Applied Superconductivity Center: HTS Coils Project

Team 501

Team Introductions

Antonio Goodman
Simulations Engineer

Fernando Quiroz
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Fernando Quiroz

Sponsor and Advisor

Engineering Sponsor
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ASC Staff

Academic Advisor
Lance Cooley, Ph.D.
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Fernando Quiroz

Objective

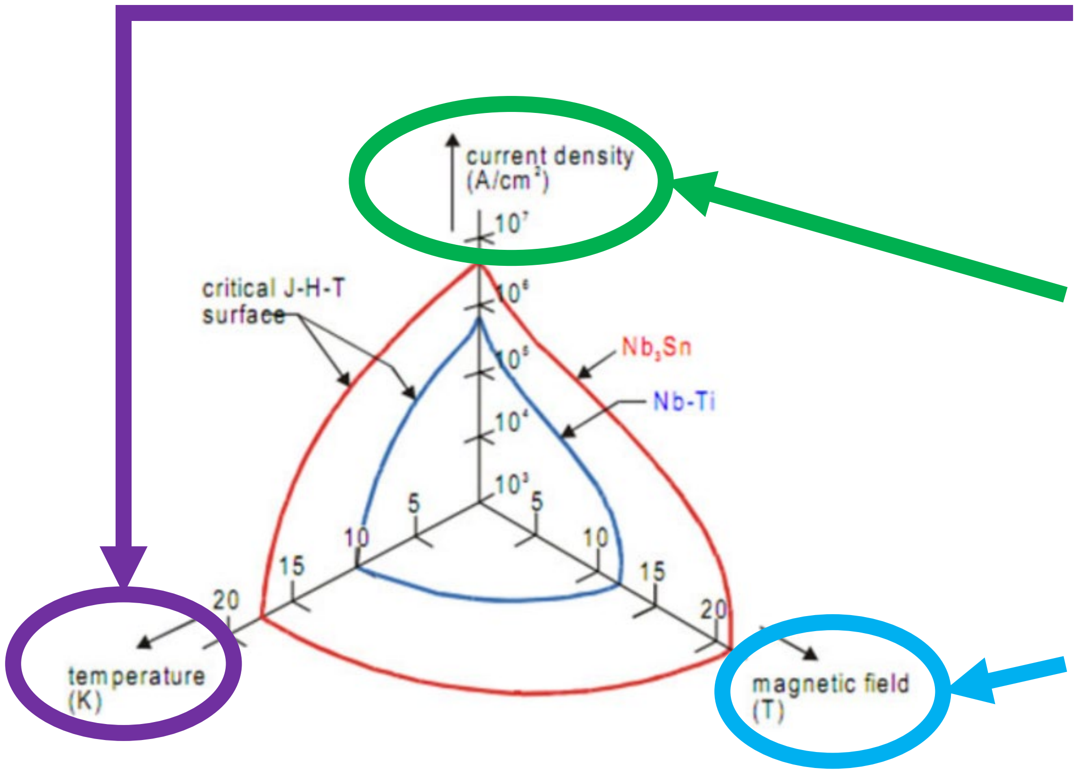
The objective of this project is to design and fabricate a current lead for the Applied Superconductivity Center(ASC) that delivers 1000A of electricity with a heat dissipation of less than 4 watts.

Fernando Quiroz

Project Background

Christopher Reis

Background: Superconductivity



Critical Temperature: Dutch physicist H. Kamerlingh Onnes discovered that for some materials, a certain temperature exists, called the critical temperature (T_c), below which electrical resistivity is zero.

Current Density: The amount of current flow per unit of area is another critical value, called critical current (J_c), superconductivity does not exist at any temperature.

Magnetic Field: In the presence of magnetic field (T), T_c is lower than it is where there is no field. As the magnetic field increases, T_c decreases. If the magnetic field is greater than some critical field (B_c), superconductivity does not exist at any temperature.

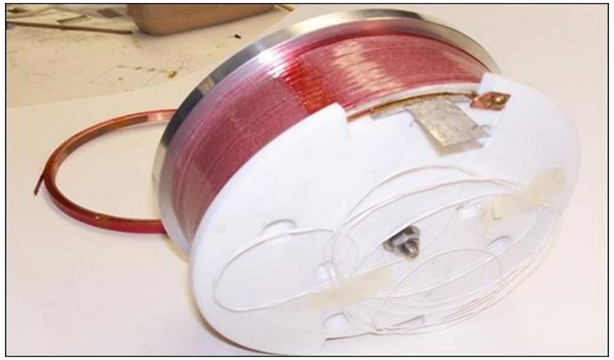
Christopher Reis

HTS Test Coils and Insert Magnets

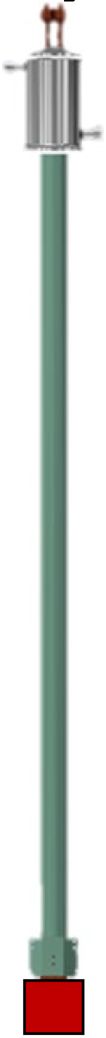
- Applications for this include experiments in magneto-optics, Mossbauer Effect, nuclear magnetic resonance measurements, solid state physics and in high resolution lenses for electron microscopy

- Researchers at the ASC test the strength of high-temperature superconductors or ‘HTS’ coils.

HTS coil

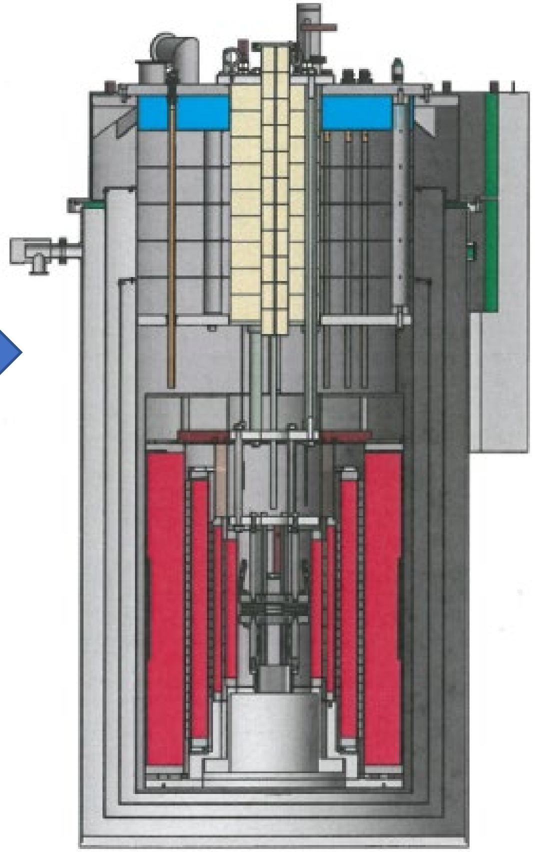


Lead Assembly (our project)



Probe

Superconducting Magnet



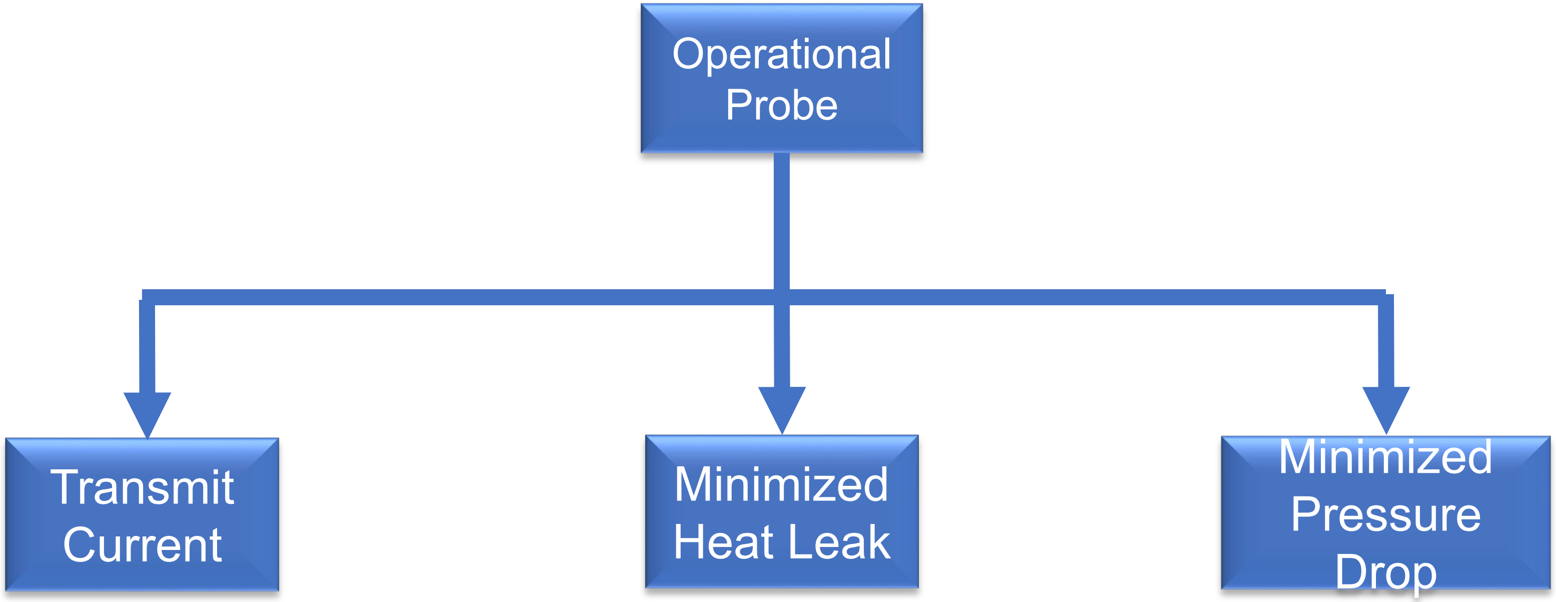
Christopher Reis

Customer Needs

Question?	Customer Statement	Interpreted Need
How can we help you?	I want a new current lead that delivers DC current to coils for electromagnet prototype testing	Design and assemble a current lead to deliver DC power to an electromagnet
Where is the power coming from?	It is running from a power source on the outside to the coil in a cryostat	Probe withstands room temperature-supercooled thermal gradient
What engineering challenges does this present?	The current lead needs to be able to conduct 700 amps without releasing too much heat	Current lead has to deliver electricity with low thermal conductivity
Are there any other key goals desired for the design?	I want the current lead to be versatile	Current lead is capable of being used with multiple insert solenoids

Fernando Quiroz

Functional Decomposition



Fernando Quiroz

Targets

Metric	Target	Units
Current Capacity	>700	Amperes
Thermal Dissipation	<4	Watts
Pressure Loss	<3,000	Pa
Length	1.3 < L< 1.5	Meters
Current Lead Shaft Diameter	50.8	Millimeters
Cross Sectional Area	2.857	Centimeter^2
Helium Consumption	5	Liters/Hour
Voltage Drop per Lead	80	MilliVolts

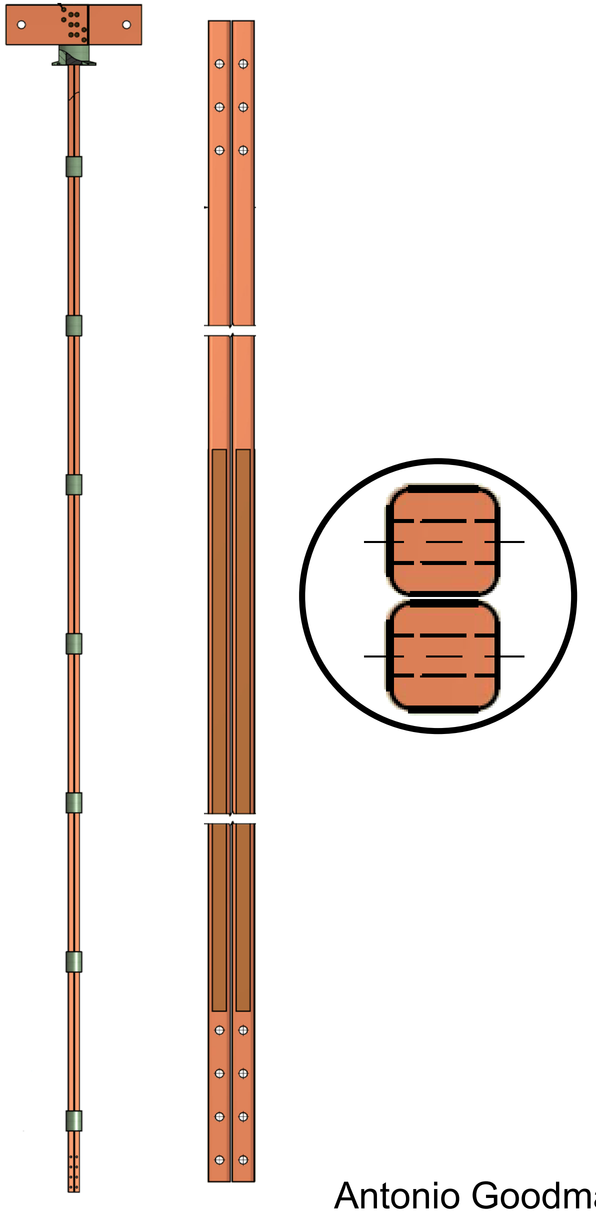
Fernando Quiroz

Concept Generation and Selection

Antonio Goodman

Concept Generation

- Concept generation has been an important part of the project
- Brainstorming sessions were held to generate many design ideas
- After brainstorming was finished, ideas were classified into different categories with respect to different physical characteristics
- These characteristics were primarily compared to the standard lead used today, depicted on the right
- The heat transfer efficiency of these classic leads was found to be around 30%



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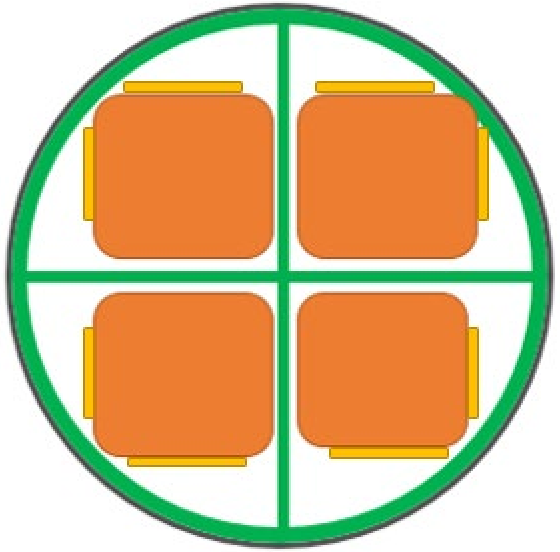
Generated Concepts Cont.

Quartered Lead Design

- This design incorporates a larger amounts of copper, taking advantage of more tube area and is lined with HTS materials almost the entire length of the current lead.
- This translated into higher current carrying capability
- However, calculations showed that this design does not have enough surface cooling area.



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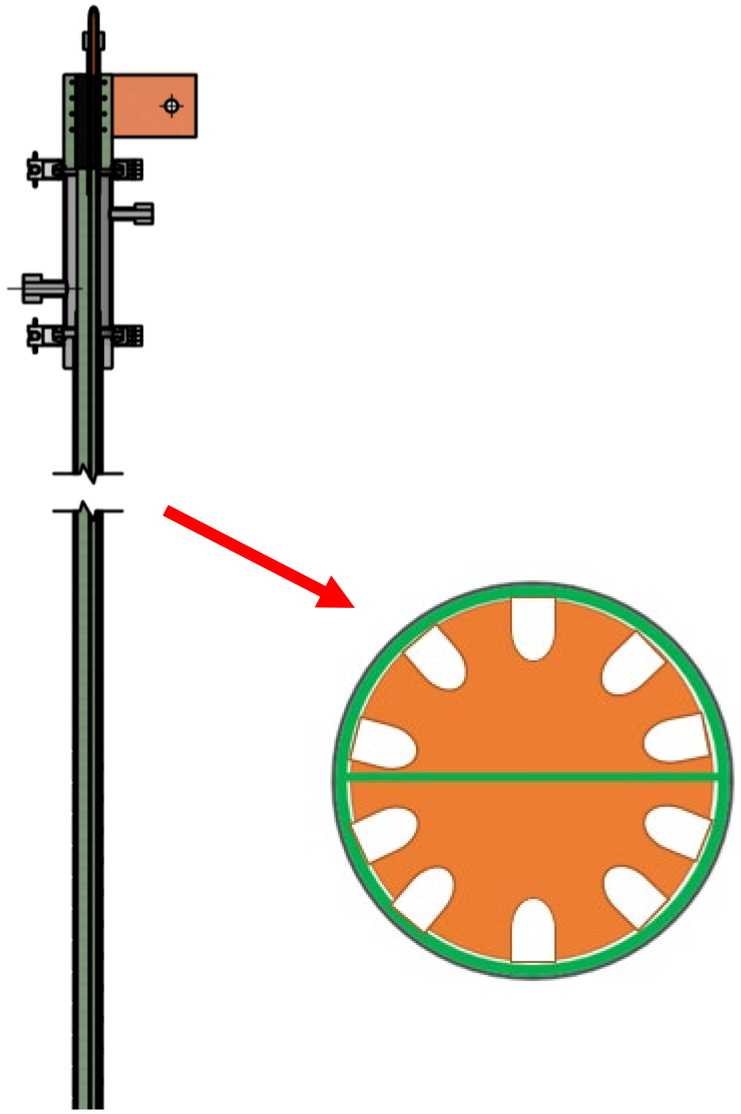
Generated Concepts Cont.

Maximized Lead Concept

- The ideas from the previous concept was then stretched to maximize cross-sectional area
- On top of this, cooling grooves were added to the design to enhance the heat transfer efficiency



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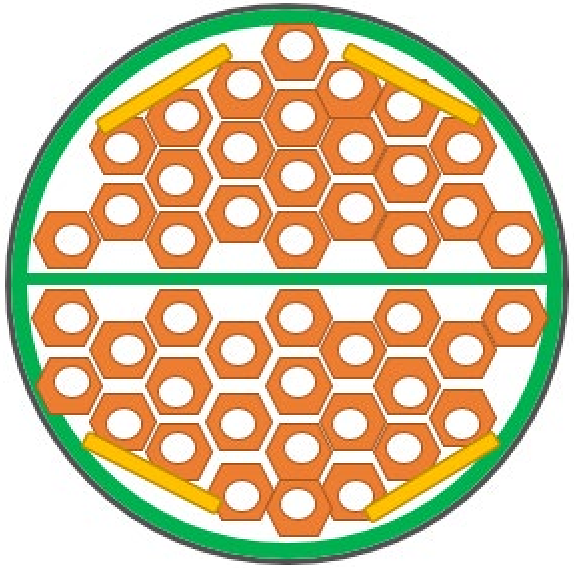
Selected Concept

Hexagonal Tube Design

- This design was chosen because after running the calculations with the mathematics explained in a previous slide the stacked hexagonal shape was found to be theoretically the most efficient design with the highest current carrying capacity.
- The hexagonal shape of the tubes is ideal for increased cooled surface area and better packing of tubes.
- With the use of 52 tubes total the current lead should be capable of carrying 1000amps at an efficiency of 89.8%.
- The heat loss with this design should be less than 3 Watts which is below the customer requirement



Antonio Goodman

Mathematics Used to Establish Design Criteria

Minimum Heat Leak Eqn.

$$1.04 \times 10^{-3} \times 2 \times 1000 = 2.01W$$

Helium Consumption with Min Heat Leak

$$2.49 \frac{Liters}{hour}$$

Heat Leak at Zero Current

$$\frac{W'}{I_o} = 0.77W$$

Helium Consumption at Zero Current

$$1.06 \frac{Liters}{hour}$$

Shape Factor

$$\frac{I_0 X_0}{A} = 1195A$$

Area Formula

$$A = \frac{(1000A)(1m)}{1195A} = 4.78 \times 10^{-4} m^2$$

Hydraulic Diameter

$$D = \frac{4A}{P} = 4.19mm$$

Reynolds Number

$$\mathrm{Re} = \frac{\dot{m}D}{\eta A} = 902.2$$

Efficiency Formula

$$f = \left\{1 + \frac{2w_0 u}{PhX_2}\right\}^{-1} \approx 89.8\%$$

Head Loss

$$h_L = \frac{\Delta P}{\rho g} \cong 25mm$$

Christopher Reis

Deliberation and Final Selection

- Complex math and heat transfer physics, including utilizing the shape factor ($\frac{I_0 L}{A}$) and the heat transfer equation $\left\{1 + \frac{2w_0 u}{PhX_2}\right\}^{-1}$, were used to find the efficiency of the leads.
- When the numbers were run for the Standard and Quartered designs and the efficiency could not be brought above 34.40%
- The Maximized design, while theoretically having an efficiency of 74.17%, was described as being near impossible to machine with the available equipment
- To overcome both theoretical and real-world design limits the team came up with a new completely original design.

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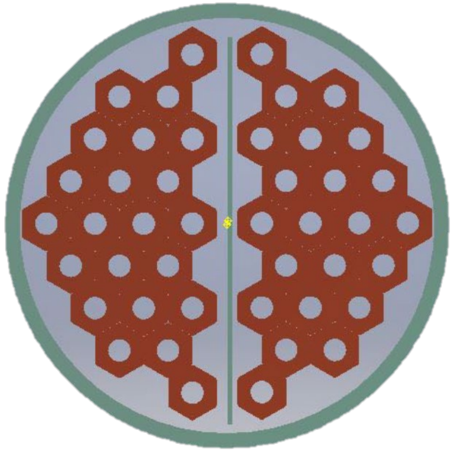
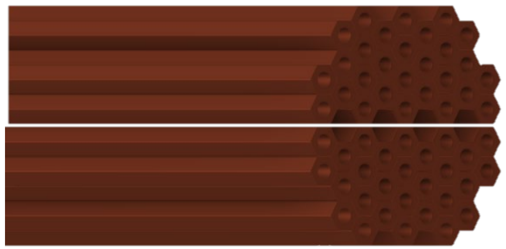
Embodiment

Fernando Quiroz

CAD Drawings

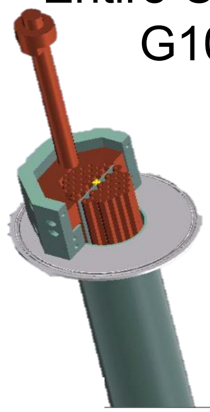


Cross Sectional View



Lateral View of Hexagonal Tubes

Entire Current lead with G10 insulation



Overview of Nipple

Shown here is the different views of the whole assembly of the entire current lead.

- The G10 sleeve will run the entire length
- The hook at the top allows for expulsion of helium gas
- Hexagonal Tubes stacked together
- Nipple serves for helium passage and connections for instrumentation

Full CAD designs were given to James Gillman for fabrication

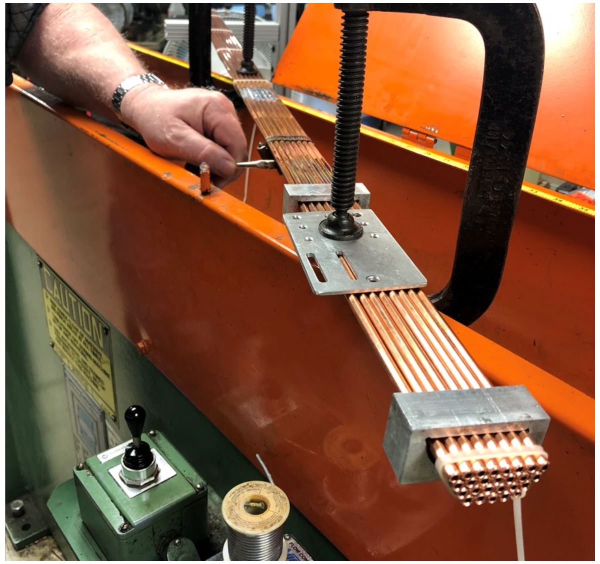
Fernando Quiroz

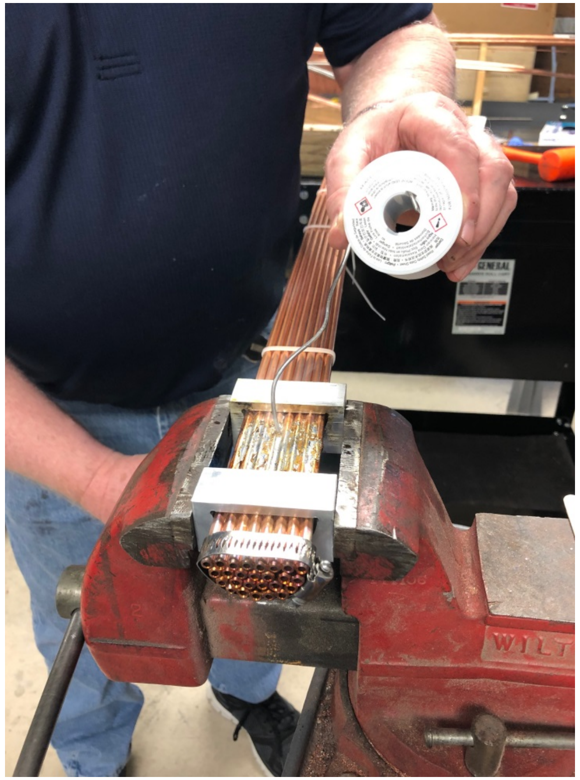
Manufacturing

Benjamin Walker

Fabrication-Soldering Process

- The copper tubes were hexed, cut, stacked, and soldered to create the two individual electrodes. The soldering process was important to ensure that the individual tubes would achieve good electrical conductivity during operation.





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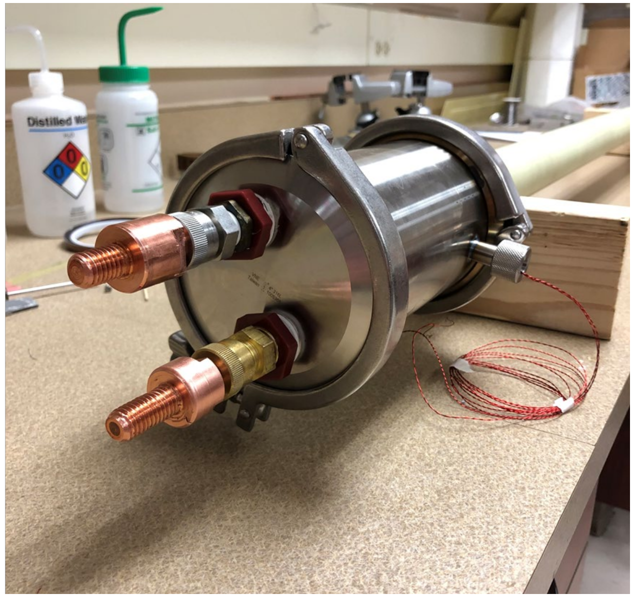
Fabrication-Machining and Different Parts

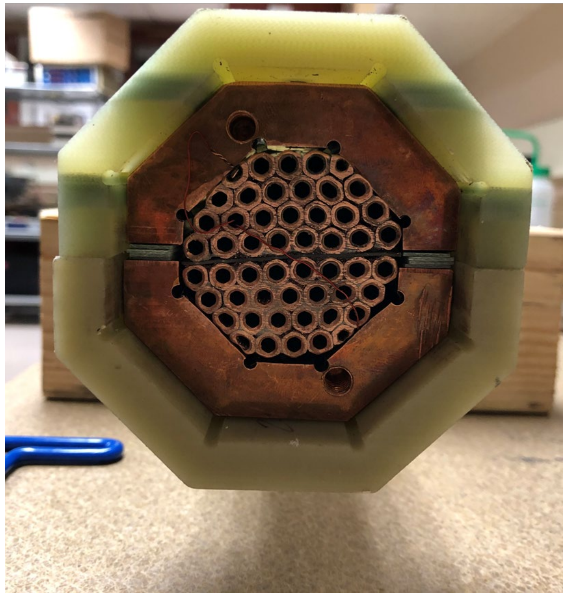
- The probe involved many different parts that had to be constructed at the ASC. The use of a Tormach PCNC1100 was used for more complicated parts.
- The nipple was handmade on site to save the project money.
- The nipple was tested for leaks to ensure helium would not escape.
- The G-10 chassis was Stycast together achieve required length.

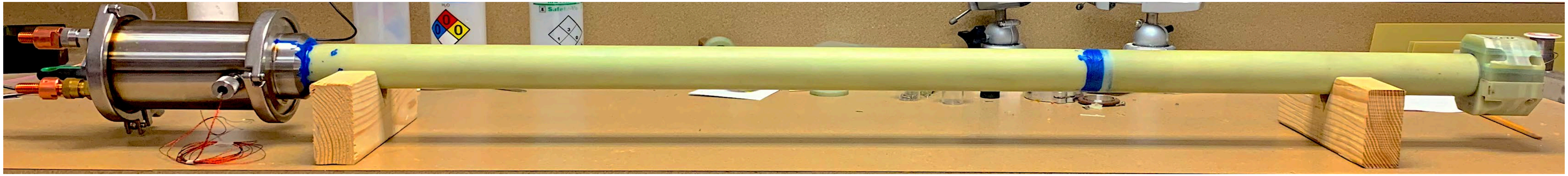
Benjamin Walker

Fabrication-Complete Assembly



- After all parts were fabricated the copper tubes were inserted into the G-10 chassis.
- The copper and G-10 Clamps were then attached.
- The helium nipple was the placed on top.
- The bus leads were then attached and the probe shorted, completing the circuit.





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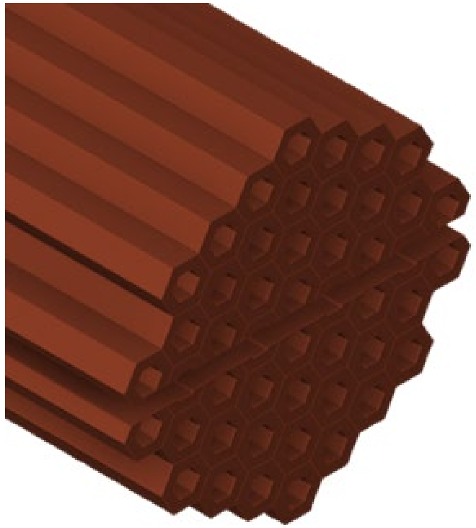
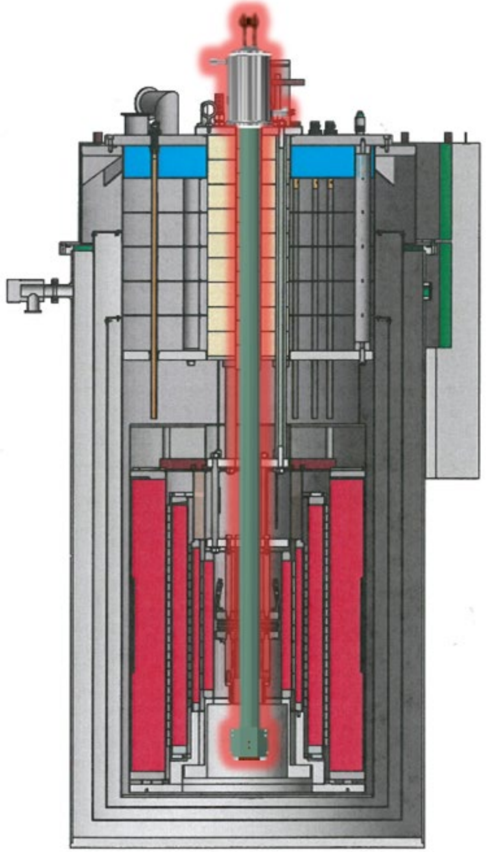
Assembly-Recap and Use



Tubes are "Hexed“, stacked, and soldered together

A nipple is created for instrumentation and helium passage

Hexagonal Tubes are inserted into a G10 Shell



Current lead is inserted into a vacuum sealed chamber

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Tests and Results

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Testing

- Operational Test was conducted to make sure there no shorts in the probe

- Instrumentation was installed onto the current leads to measure Voltage and current

- The Laboratory did not have the materials(helium, magnet) to run the experiment

Theoretical Results

Current	1,1954 A
Heat Leak	2.4895 W
Helium Consumption	3.43 L/Hr
Pressure Drop	30.90 Pa

Christopher Reis

Summary

- Final Product
  - Current lead will be ready for use beginning in Summer 2019
- Lessons Learned
  - Communication is key
  - Stick to plan as much as possible
- The main takeaway is that we developed an optimized model

Christopher Reis

Thank you and Acknowledgements

- Applied Superconductivity Center
  - Dr. Lance Cooley – *Project Advisor*
  - Dr. Ernesto Bosque – *Project Sponsor*
  - James Gillman – *Machine Shop*
  - Dr. Dymtro V. Abraimov - *ASC Staff*
  - William L. Starch – *Laboratory Manager*
- FAMU – FSU College of Engineering
  - Dr. Shayne McConomy – *Class Professor*

Benjamin Walker

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Questions?