EML 4551-2

VIRTUAL DESIGN REVIEW 2

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TEAM 501: HTS COILS PROJECT FOR THE APPLIED SUPERCONDUCTIVITY CENTER

Applied Superconductivity Center
HTS Coils Project
Team 01

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The Applied Super Conductivity Center (ASC)

- ASC, located in Tallahassee FL
- Association with the National High Magnetic Field Laboratory
- Advances science of superconductivity and superconductivity applications
- ASC is presently researching new types of high field magnets

- Ernesto Bosque, Ph.D. Project Sponsor
- ASC Research Faculty
- Florida State University Alumni

- Lance Cooley, Ph.D. Project Advisor
- Director of ASC
- University of Wisconsin-Madison Alumni

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Project Brief

- Design a probe with better properties for inserting superconducting device into an external magnet like the one shown in the image

- Probe must carry high electrical current from room temperature to approx. -450 ◌̊F without excessively heating cold environment

- Fabricate and test this probe under the supervision of the Applied Superconductivity Center

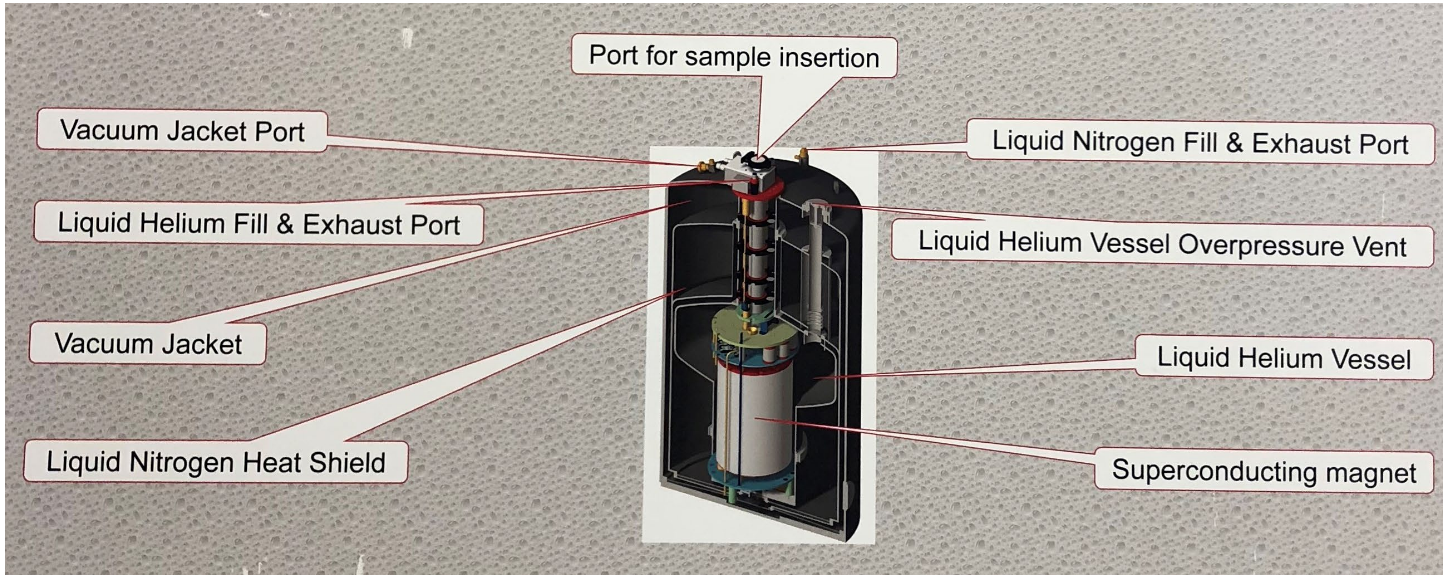

Diagram of Typical Superconducting Magnet System

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Objective

- The objective of this project is to provide the ASC with a 700A probe for high magnetic field insert coils that will be used in tandem with larger outsert magnets

  - The minimum objective is to deliver a probe to carry current to the test device with optimization for heat loss

  - The stretch objective is to deliver a probe that will carry 1000A and be thermally optimized to limit cryogen boil off

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Purpose

- To develop a probe that our sponsor will use with a specific external magnet at the Applied Superconductivity Center
- The probe will be used for high current tests of new superconducting magnets
  - Some new magnets are associated with the NHMFL
  - Some new magnets are associated with the Department of Energy Office of High Energy Physics

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Targets

Metric	Target	Units
Current through Probe	>700	Amperes
Thermal Dissipation	≤4	Watts
Pressure Loss in Probe	<0.5	psi
Cost of Probe	< 1,500	USD
Length of probe	1.75 < L < 2.5	meters
Probe Shaft Diameter	≤50.8	mm

- The critical targets for the project are the probe shaft diameter, current through the probe and thermal dissipation

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Concept Generation

- Concept generation is a crucial step in the design process
- Intensive brainstorming sessions were held with a massive volume of concepts
- Concepts where classified according to its physical characteristics and properties
- These were shaved down by using various techniques including employing house of quality and Pugh charts
- The final eight designs were pairwise comparison

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Generated Concepts

Concept #3

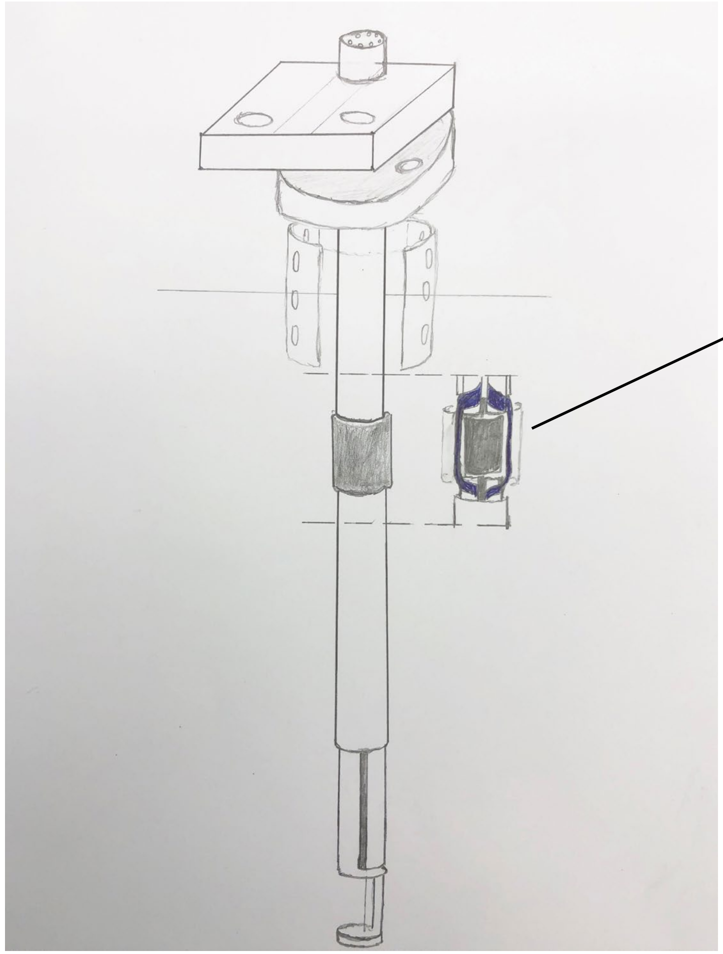
This probe utilizes a more traditional form factor but with the use of G10 insulation to break heat connection between the upper lead (heated by room temperature exposure and ohmic losses) and cryogen bath. Current passed using an HTS link between top and bottom

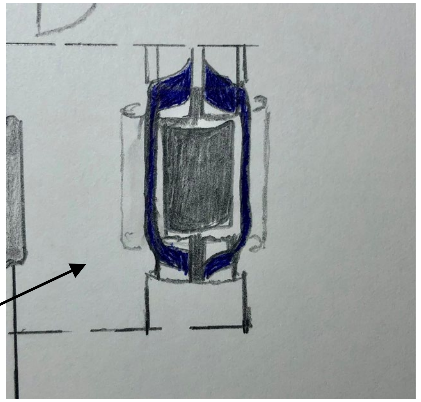
Pros:

- 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 in view of G10 thermal insulation barrier

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Generated Concepts Cont.

Concept #5

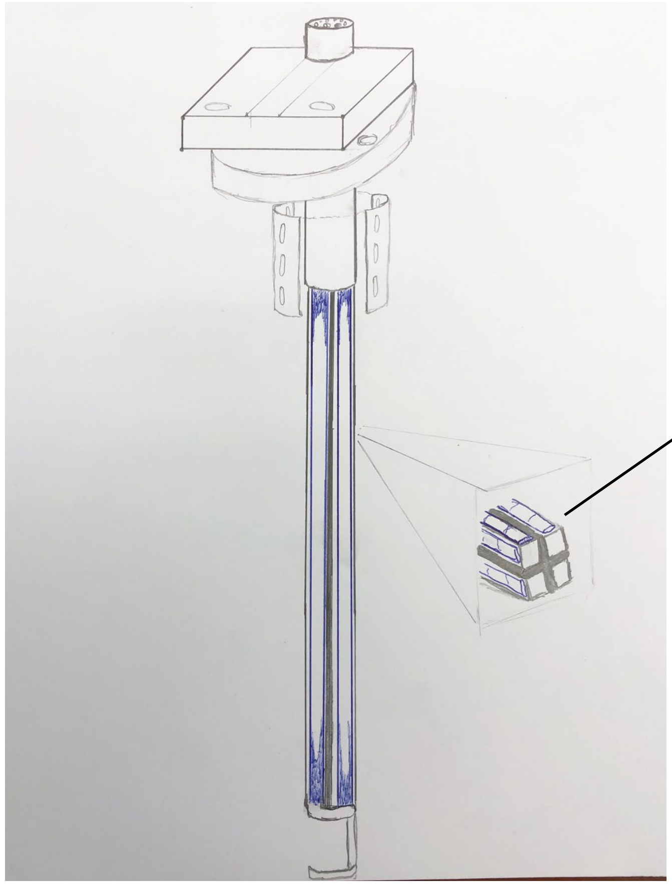
This design incorporates large amounts of copper lined with an HTS materials the entire length of the probe. This was conceived after it was projected the entire dewer would be under 77 Kelvin

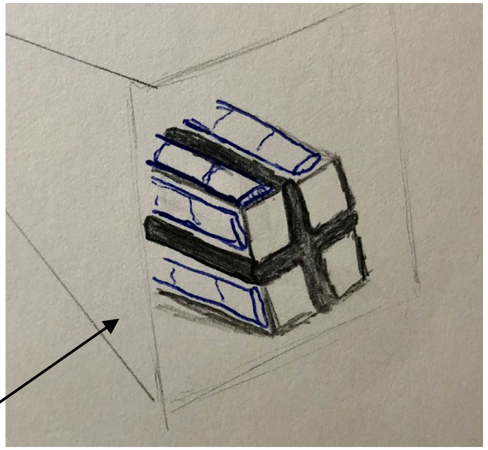
Pros:

- Minimal thermal heating because HTS, which does not joule heat, runs along entire lead
- Would minimize cryogen boil-off to a significant degree

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 (bearing the entire load may heat it up significantly and potentially burnout both rod and tape)





Exploded view of HTS-laced Copper leads

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Generated Concepts Cont.

Concept #6

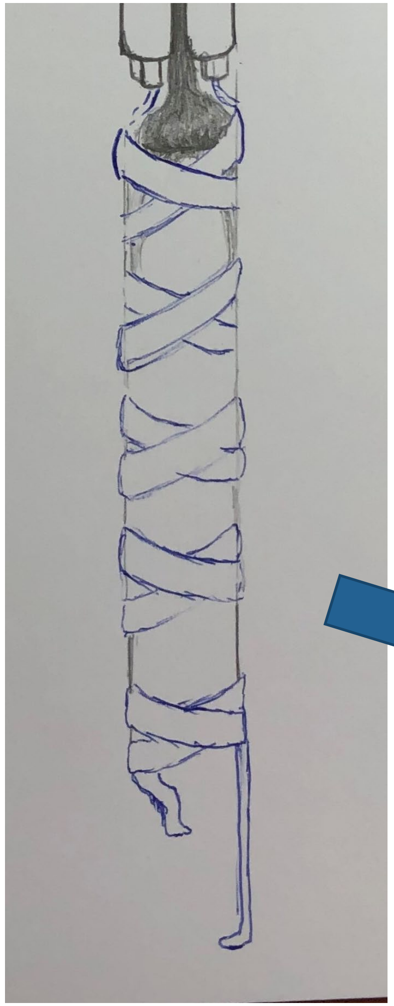
Design #6 utilizes an HTS material weave on the bottom portion of the probe that maximizes the amount of HTS material that current can pass through. Also utilizes heat sink and thermally insulative materials.

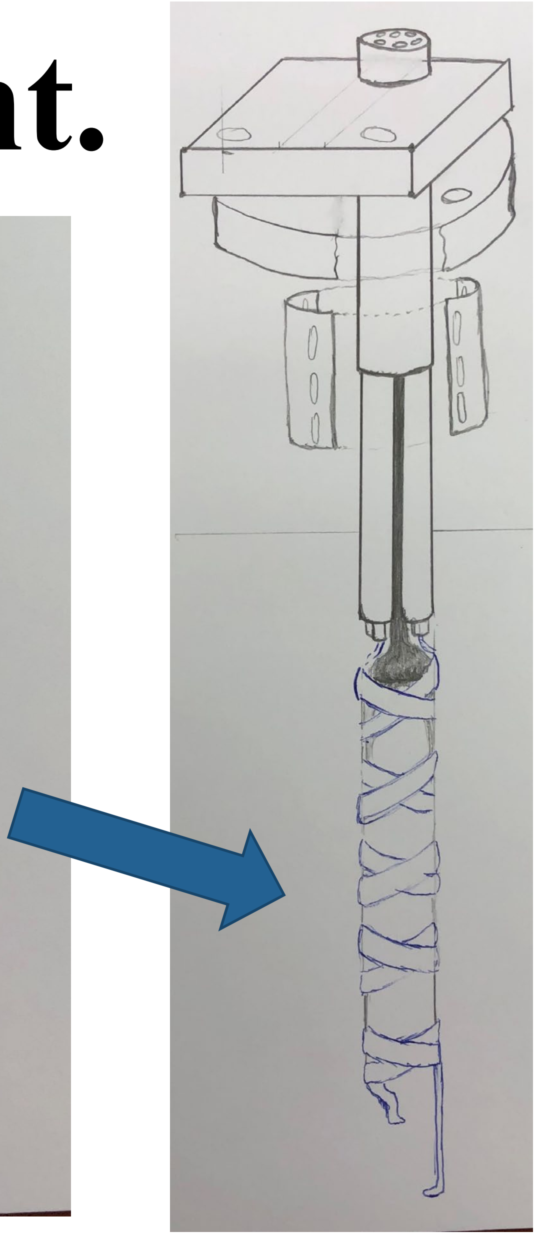
Pros:

- Innovative weave design that pushes new limits in the field of probe design
- Minimal thermal heating because of HTS utilization and heat sink
- Would maximize the helium cooling properties with its large external surface area, leaving most available enthalpy to cool upper portion

Cons:

- Fragile design because of use of HTS material
- Complex design leads to difficult assembly due to the need to weave HTS material, especially because it would need to be positioned in such a way as to not induce a magnetic field





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Pairwise Comparison

		1	2	3	4	5	6	Total
1	Cost	-	0	0	0	0	1	1
2	High Current	1	-	1	0	1	1	4
3	Low Helium Boil Off	1	0	-	0	1	1	3
4	Safety	1	1	1	-	1	1	5
5	Durability	1	0	0	0	-	1	2
6	Versatility	0	0	0	0	0	-	0
Total		4	1	2	0	3	5	n-1 = 5

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House of Quality

Imrovement Direction		↑	↓	↓	↑	↑	↓
Units of EC's		A/m^2	Pa	J	S/m	1/m	kg/m^3
Design Requirements / Customer Requirements	Importance	Current Density	Pressure Loss	Heat Dissipation	Conductivity	Surface area to Volume	Material Density
Cost	1	3		9	3	9	
High Current	4	9		9	9		
Low Helium Boil off	3	3	3	9	1	3	
Safety	5	9	9	1	9		
Durability	2			1			3
Versatility	1					3	
Technical Importance: Absolute		93	54	79	87	21	6
Technical Importance: Relative		27.84	16.17	23.65	26.05	6.29	2.43
Rank		1	4	3	2	5	6

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Pugh Matrix

		Concepts		
Selection Criteria	#3	#5	#6	#8
Current Density	Datum	S	-	S
Pressure Loss		S	S	S
Heat Dissipation		-	-	-
Conductivity		S	S	S
Surface Area to Volume		S	S	-
Number of Pluses	-	0	0	0
Number of Minuses	-	1	2	2

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AHP – Criteria Comparison

Criteria Comparison Matrix [C]					
	Current Density	Pressure Loss	Heat Dissipation	Conductivity	Surface Area to Volume
Current Density	1.000	5.000	3.000	1.000	5.000
Pressure Loss	0.200	1.000	0.200	0.333	3.000
Heat Dissipation	0.333	5.000	1.000	0.333	3.000
Conductivity	1.000	3.000	3.000	1.000	5.000
Surface Area to Volume	0.200	0.333	0.333	0.200	1.000
Sum	2.733	14.333	7.533	2.867	17.000

Normalized Criteria Comparison Matrix [NormC]						
	Current Density	Pressure Loss	Heat Dissipation	Conductivity	Surface Area to Volume	**Criteria Weights {W}**
Current Density	0.366	0.349	0.398	0.349	0.294	0.351
Pressure Loss	0.073	0.070	0.027	0.116	0.176	0.092
Heat Dissipation	0.122	0.349	0.133	0.116	0.176	0.179
Conductivity	0.366	0.209	0.398	0.349	0.294	0.323
Surface Area to Volume	0.073	0.023	0.044	0.070	0.059	0.054
Sum	1.000	1.000	1.000	1.000	1.000	1.000

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AHP- Final Concept Ratings

Final Rating Matrix			
	Concept #3	Concept #5	Concept #6
Current Density	0.429	0.429	0.143
Pressure Loss	0.333	0.333	0.333
Heat Dissipation	0.633	0.106	0.260
Conductivity	0.333	0.333	0.333
Surface Area to Volume	0.429	0.429	0.143

Concept	Alternative Value
#3	0.425686557
#5	0.331184542
#6	0.243128901

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Bill of Materials

Category	Item	Quantity	Units	Quantity Received	Cost per Unit	Total Cost	Purchased?	Arrived?	Installed?	Description
Electrical										
	Copper 101 Round Stock	4	FT		$ 81.05	$ 324.20	No	No	No	Lead head assembly
	Copper 101 Bar	1	FT		$ 90.92	$ 90.92	No	No	No	Lead main body
Mechanical										
	Garolite Tubing	1	FT		$ 53.76	$ 53.76	No	No	No	Lead chassy
	Garolite Strip	2	FT		$ 4.76	$ 9.52	No	No	No	Lead electrical separation
	Garolite Block	1	FT		$ 56.61	$ 56.61	No	No	No	Dipper/solenoid support
	Gap-Filling Epoxy	1	OZ		$ 53.05	$ 53.05	No	No	No	Various sealings and fittings
	18-8 1-64 SS Socket Head Screw	1	Pack of 50		$ 5.55	$ 5.55	No	No	No	Clamps and fastening
	304 SS Barbed Hose Fitting	2	Each		$ 14.30	$ 28.60	No	No	No	Fittings
	KF50 Flange Clamp	2	mm		$ 28.90	$ 57.80	No	No	No	Clamps and fastening
	1/2 Inch Aluminum Pipe	1	FT		$ 16.28	$ 16.28	No	No	No	Instrumentation and ventilation
Instrumentation										
	Thermocouple	1	Pack of 5		$ 59.00	$ 59.00	Yes	Yes	No	Temperature studies
	Fluke 8845A Multimeter	1	Each		$ 1,115.00	$ 1,115.00	Yes	Yes	No	IV documentation and studies
	Magnet Wire, 35 AWG	1	Each		$ 7.27	$ 7.27	Yes	Yes	No	Working piece/ solenoid prototype wiring
	Flow Meter for Inert Gas	1	Each		$ 262.98	$ 262.98	Yes	Yes	No	Helium boil-off studies

Total Cost of Parts to be ordered	$ 696.29
Total Cost of all Parts (Including parts already in facility)	$ 2,140.54
Maturity Total	24%

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Next Steps

- Preliminary designs
  - Design and test small scale prototype designs
  - Software design and appropriate simulations
  - Bill of materials for final design
- Acquire materials and assemble prototype
  - Test the probe with the insert magnet

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References

- https://essay.utwente.nl/62400/1/MSc_W_vander_Kamp.pdf
- https://nationalmaglab.org/magnet-development/magnet-science-technology/magnet-projects/32-tesla-scm
- Shayne McConomy, *Engineering Design Methods,* lecture slide sets, FAMU-FSU College of Engineering, Spring 2018

Questions