Fermi National Accelerator Laboratory

# Assembly of Multi-Sample Probe

## To Measure Critical Current ($I_c$) of Superconducting Materials.

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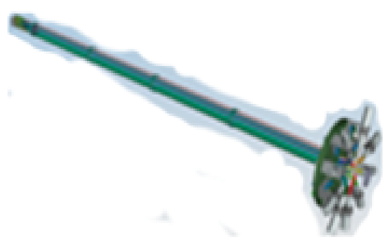


At Fermilab's Technical Division the critical current of superconducting materials have so far been measured using probes which only carry one or two samples at a time. The loss of unwanted amounts of cryogen is inevitable when these probes are used to perform tests. However, in order to preserve precious cryogenic material (i.e. Helium), a multi-sample probe which can accommodate eight superconducting strands at a time was constructed. This also allows experimenters to be more efficient in their testing of multiple samples without having to remove the probe from the Dewar to switch the material being investigated. This design saves time, man power and creates a more convenient method of accumulating data. Superconducting strands such as YBCO, Nb-Ti and BSCCO-2212 resting on Fiberglass Laminate (G-10) stages were tested at 4.2K. Probe design, assembly and commissioning of room temperature and liquid nitrogen tests are detailed throughout this paper. Labview software's graphical interface was used to monitor, store and analyze accumulated data.

# Table of Contents:

**Introduction:**

In order to develop efficient superconducting materials for particle accelerators, the key characteristics of the materials must be identified. Such characteristics include: (1) critical current and (2) critical temperature. Therefore if we improve the method of our test approach then every step which follows is improved. This paper aims to document the steps taken to improve the testing of superconducting materials. The idea to construct a model probe which is capable of holding eight superconducting strands simultaneously results in reduced frequency of extrusion of the probe from its system. In the past, the probes used for testing were limited to one or two strands. Another advantage of building such a system is that comparisons can be made amongst the samples at a more radical pace as opposed to waiting for individual batches of data to be compiled. Topics such as design, probe assembly and heat transfer analysis will be mentioned. To assure safe use of the probe, certain precautionary measures were taken. The step by step process of construction is explained in detail with subsequent results from room temperature and liquid nitrogen tests. **Figure (1)** below shows the top end of the assembled multi-sample probe.

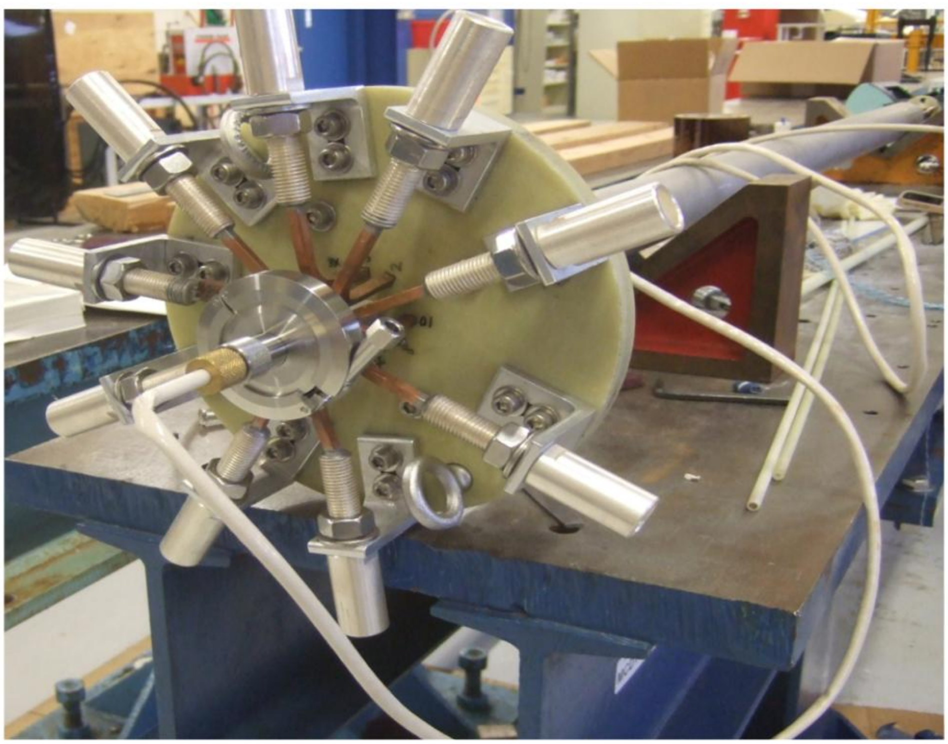


Fig.1: Top end of probe showing copper leads bent into silver-plated/brass socket connectors.

**Probe Design**:

Some essential design specifications of the multi-sample probe are: (1.) it is capable of an operating field of up to14 T, (2.) it has a current rating of up to 600 amperes, (3.) it is capable of operation between 4.2K and room temperature and (4.) it can hold up to 8 samples at a time. **Figures (2)** and **(3)** below show CAD drawings which aided in the construction of the probe.

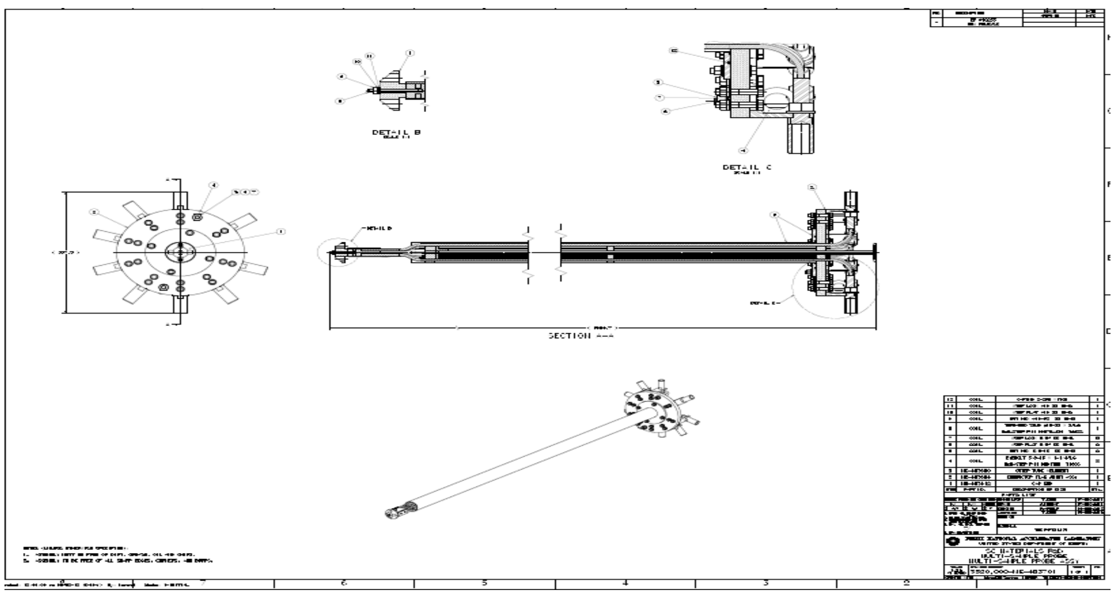



Fig. 2.

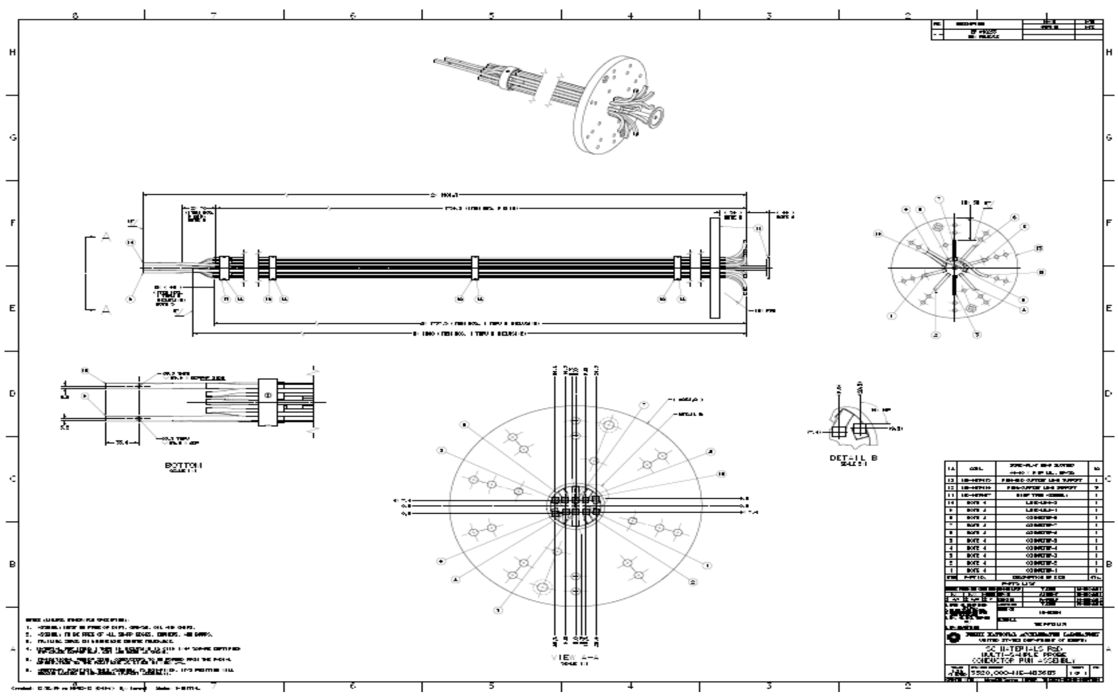



Fig. 3.

Superconducting samples which await testing rest securely on a G-10 plate in helium cooled environment of 4.2 K. From this end, 10 single Copper current leads held in a decagon formation by G-10 rings extend approximately 1.8 meters up to a large G-10 ring. Through this large ring all copper leads emerge and bend into silver-plated-brass sockets which are then attached to a high current Hewlett Packard 6681A DC power supply. This power supply is capable of applying up to 600 amperes of current. To enable individual access of one sample at a time, paired instrumentation wires were numbered and soldered to each sample. **Figure (4)** below shows the instrumentation wire connected to superconducting specimens at the bottom end of the probe.

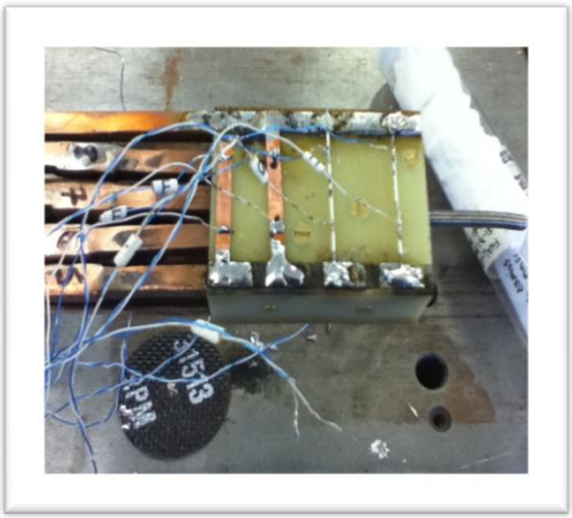
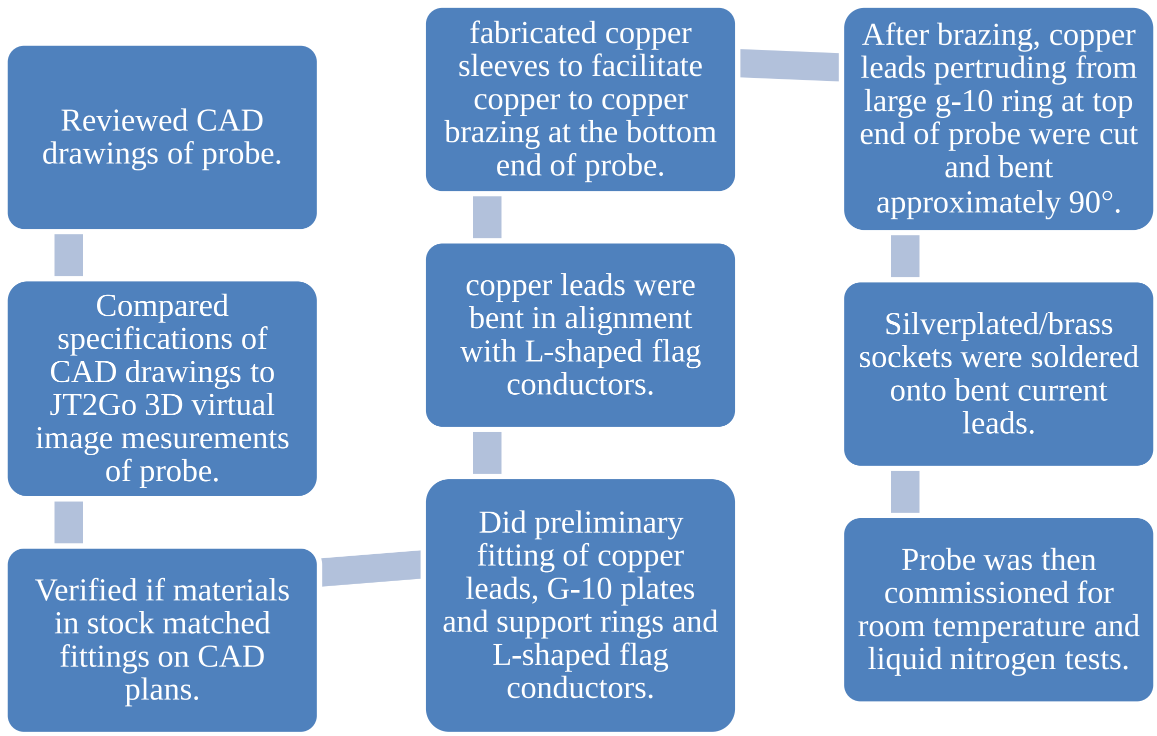


Fig.4: two superconducting YBCO (left) and two Bi2212 (right) soldered onto sample holder. Instrumentation wire is also featured in image.

In order to legitimately obtain the ( $I_C$ ) of the superconductors, high levels of current must be passed through Copper (Cu) current leads which facilitate the transport of the current and traverse the current passed into the Sc strands. What will be further explained in this paper is how the length and controlled heat conduction of these current leads affect the (or is paramount to the) survival and successful running of the multi-sample probe. Certain precautionary measures such as soldering YBCO onto each copper lead at specific regions aided in the avoidance of overheating/joule heating. During construction some major issues were encountered such as efficient bending methods of copper and consideration of high temperature copper brazing that needed to be done. Another issue was assuring that mechanical strength was not being compromised in tasks involving copper to copper brazing and sliver/brass to copper soldering. Some major limitations due to the large unwarranted tolerances of the raw materials/parts initially given by manufacturers existed. Therefore much fabrication and alteration of parts was essential in making this probe functional.

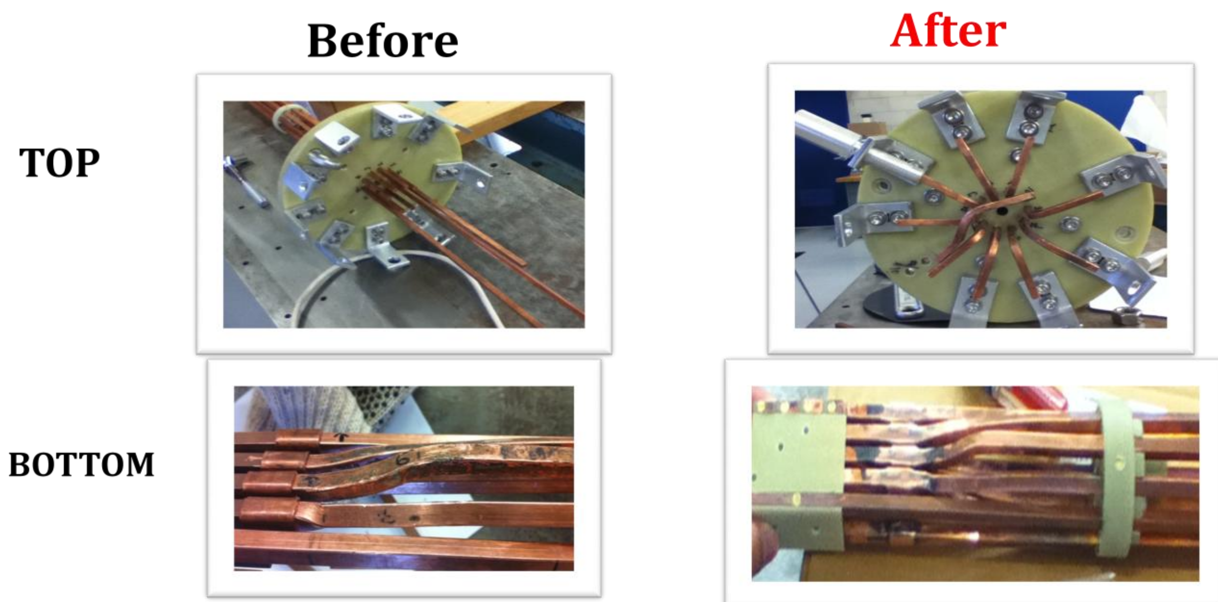
**Probe Assembly Process**:




Flow chart illustrates a summation of the entire assembly process.

After determining that all of the necessary equipment was gathered, attention was focused on the assembly aspect of the probe. L-shaped copper rods called flag conductors which fit into a G-10 holder sample appeared to be an inexact match for the grooves in the holder. An electronic sander was used to etch proper grooves. This etching served an important role in the brazing of flag conductors to copper current leads. The copper leads needed to be bent from their original harnessed position within the G-10 spider-support in order to mirror the position of the flag conductors. Therefore any misalignment during brazing is minimized. To assure accurate bending angles, the probe was partially assembled so that the flag conductors and copper rods were in almost direct contact. From there the degree of bending was measured using measuring tape, rulers and approximations.

Tools actually meant for bending hollow copper tubes were used in the bending of these copper rods. Fortunately, during the bending process the applied force was minimal due to the mechanical advantage of the tools. After forming the current leads into the desired alignment; copper sleeves fabricated by Fermilab's Technical division were designed to facilitate the copper to copper brazing of leads to flag-connectors. Upon brazing, the sleeves assured that hardly any displacement occurred between the two surfaces being merged. The finished product was examined and placed into its G-10 structure to assess whether any adjustments were necessary. After brazing, a slight bulge was left along the perimeter. This area was made smooth by polishing it with a pressurized sander. **Figure (5)** below displays the multi-sample probe, before and after bending and brazing.




(Fig. 5): before and after bending and brazing.

Smoothing these edges presented less trouble for the soldering of YBCO onto the surface of the leads which protects against Joule Heating. Focus was then shifted to the opposite end of the probe. At this end all cooper rods except for the two longest [Line Loads] were cut to approximately the same length, then bent roughly $90^{o}$ .This facilitated the current leads connection to the silver-plated brass socket connectors. In order to make a strong connection, circular holes about an inch deep were drilled into the brass socket. A fitting rehearsal had to be executed to ensure that when the current lead and socket were hard soldered together that the alignment was perfect. In preparation for soldering, the ends of the copper rods were cleaned with ethanol and coarse foam pad. After many minor adjustments the current leads were ready to be soldered together with the socket connectors. The exterior stainless steel protective case was bolted on and the probe was then ready for room temperature tests. **Figures (6)** and **(7)** show the stainless steel case and tubing which protects the probe and instrumentation wire.

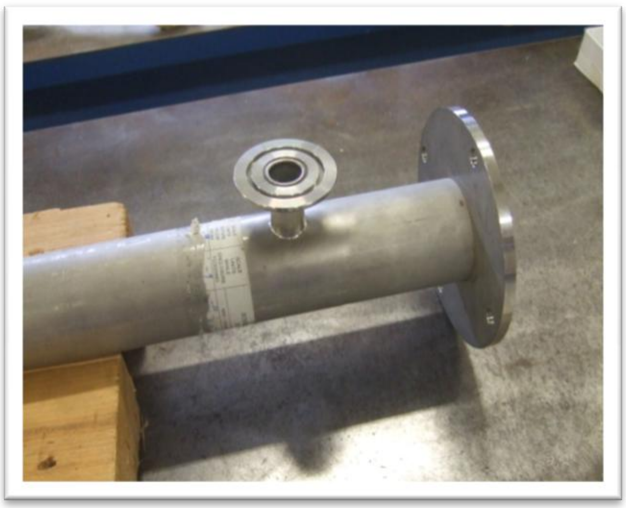


Fig. 6: multi-sample probe stainless steel case.

Fig. 7: stainless steel tubing which protects instrumentation wire.

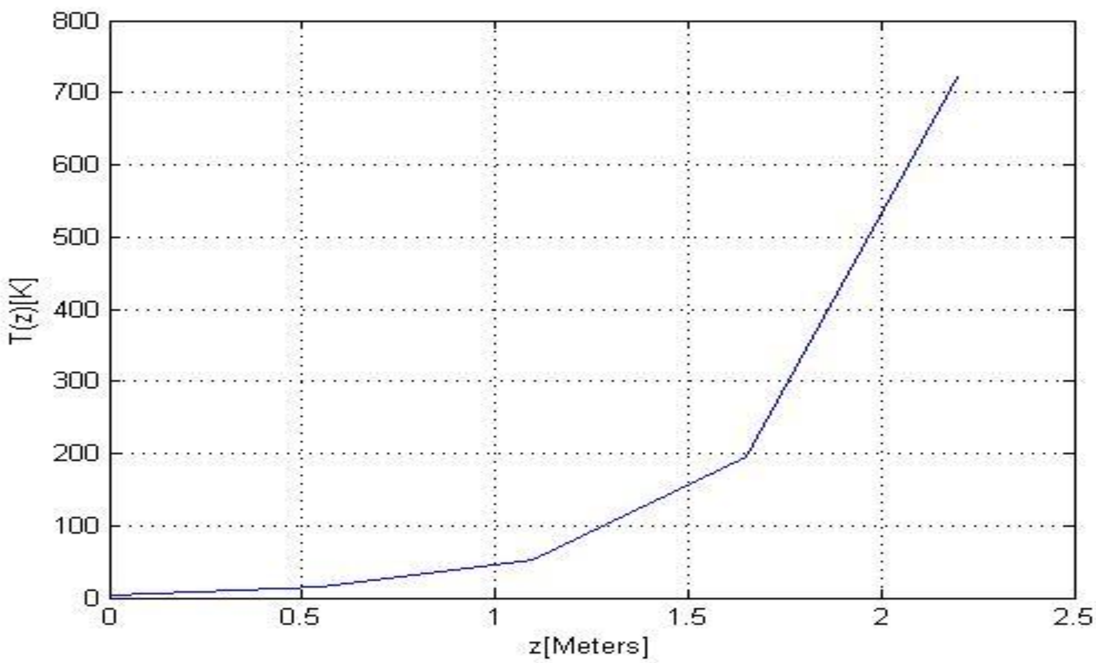
**Heat Transfer Analysis:**

To prevent Joule heating at any localized point on the copper current leads, YBCO superconductor was soldered onto the surface. Soldering of the YBCO improves conductivity. The partial differential equation below was used in the calculation of a temperature profile as well as the length of YBCO required.

$$\frac{d}{dx}\left[\kappa(T)\frac{dT}{dx}\right]-\frac{\dot{m}c_p(T)}{A}\frac{dT}{dx}+\frac{\rho(T)I^2}{A^2}=0$$

where, A is the conductor cross sectional area [$m^2$]; $\dot{m}$ is the helium mass flow rate [kg/s]; $c_p$ (T) is the gas specific heat capacity [J/kg.K]; ρ (T) is the electrical resistivity [Ω.m]; I is the current [A] and k (T) is the thermal conductivity of conductor [W/Mk].

**Graph (1)** below is a plot of the temperature profile analysis of 10 copper leads in a standing heat scenario i.e. [current =0]




Graph 1: displaying standing heat temperature profile.

**Data Acquisition**:

Labview software was the program used to monitor and measure the critical current. Labview supplies a graphic interface which allows the user to control instruments, store, interpret and analyze data. **Figure (8)** below shows the entire setup used in testing.

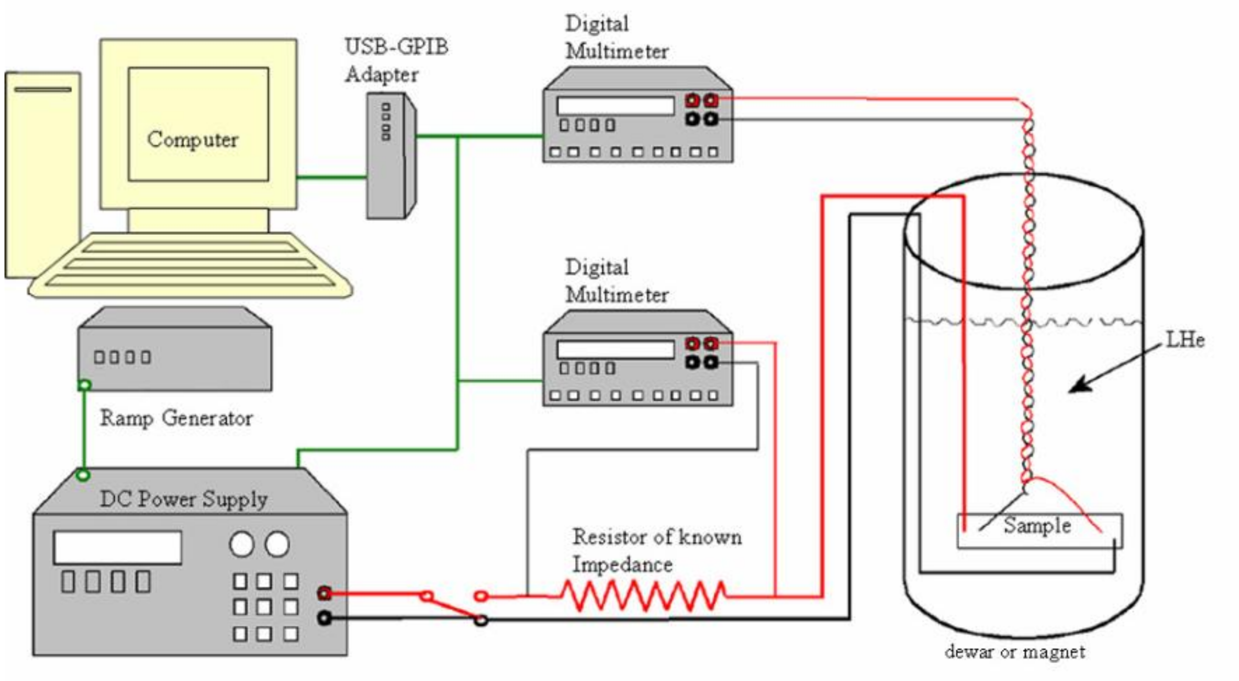



Fig. 8.

The diagram above shows a Hewlett Packard 6681A DC power supply capable of supplying up to 600 amperes. Also two Keithley 2001 digital multi-meters, one which tracks the current emanating from power supply and the other which measures the voltage supplied to the samples from the voltage taps. The information from each multimeter is sent to Labview which is running on a desktop computer.

**Results:**

**Graph (2)** below shows the results from a room temperature test.

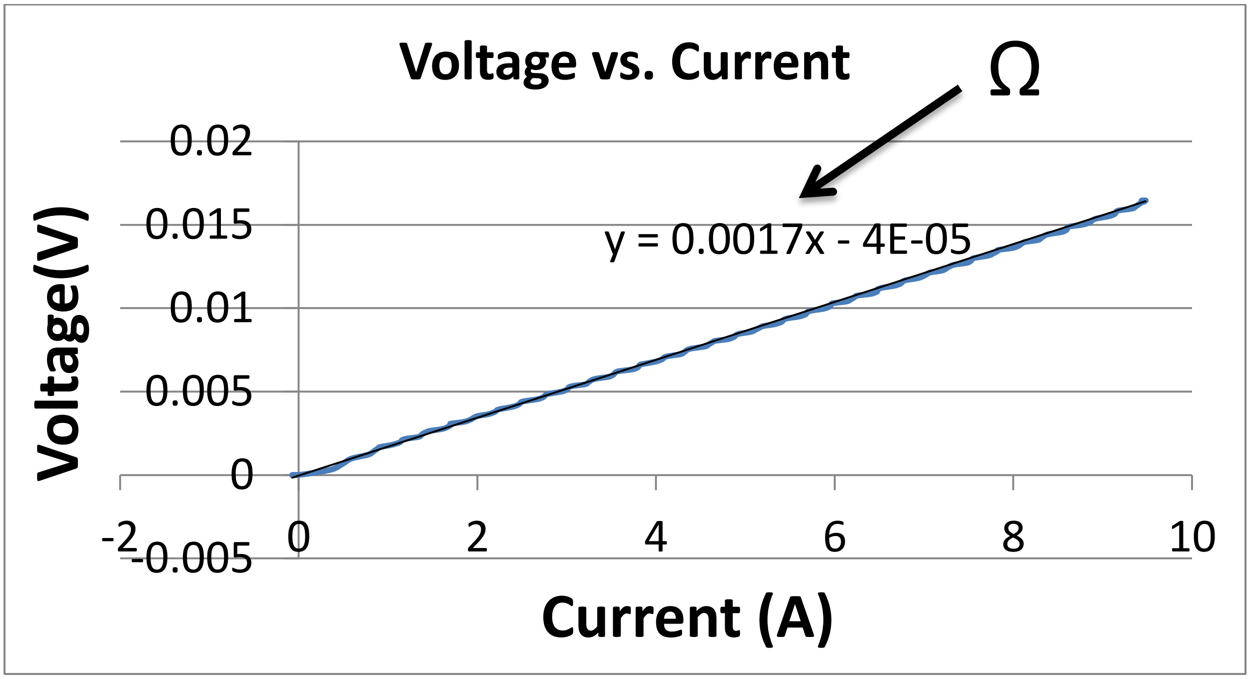
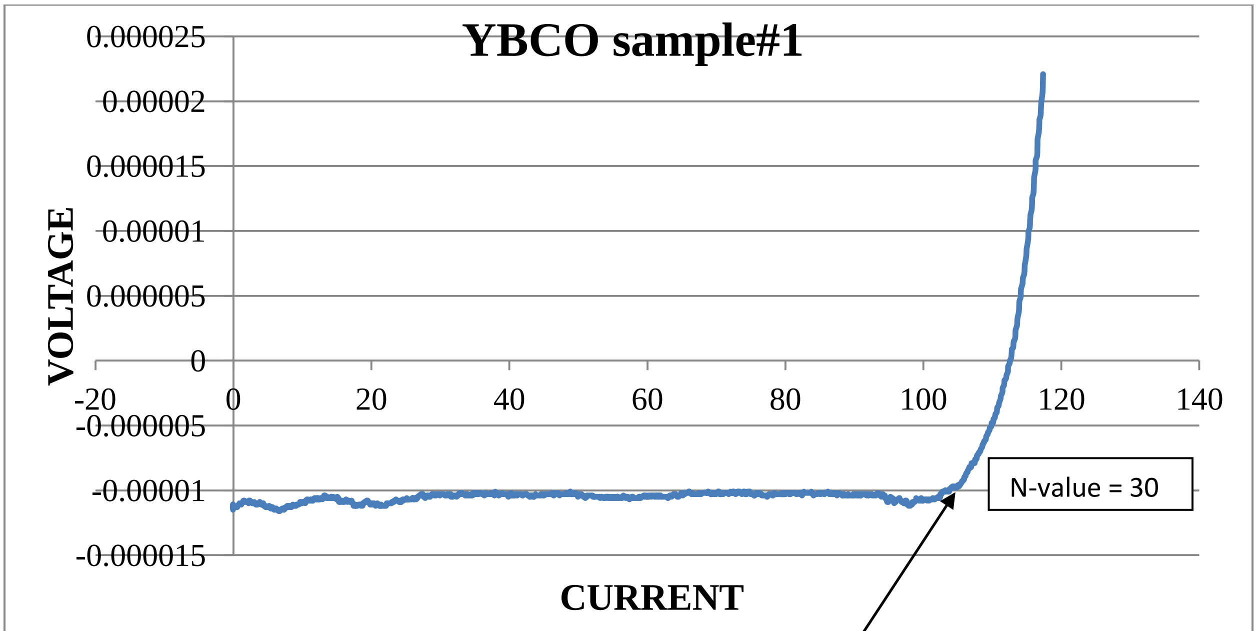



**Table (1)** shows results from liquid nitrogen tests:

| Sample# | Superconducting Material | $I_C$ | N-Value |
|---|---|---|---|
| 1 | YBCO | 107 | 30 |
| 2 | YBCO | 103.3 | 28 |
| 3 | YBCO | 109.7 | 30 |
| 4 | YBCO | 107 | 29 |
| 5 | YBCO | 57* | 17 |
| 6 | YBCO | 104 | 25 |
| 7 | Bi2212 | 0.14 | 3 |
| 8 | Bi2212 | 0.7 | 3 |

**Results:**

Room temperature tests were a success. In graph (2), voltage vs. current was plotted and then the gradient [resistance] was then calculated. In table (1) the only irregularity was sample# 5 which deviated from the normal recorded ($I_C$) of YBCO. The cause was thought to be improper soldering of the YBCO which then changed the results received. **Graph (3)** below is an illustration of the results from sample#1 (YBCO) liquid nitrogen test.




At this point where the graph begins to spike marks the critical current of the YBCO superconducting strand. N.B (the $I_c$ for this sample was 107 amperes.)

The YBCO strands used in these experiments were manufactured Superpower and the Bi-2212 round wire of 0. 8 mm diameter was manufactured by Oxford Superconducting Technology, New Jersey.

**Conclusion:**

The assembly of a multi-sample probe capable of holding 8 superconducting strands was a success. Commissioning of the probe for room temperature and liquid nitrogen tests was also accomplished.

**Future work:**

The next step is the testing of superconducting materials at 4.2K (helium) within a high magnetic field.

**Acknowledgements:**

This paper would not have been possible without the help of my supervisor Dr. Tengming Shen and co-worker Liyang Ye who guided me throughout the entire assembly and test process of probe. Furthermore I would like to thank the Fermilab SIST committee Ms. Dianne Engram, Ms. Linda Diepholz and Dr. Elliott Mccrory for selecting me as an intern this summer. Special thanks also go to David Peterson and Dr. Davenport for helping me iron out my presentation and paper.

# Appendix

**Brazing**:

Considering varying melting points of the various materials assembled on the probe and lack of much space to maneuver, Brazing appeared to lend itself to the task at hand. Suitable for tight spaces where full access to surfaces for welding is unavailable, Brazing also is the procedure of choice when dealing with high-magnetic-field apparatus.

**Copper**:

Copper is a great conductor of electricity. This allows a high enough electric current to traverse the copper rod without totally destroying the sample material being studied. Copper is also quite ductile and is the conductor of choice for most electrical jobs.

**G-10:**

G-10 (Fiberglass Laminate) is an excellent electrical insulator and is relatively easy to carve, grind or etch into more desired shapes and sizes. G-10 is used widely in electrical jobs due to its imperviousness to moisture. When immersed completely in a liquid medium G-10 tends to remain unaffected.

**Hard Solder**:

Soldering which is performed using alloys above a melting range of (840$^{o}$ F) is considered to be Hard Soldering, silver soldering or brazing. [http://en.wikipedia.org/wiki/Solder]

**Joule Heating/Ohmic Heating**:

Many experiments dealing with high volumes of current are susceptible to the releasing of heat as a byproduct. This occurrence is known as Joule Heating and needs to be avoided at all costs or one runs the risk of damaged machinery and explosions.

**Sil-Fos (15)**:

Sil-Fos (15) is a brazing metal that has a composition of (5%**)** phosphorus, (80%**)** copper and (15%**)** silver. The active phosphorous component alloy makes it the best bonding agent for copper to copper brazing. If exposed to extreme frigid conditions this materials' ductile characteristics serves as a valuable attribute; it is able to endure strains and stresses applied as a result of intense cooling.

**Silver-plated Brass socket connector**:

Silver can be found as a coating for instrumentation which requires high doses of current. Brass is best for preventing sparks which is essential when dealing with highly corrosive elements. These sockets serve as a switch where the power supply is connected via high voltage wires.

**Soft Solder**:

The common melting range of the soldering process is between (190 to 840$^{o}$ F). This is considered to be soft soldering.

**JT2Go:**

JT2Go software is a viewing solution which allows 3D measurement as well as 3D sectioning. **Figure (9)** below displays a virtual image of the multi-sample probe generated using JT2Go software.

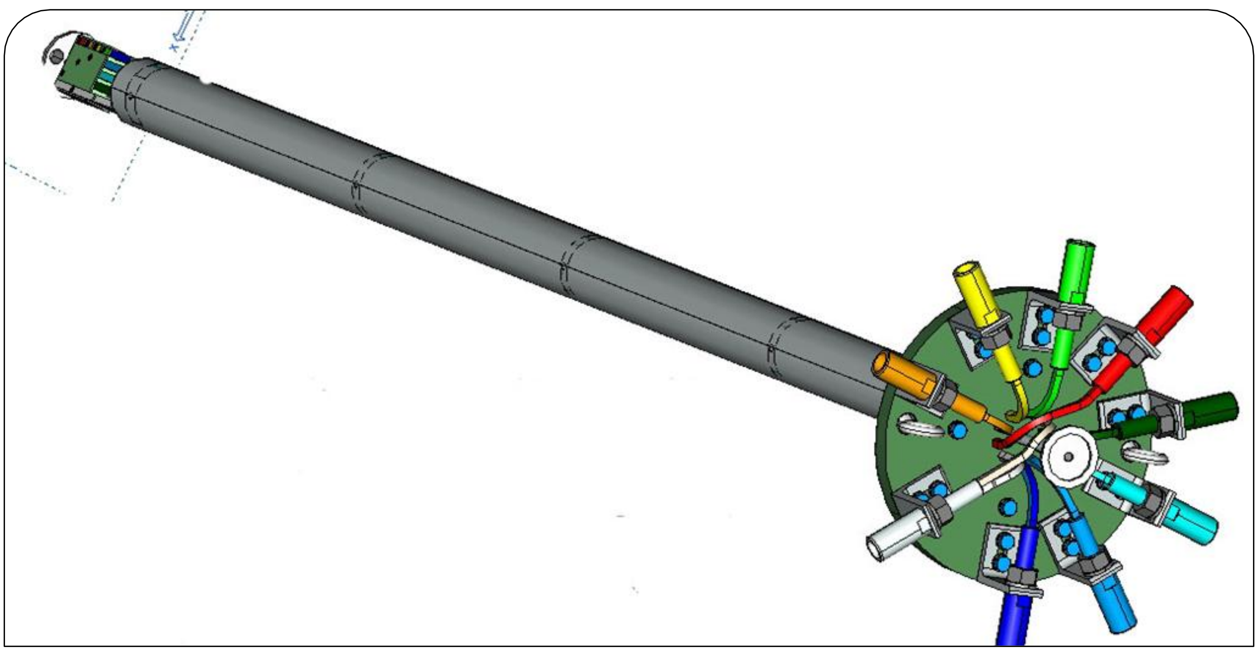


Fig. 9.

**References:**

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