Applied Superconductivity Center: HTS Coils Project

Team 501

Team Introductions

Antonio Goodman
Simulations Engineer

Fernando Quiroz
Electrical Engineer

Christopher Reis
Material Scientist

Benjamin Walker
Test Engineer

Fernando Quiroz

Sponsor and Advisor

<u>Engineering Mentor</u>
Ernesto Bosque, Ph.D.
ASC Staff

<u>Academic Advisor</u>
Lance Cooley, Ph.D.
ASC Director, FSU Faculty

Fernando Quiroz

Objective

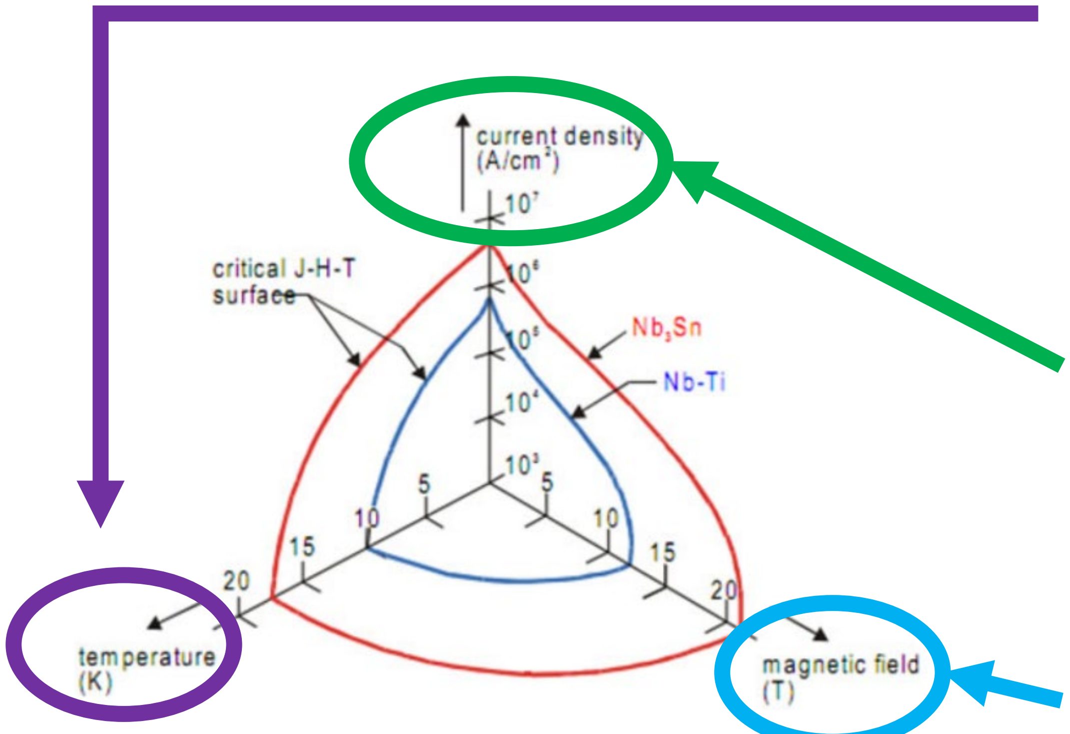
The objective of this project is to design and fabricate a current lead for the ASC that delivers 1000A of electricity with a heat dissipation of less than 4 watts.

Antonio Goodman

Project Background

Christopher Reis

Background: The Conditions of 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 resistivity is zero and conductivity is infinite.

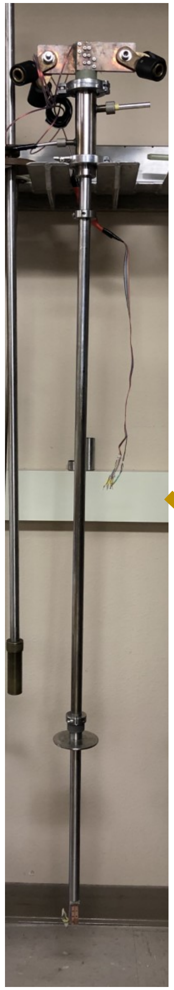
Current Density: The amount of current per unit of area where the area's normal is parallel to the current flow direction. If the current reaches what is called critical current (J_c), superconductivity does not exist at any temperature.

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.

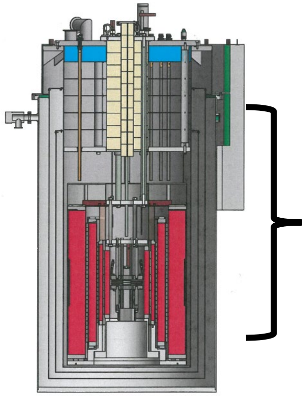
Christopher Reis

Background: Powering an Insert Magnet

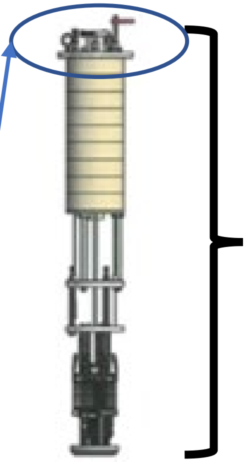
Current Lead



Outsert Magnet



Insert Magnet



Top Plate

- A current lead, attached to a small electromagnet, is inserted into a larger electromagnet.
- A DC power source attached to the current lead sends electrical current to the smaller electromagnet.
  - This is done so that the magnetic field can be generated by the smaller magnet.
- The magnetic field of the smaller magnet adds to the magnetic field of the larger magnet.
  - During this process many different material, mechanical, and electrical traits of the smaller magnet can be tested and observed.

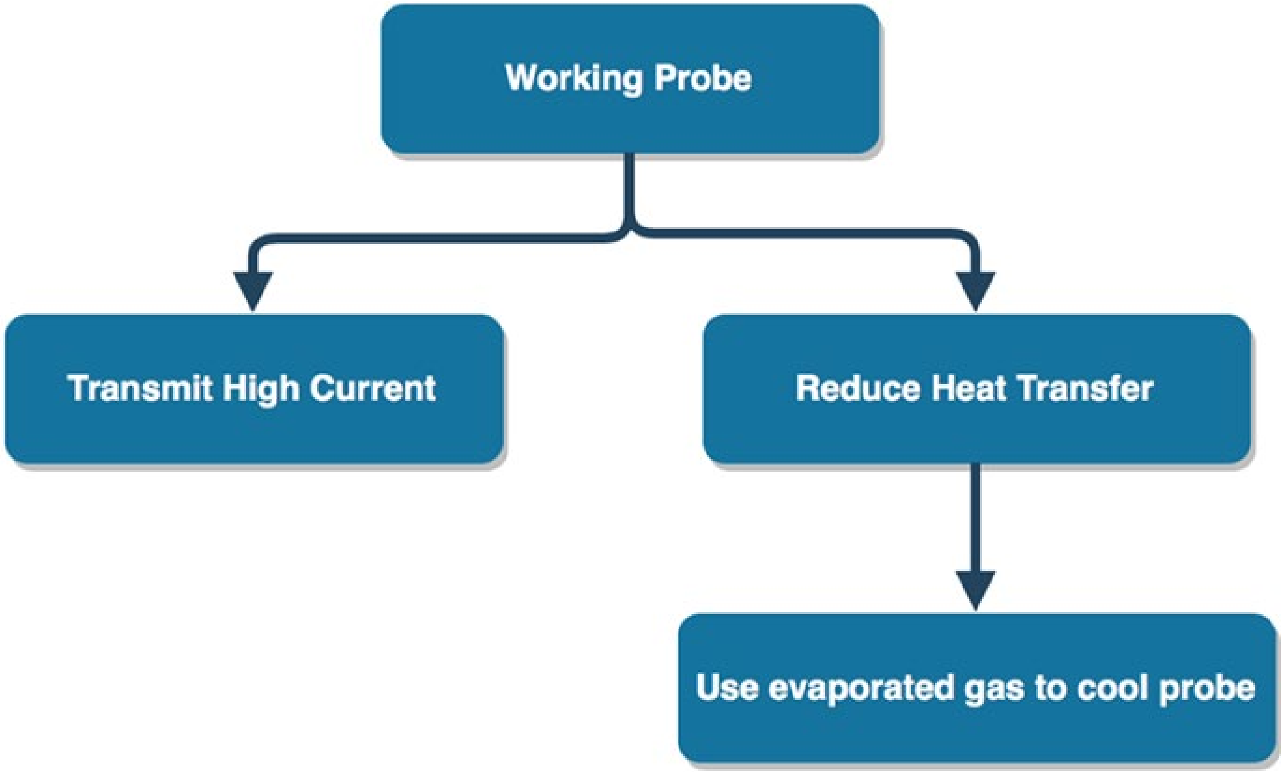
Christopher Reis

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

Antonio Goodman

Functional Decomposition



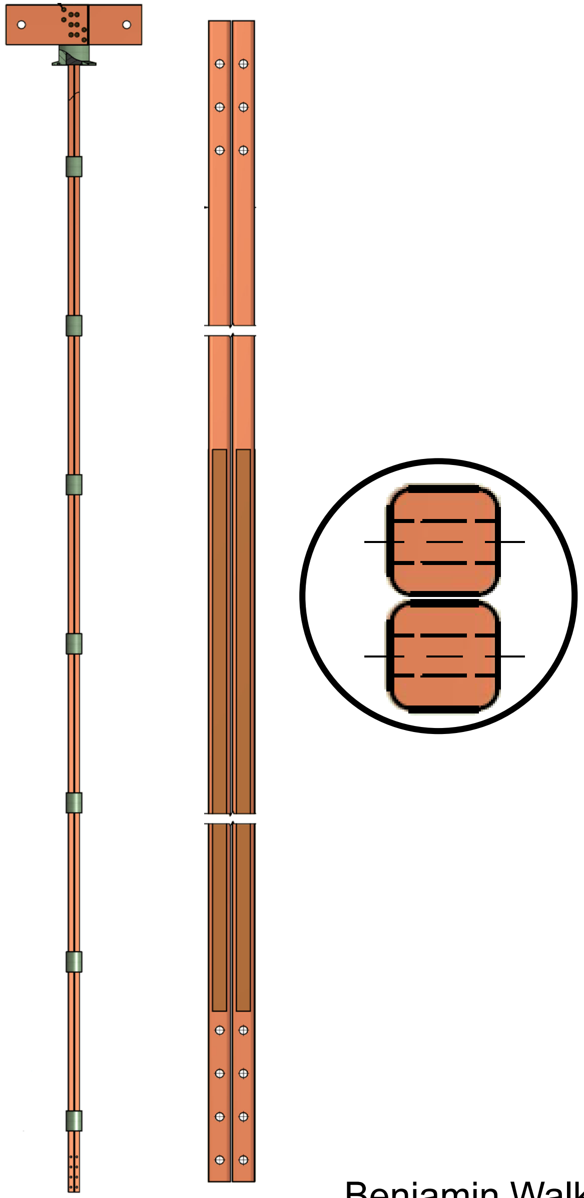
Antonio Goodman

Concept Generation and Selection

Benjamin Walker

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%



Benjamin Walker

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

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

Area Formula

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

Hydraulic Diameter

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

Reynolds Number

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

Efficiency Formula

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

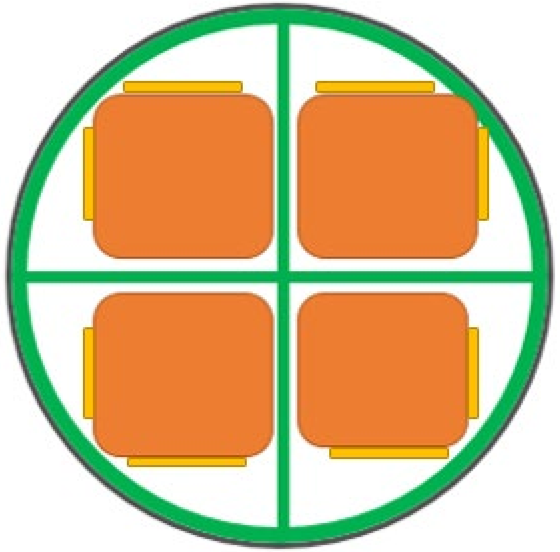
Head Loss

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

Benjamin Walker

Generated Concepts Cont.

Quartered Lead Design



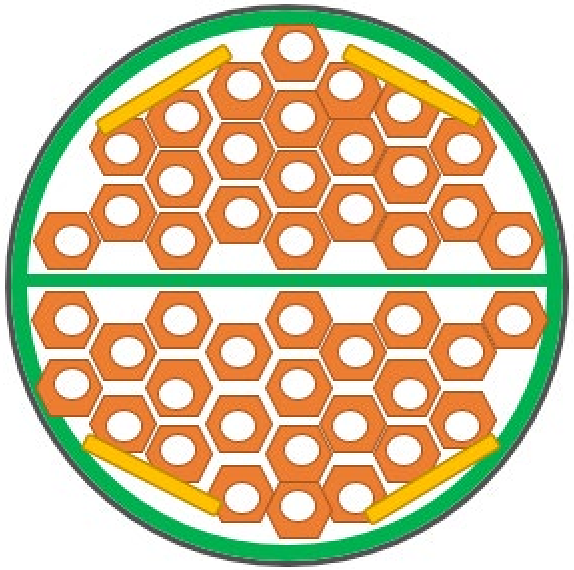
- This design incorporates a larger amounts of copper, taking advantage of more tube area and is lined with HTS materials almost the entire length of the current lead.
- This translated into higher current carrying capability
- However, calculations showed that the cross-sectional area was still not enough for the desired 1000 amperage.

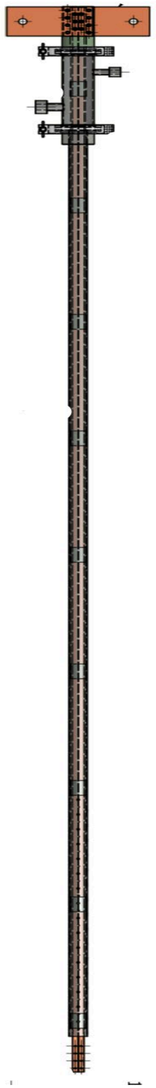
Benjamin Walker

Generated Concepts Cont.

Hexagonal Tube Design

- This new design incorporates dozens of small and readily available copper tubes which will be drawn through a hexagonal dye
- This shape gives them the ability to have maximal electrical contact while allowing for sufficient evaporated helium gas to pass through the lead.
- The efficiency was found to be 89.8%



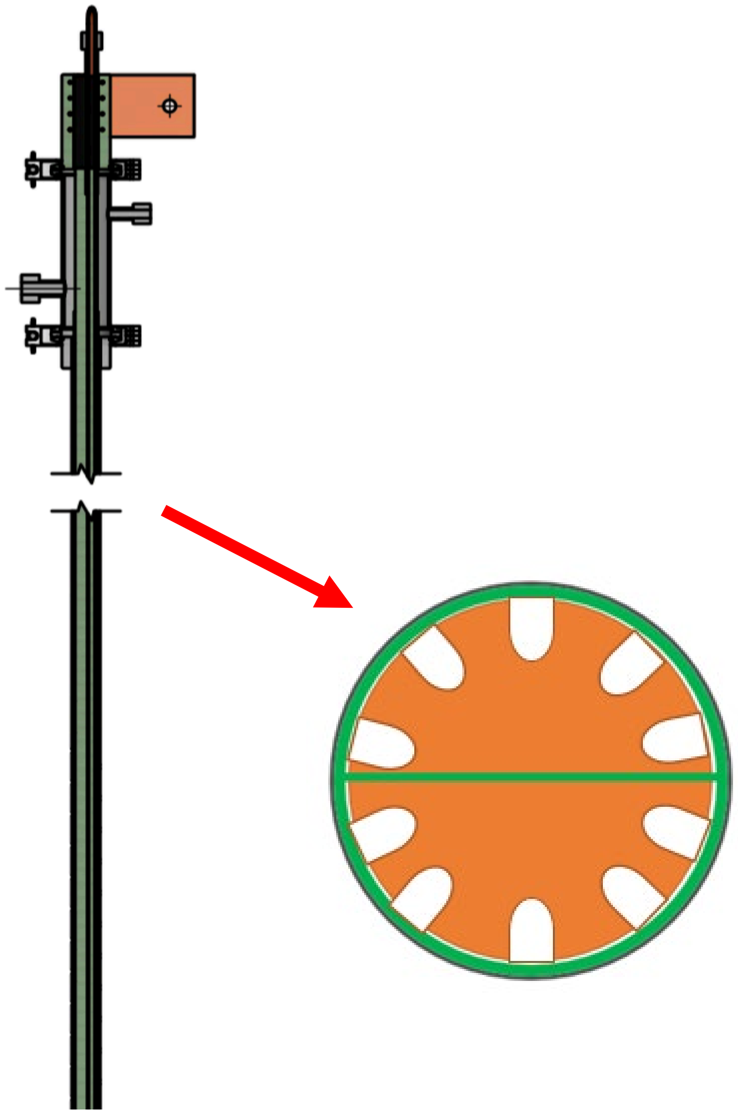


Christopher Reis

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 where added to the design to enhance the heat transfer efficiency



Christopher Reis

Deliberation and Final Selection

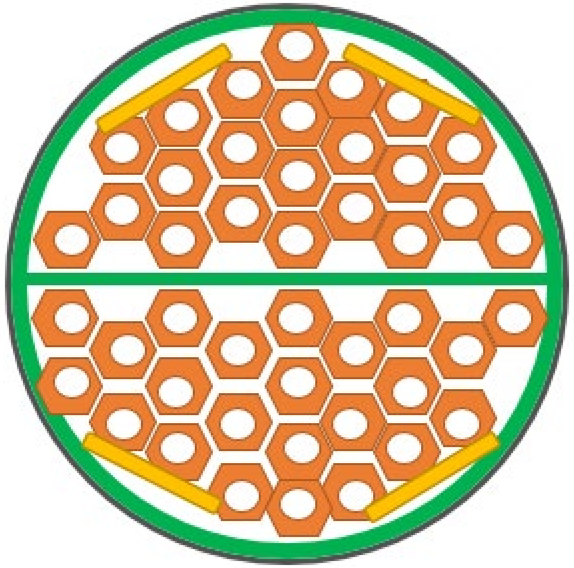
- Complex math and heat transfer physics, including utilizing the shape factor ($\frac{I_0 L}{A}$) and the heat transfer equation $\left\{1 + \frac{2w_0 u}{PhX_2}\right\}^{-1}$, were used to find the efficiency of the leads.
- When the numbers were run for the Standard and Quartered designs and the efficiency 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.

Antonio Goodman

Selected Concept

Hexagonal Tube Design

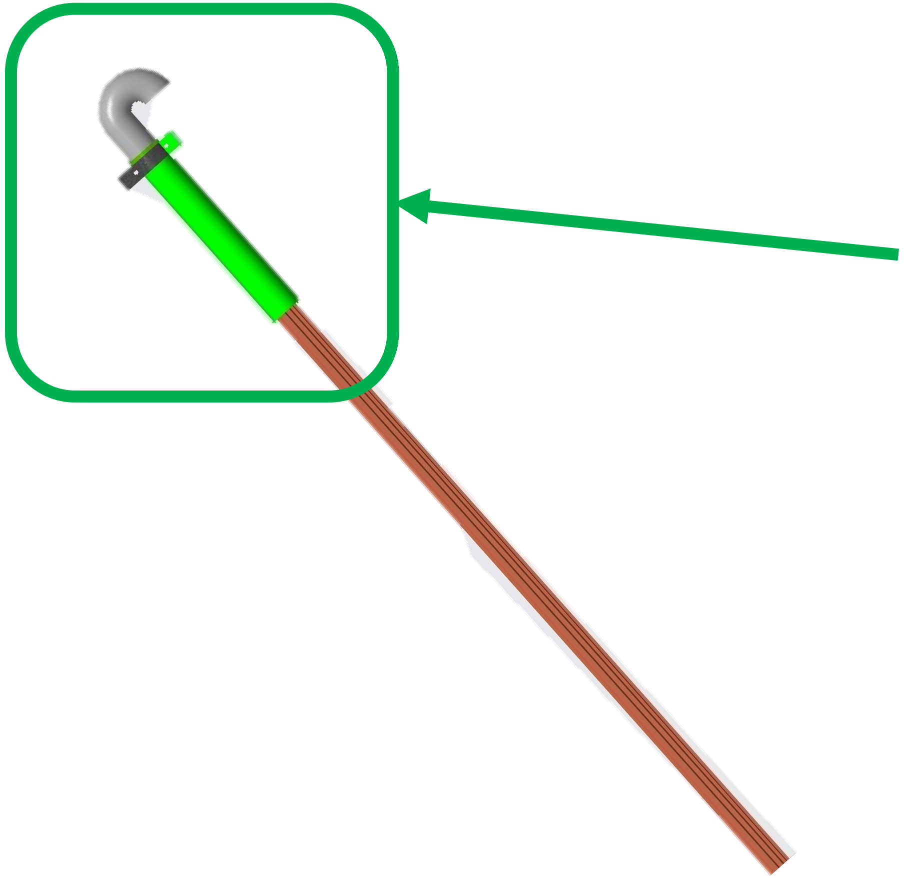
- This design was chosen because after running the calculations with the mathematics explained in a previous slide the stacked hexagonal shape was found to be theoretically the most efficient design with the highest current carrying capacity.
- The hexagonal shape of the tubes allows for the greatest amount of cooling surface
- With the use of 42 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 the 3 Watts which is below the customer requirement



Antonio Goodman

Embodiment

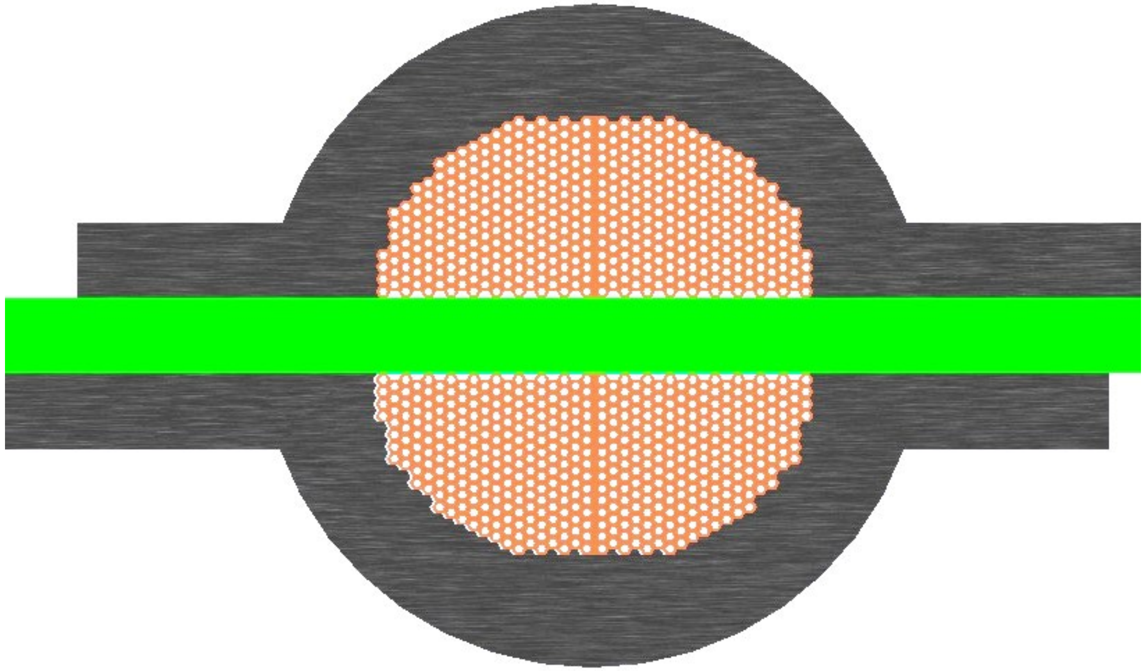
Fernando Quiroz

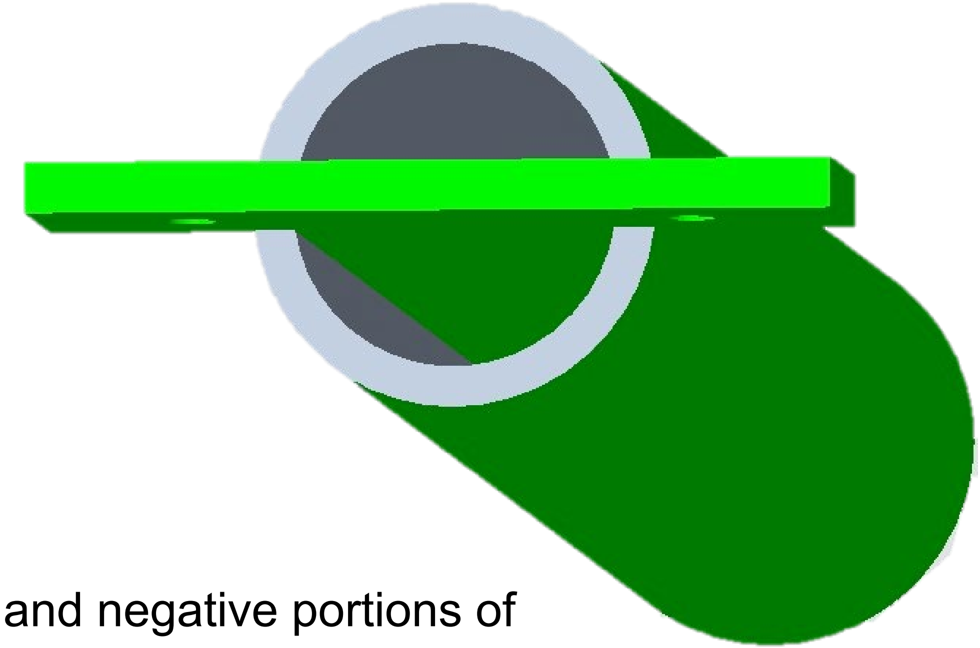


Shown here is the assembly of the entire current lead.

- The G10 sleeve at the top only shows a portion, the material will run the entire length
- The hook at the top allows for expulsion of helium gas

Fernando Quiroz





As seen here the positive and negative portions of honeycomb are separated by G10 insulation.

- Tubes were a key design feature as they allow the gas to pass through increasing cooling surface area

Fernando Quiroz

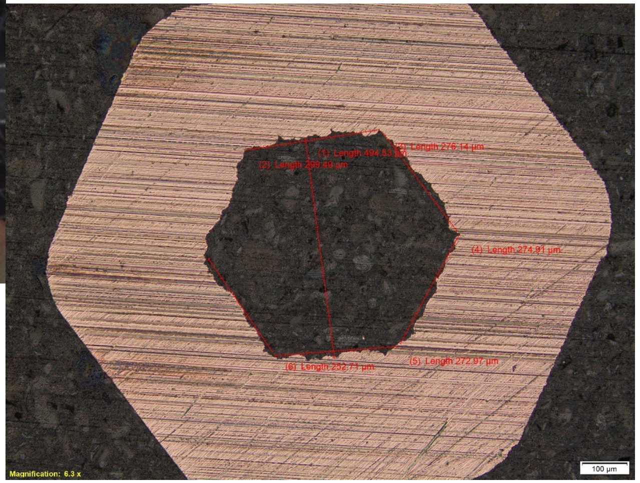
Manufacturing

Benjamin Walker

Fabrication Begins

Shown here is the very beginning of the fabrication phase of the project

- Copper tubing must be “drawn” and “hexed” using a hydraulic drawing bench as shown below
  - ❖ Over 200 tubes will go through this process
  - ❖ This shape allows for stacking of the tubes as shown in the embodiment design
- After stacking, tubes will be set in a resin and placed into the body of the current lead



Benjamin Walker

Project Management

Christopher Reis

Moving Forward

1. Complete fabrication of all custom current lead parts
2. Draw all copper tubes into hexagonal shape
3. Assemble current lead
4. Complete test in Liquid Nitrogen environment
5. Gather data and compile results
6. Write Final Report
7. Present findings on Engineering Day

Christopher Reis

Project Summary

Antonio Goodman

Most Important Points

1. Finish assembly
2. Test current lead
3. Gather and record test results
4. Project is on track to be finished by Engineering Day 2019

Antonio Goodman

Lessons Learned

1. Communication is key
2. Formulate a strategy and stick to it as much as possible
3. Recognize weaknesses and determine what needs to be done to strengthen those areas

Antonio Goodman

References

1. Tipler, P. A., & Llewellyn, R. A. (2012). *Modern Physics Sixth Edition.* New York: W. H. Freeman and Company.
2. Wilson, M. N. (2002). Superconducting Magnets. New York: Oxford University Press.
3. Rohsenow, W. M., Hartnett, J. P., & Cho, Y. I. (1998). Handbook of Heat Transfer. New York: McGraw-Hill.

Antonio Goodman

Questions?