Applied Superconductivity Center: HTS Coils Project

Team 501

Team Introductions

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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.

Project Background

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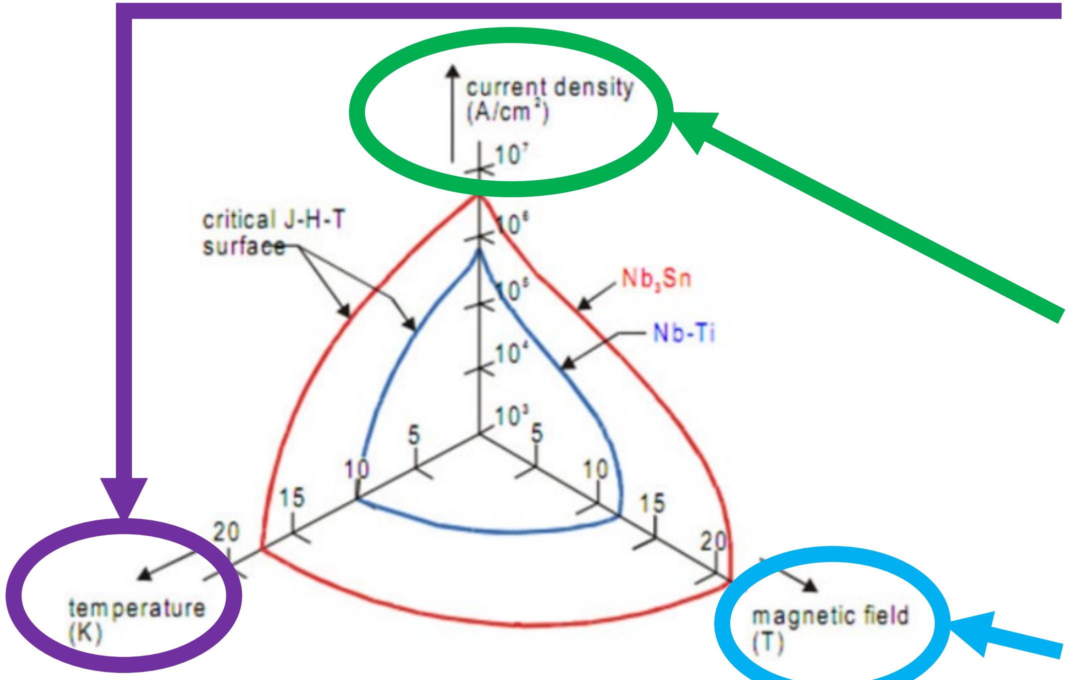
Background: What is Superconductivity?



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.

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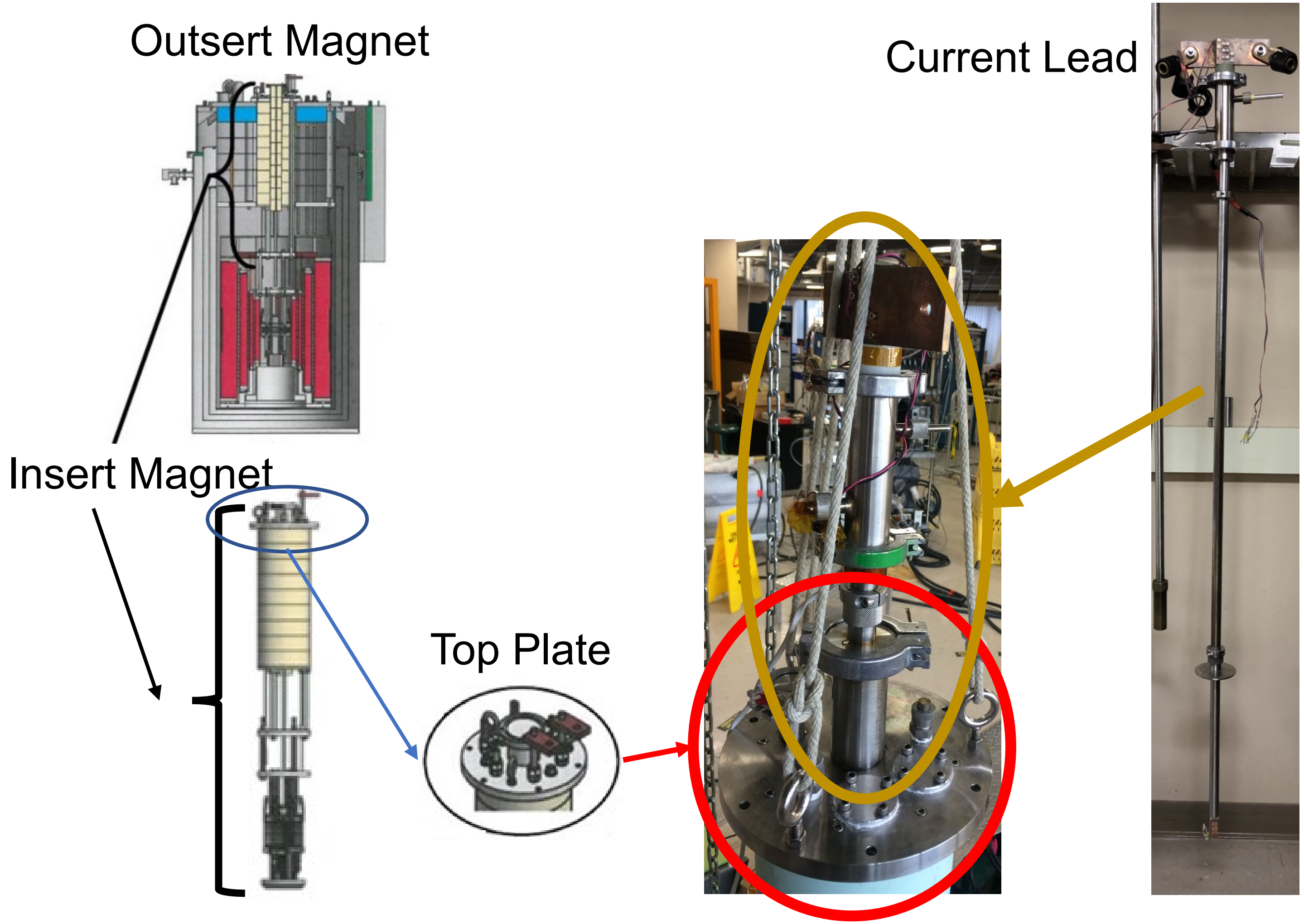
Background: Powering an Insert Magnet



- 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.

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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 wan the current lead to be versatile	Current lead is capable of being used with multiple insert solenoids

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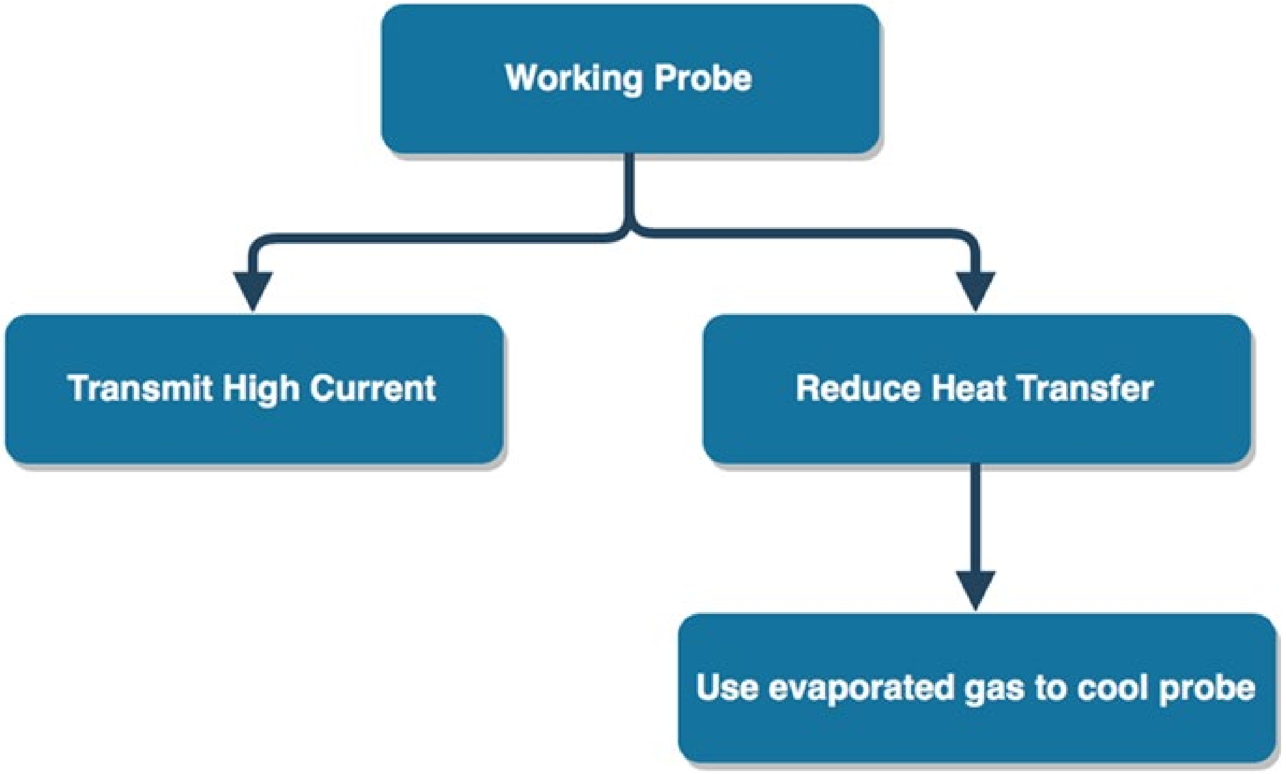
Functional Decomp



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Concept Generation

- Concept generation has been and continues to be 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
- With the use of a house of quality, Pugh charts and various other elimination processes certain ideas were selected on their performance in these decision matrices

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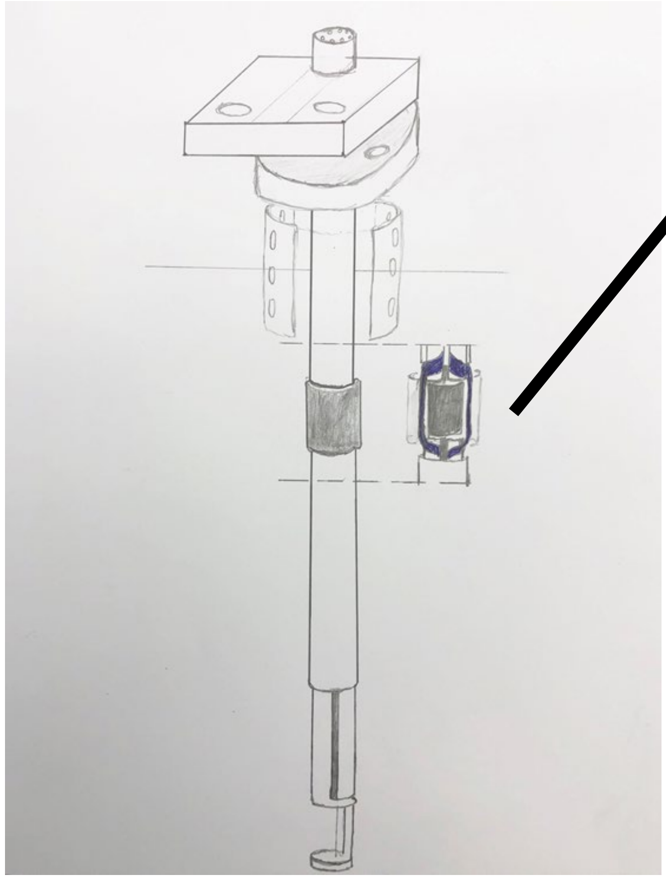
Generated Concepts

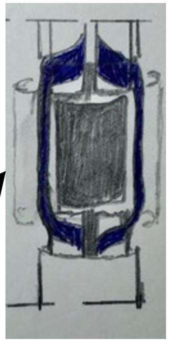
HTS “Bridge” Concept

This design utilized a more traditional form factor but with the use of G10 insulation. Current would be passed using an HTS “bridge” between top and bottom of the current lead

Pros:
- Simple design with readily available materials
- Effective thermal link termination using insulating materials
- Sturdy and resilient to mishandling

Cons:
- If there is a malfunction at the link no current will pass
- Thermal link must be below 77K mark for HTS activation, which must be found empirically





Zoomed image of HTS “Bridge”

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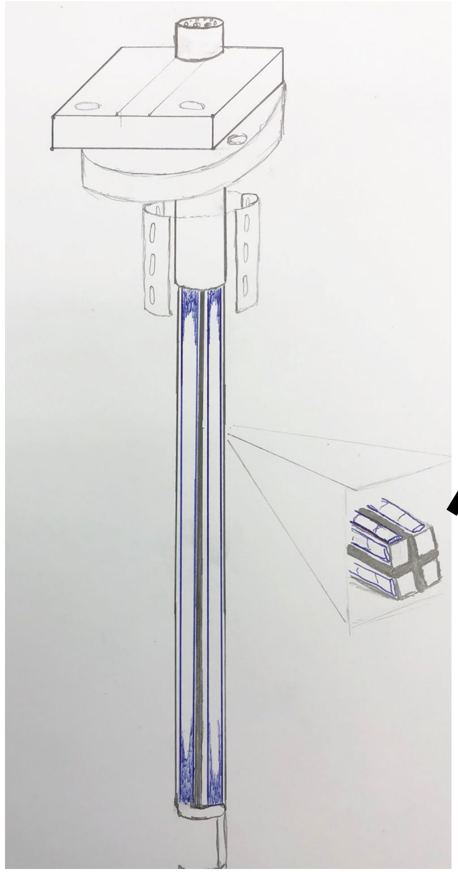
Generated Concepts Cont.

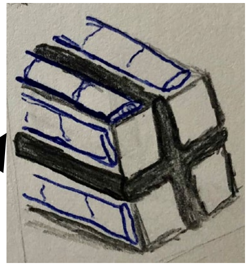
Long HTS Design

This design incorporated large amounts of copper lined with HTS materials the entire length of the current lead.

Pros:
- Minimal thermal heating because HTS runs along entire lead
- Minimizes cryogen boil-off

Cons:
- Fragile due to the length-wise configuration of the HTS material
- Expensive because of extensive use of HTS
- Potential risk of destroying HTS material if the material does not stay below 77 K and all current passes through copper





Exploded view of HTS-laced Copper leads

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Generated Concepts Cont.

Honeycomb Design

This design incorporated hundreds of small copper tubes bound together to allow for evaporated helium gas to pass through and cool the lead. HTS tape runs along outsides of copper to allow for current sharing.

Pros:
- Tubing creates larger surface area compared to solid copper which allows for more convective cooling
- HTS element allows for current sharing

Cons:
- Large amount of copper tubing is expensive
- Shaping of tubes requires large amount manufacturing time

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Concept Selection

The honeycomb design was chosen after all of the mathematical calculations were completed showing that it Outperformed the other designs in current carrying capacity, thermal efficiency, and resilience.

- Heat transfer is increased by increased surface area used for cooling the current lead.
- The hex tubes are better than normal circular tubes because they allow for better contact between the tubes.
- Hexagonal shapes are best for packing while utilizing the most area

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Embodiment

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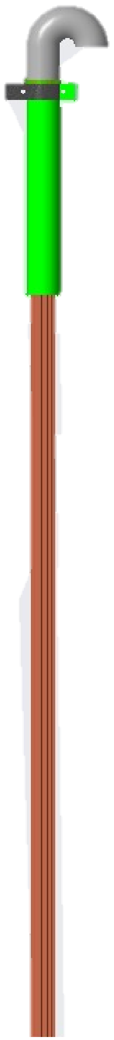

Shown here is the assembly of the entire current lead.

- 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

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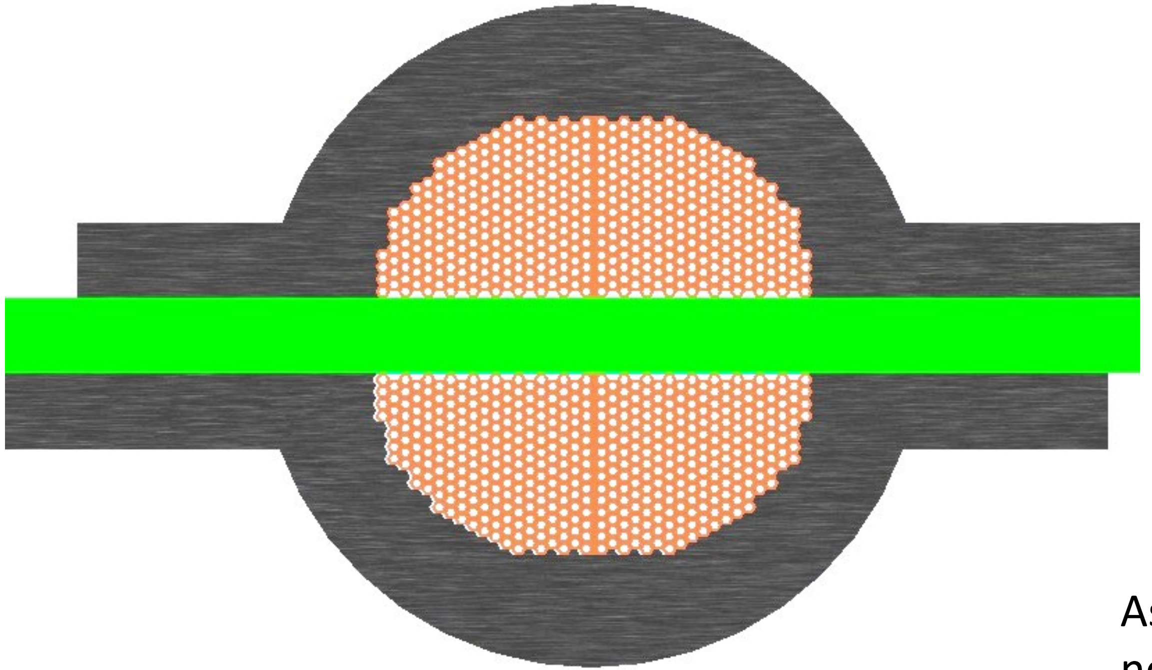

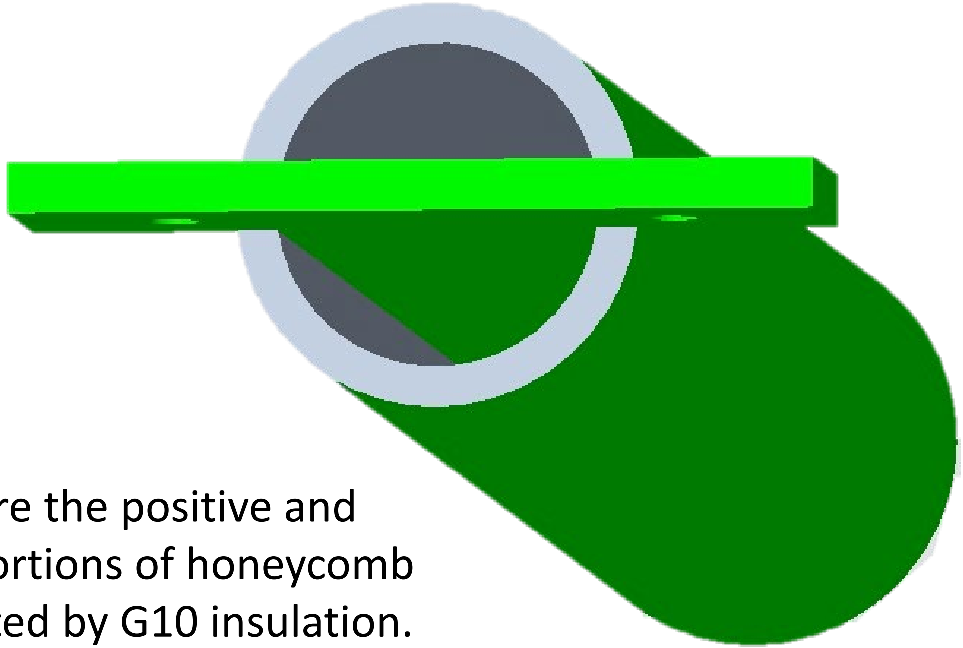

As seen here the positive and negative portions of honeycomb are separated by G10 insulation.

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

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Manufacturing

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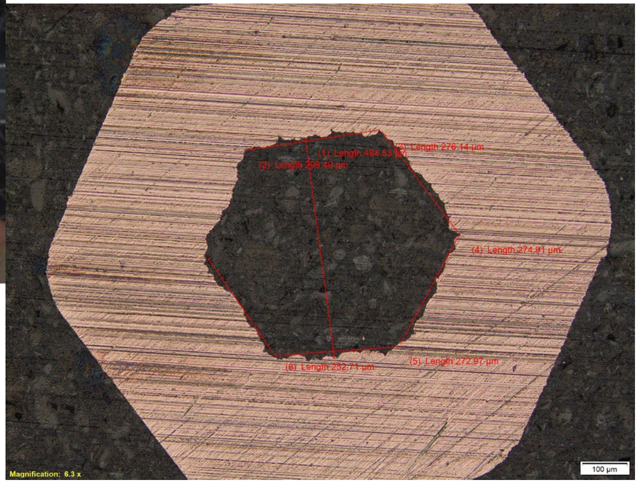
Fabrication Begins

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



Summary

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Most Important Points

1. Final design is in final stages to meet budget requirements
2. Materials for testing have begun to be ordered
3. Organization of machinists help at ASC has been organized
4. Project is on track to be finished by Engineering Day 2019

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Lessons Learned

1. Nothing goes according to plan
2. Budgets do not always allow for optimal performance
3. Highest efficiency does not mean best performing

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Reference

Tipler, P. A., & Llewellyn, R. A. (2012). *Modern Physics Sixth Edition.* New York: W. H. Freeman and Company.

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Questions?