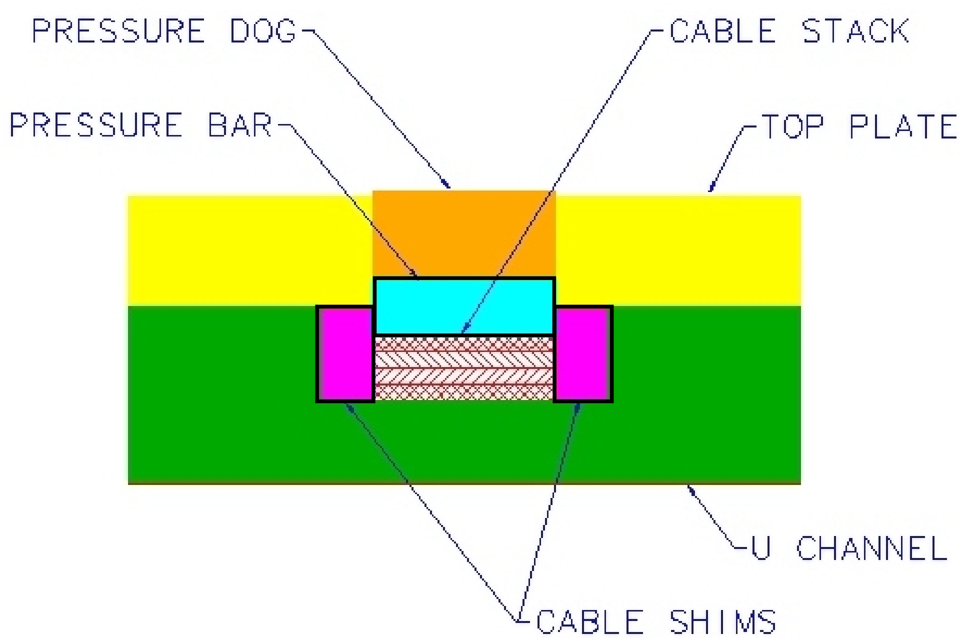

Fig. 2.) Cross section view schematic. Shim adjustment screws, Cu splice box, and assembly screws not shown.

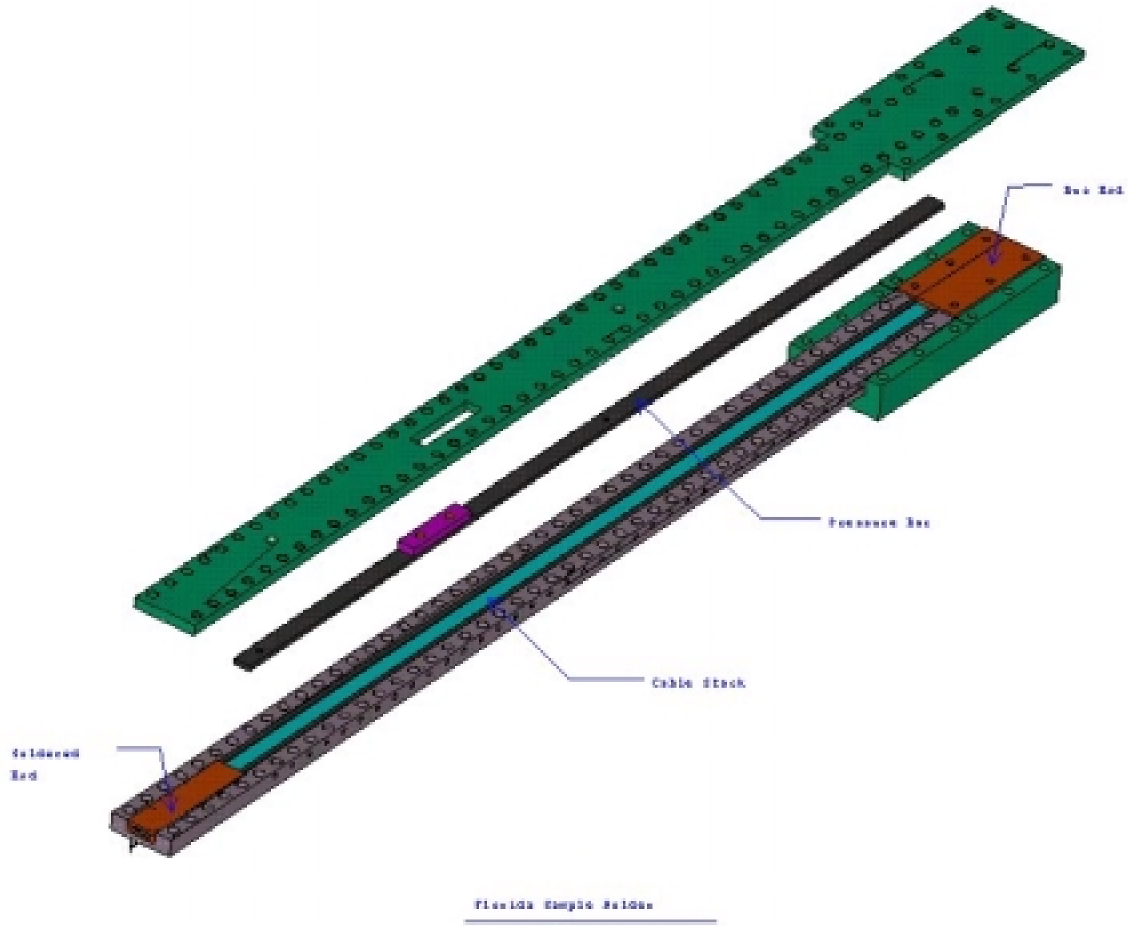

Fig. 3.) Overall 3-D layout of NHMFL version sample holder. The Cu splice box is shown on the bottom left, the Cu bus plates at the top, right. The pressure 'dog' is mounted on the pressure bar, and protrudes through the cutout in the top plate.

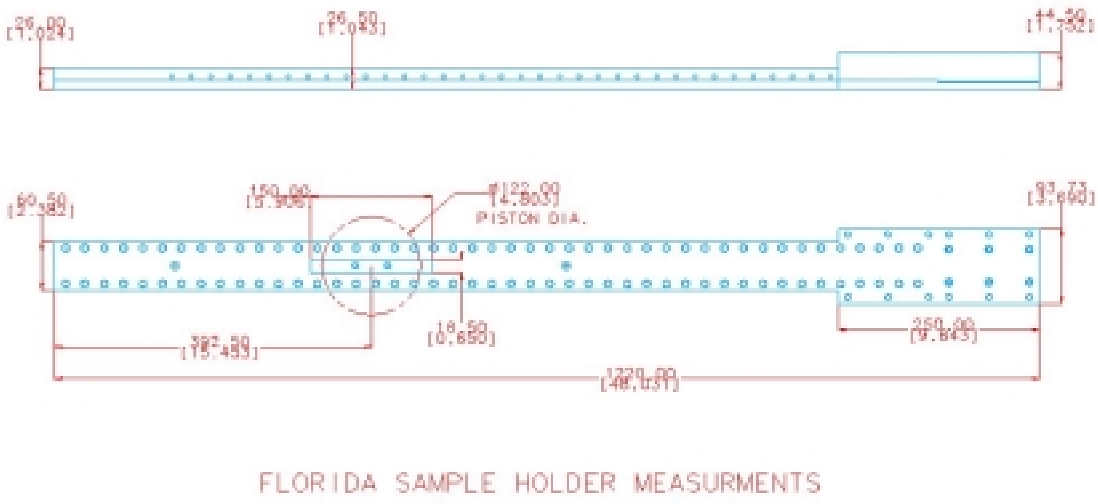

Fig. 4.) Relevant dimensions of sample holder for NHMFL facility.

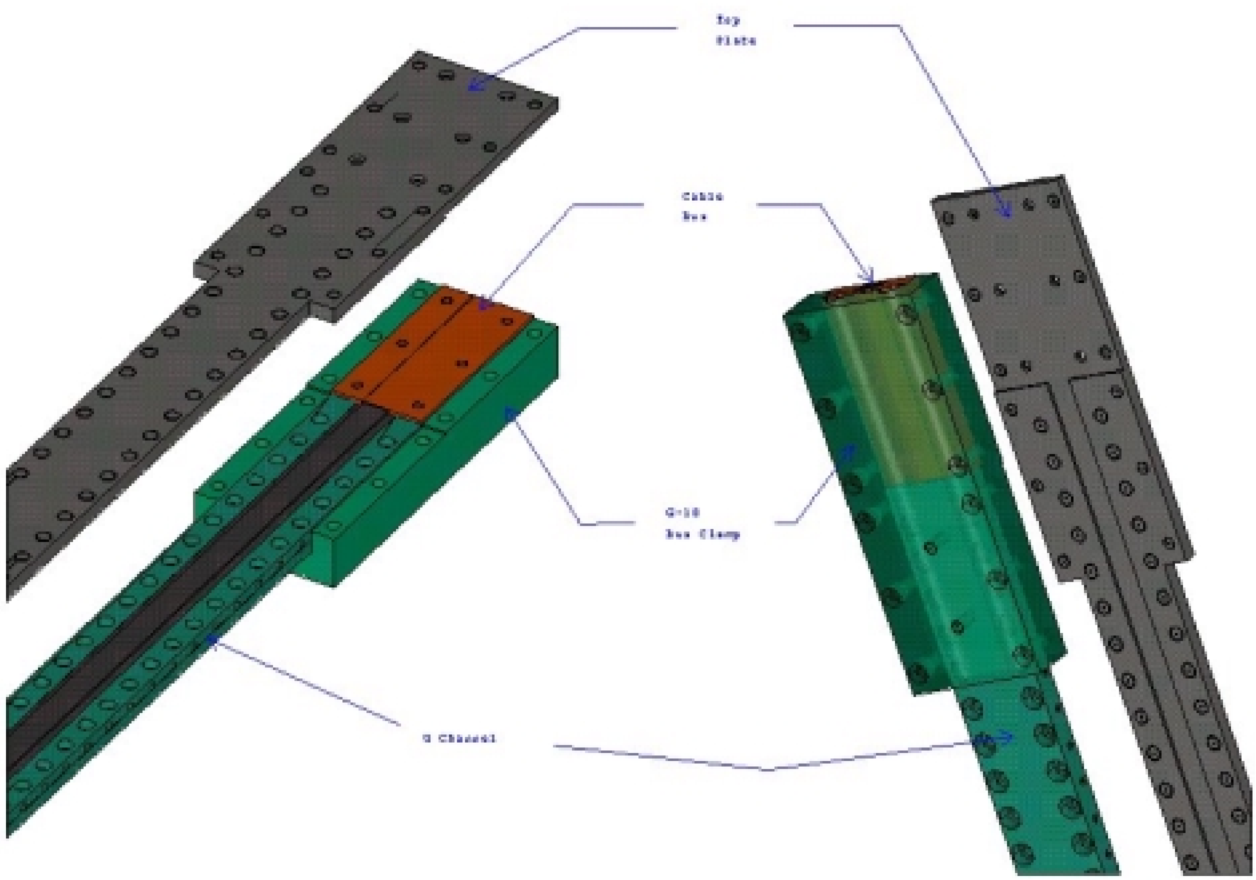

Fig. 5.) Detail of upper splice-bus connection, showing Cu bus splice plate and G-10 bus clamp. A G-10 support rod (not shown) mounts to the top of the sample holder, using the two centerline holes of the G-10 bus clamp, shown on the right.

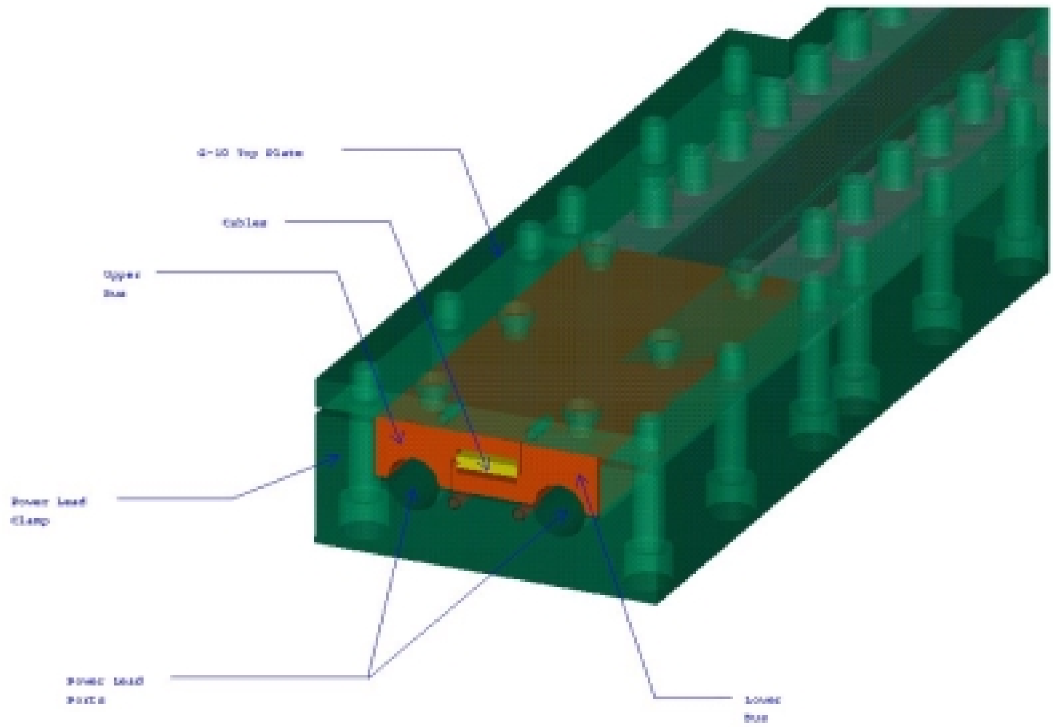

Figure 6.) Lead end view of the NHMFL sample holder, showing the Cu bus plates to which the Nb_3Sn cables are soldered, and NbTi lead "ropes" from the test facility are connected. The lower G-10 bus cover plates extends past the Cu bus plates and onto the U channel, in order to provide mechanical support at the gap between the U channel and Cu bus plates.

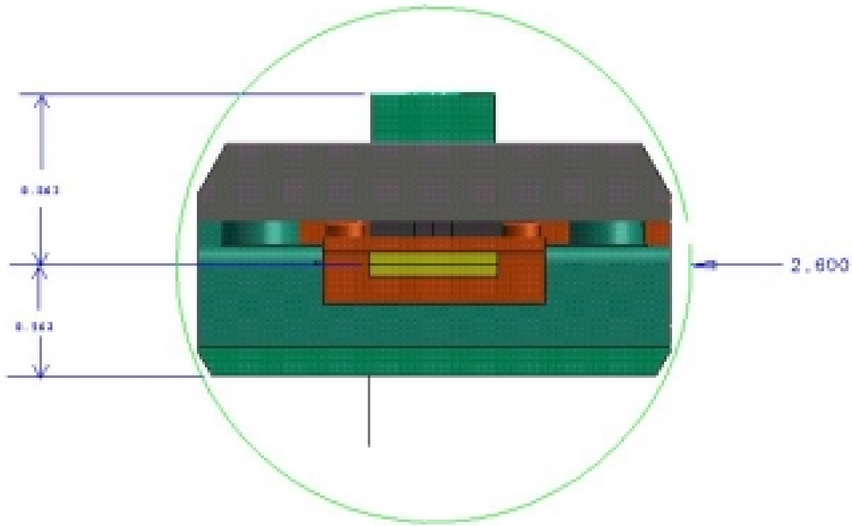

Figure 7.) Cross sectional view of the BNL version of the sample holder, at the bottom (non-lead) end. The cover plate is made of stainless steel.

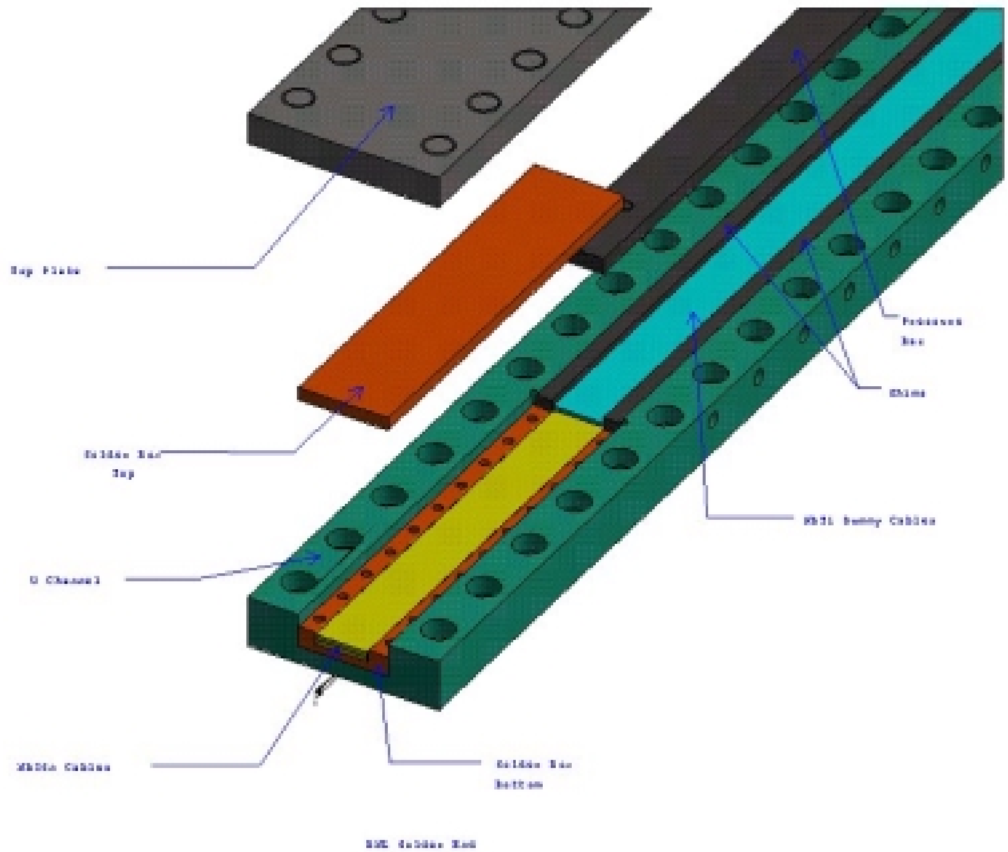

Figure 8.) Bottom end of the BNL sample holder (which is in fact identical to the bottom end of the NHMFL sample holder), showing the Cu box enclosing the splice, dummy Nb_3Sn cables, and lateral shims.

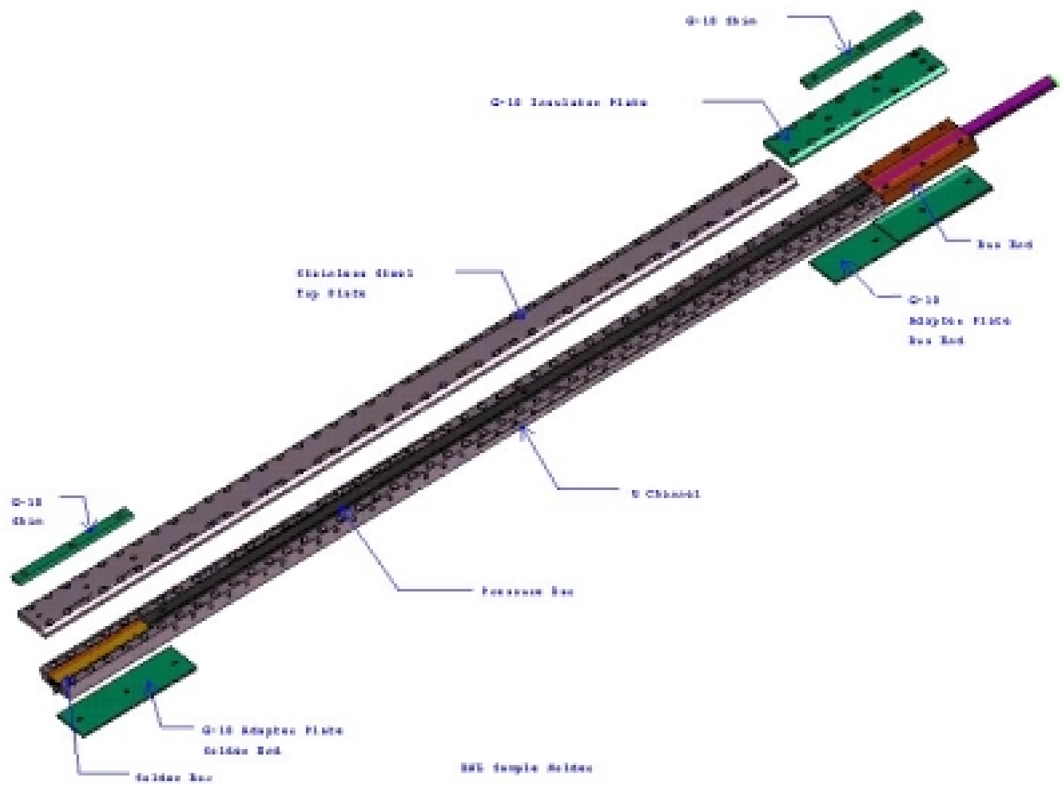

Figure 9.) Exploded view of the BNL sample holder. Note the G-10 cover plates extending across the transition from the U channel to the bus plates, and the extended NbTi leads which are to be soldered to the power leads of the test facility. The G-10 shims and adapter plates are used to accommodate the alignment "nosepieces" used at the BNL facility.

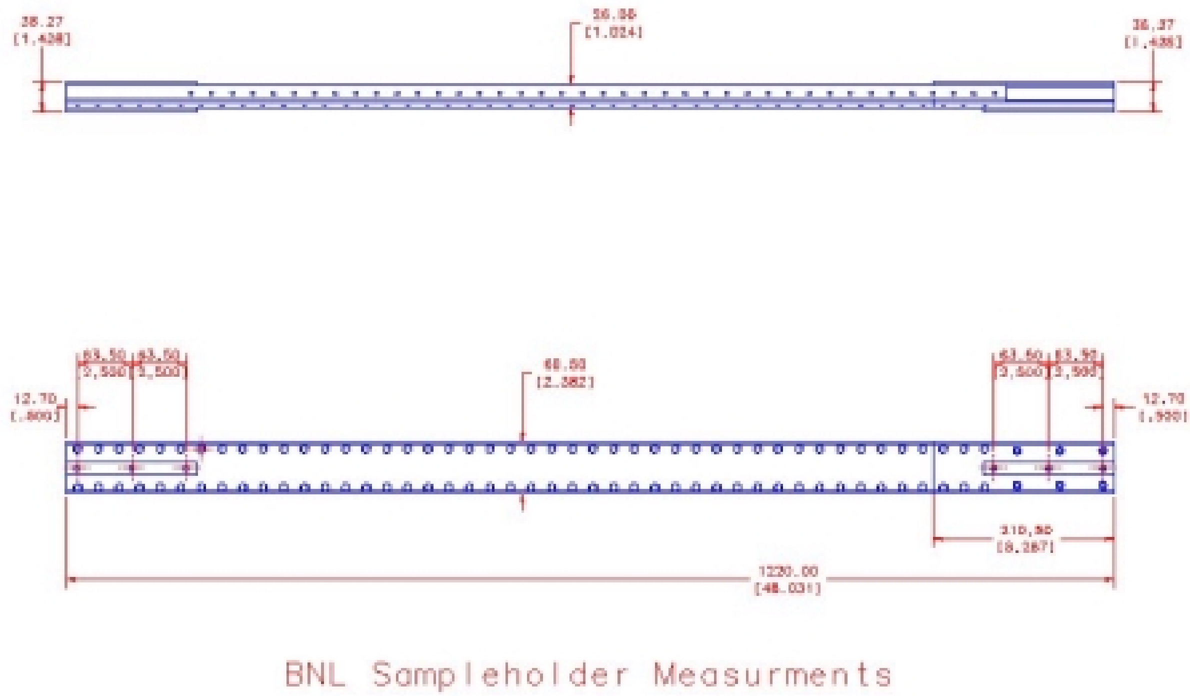

Figure 10.) Dimensional details of the BNL sample holder.